A System Dynamics and Agent-Based Approach to Model Emotions in Collaborative Networks

Filipa Ferrada, Luis M. Camarinha-Matos

A System Dynamics and Agent-Based Approach to Model Emotions in Collaborative Networks

Filipa Ferrada[1], Luis M. Camarinha-Matos[1,2]

[1] CTS – Center of Technology and Systems, Uninova, NOVA University of Lisbon, 2829-518 Caparica, Portugal
[2] Department of Electrical Engineering, Faculty of Sciences and Technology, NOVA University of Lisbon, 2829-518 Caparica, Portugal
{faf, cam}@uninova.pt

Abstract. A good amount of research within the last few decades has been focusing on computational models of emotion and the relationships they have with human emotional processes and how they affect the surrounding environments. The study of emotions is interdisciplinary and ranges from basic human emotion research, like in psychology, to the social sciences studies present in sociology. The interactions between those and the computational sciences are becoming a challenge. One particular challenge that is presented in this paper is the study of collaborative emotions within a Collaborative Network (CN) environment. A CN is composed of different participants with different interaction characteristics such as, expectations, will to cooperate and share, leadership, communication, and organizational abilities, among others. This paper presents an approach, based on system dynamics and agent-based modeling, to model the emotional state of an individual member of the network (via a non-intrusive way).Some simulation results illustrate the approach.

Keywords: Emotions, Collaborative Emotions, Collaborative Networks, System Dynamics, Agent-Based Modeling.

1 Introduction

Nowadays the area of Collaborative Networks (CNs) is being challenged by the necessity of improvements not only in technical terms but also in relation to social interactions among their participating members. According to some research in socio-technical systems [1, 2], the failure of large complex systems, such as CNs, is not directly related to the technology neither to the operational systems that compose them. Rather, they fail because they do not recognize the social and organizational complexity of the environment in which these systems are deployed. A survey conducted by Morris et al. [2] highlights that neglecting social and organizational complexity can cause large, and often serious, technological failures and also recognize that there is a need to provide "human-tech" friendly systems with cognitive models of human factors like stress, emotion, trust, leadership, expertise, or decision-making ability.

Emotion is an important factor in human cognition and social communication [3] and has been used as a mean of interaction in several fields of science like psychology, sociology, AI, and HCI with the use of emotional agents. In this context, a large amount of research within the last few decades has been focusing on computational models of emotion and the relationship they have with human emotional processes and how they affect the surrounding environments.

A new approach that is expected to improve the performance of existing CNs, namely the collaboration sustainability and interactions, is introduced here by adopting some of the models developed in the psychology, sociology and affective computing areas. The idea is to "borrow" the concept of *human emotion* and apply it within the context of a CN environment, turning it into a more "human-tech" friendly system without being intrusive, i.e. without violating the intimacy of each member.

When thinking about complex systems such as CNs that are composed of several nodes representing organizations, SMEs, large companies, among others, collaborating with the aim to achieve a purpose, it is reasonable to imagine that all of these entities interacting might also generate "emotions" that would be affected by the dynamics of the collaborative environment. Thus, the emotional state of each participating organization (CN Member) would contribute to the assessment of the collective emotional state of the CN and in this way contribute for its well-functioning. The individual emotional state of a member would affect its performance and relationships within the CN [4]. In this paper, it is assumed that the modeling of individual emotions will allow a CN Administrator to have a better understanding of each member's reality within the network environment.

In this context, the main research question guiding this work is: *What could be a suitable modeling framework to support the concept of collaborative emotions and assist on simulation experiments in order to understand the behavioral dynamics within a collaborative networked environment?*

The modeling framework developed to give an answer to this research question is based on System Dynamics and Agent-based Modeling and Simulation. System Dynamics allow the understanding of the behavior of each member over time. Agent-based models and simulation offer a good representation of the real-world environments with appropriate level of complexity and dynamism and allow to explain (simulate) a variety of situations and behaviors through selection of scenarios, which are difficult to analyze with the traditional approaches.

The remainder of this paper is organized as follows: Section 2 identifies the relationship of this work to smart systems; Section 3 gives a brief overview of the psychological and computational models of emotion; Section 4 presents the proposed modeling framework; Section 5 presents the model implementation and the simulation results; and finally Section 6 concludes and identifies the future work.

2 Relationship to Smart Systems

The current increase of systems complexity and the fast growing hyper connectivity raises the necessity to have mechanisms to assess the behavior of such systems. Their complex dynamism not only incorporates technological and operational mechanisms but also integrates social and organizational constructs [1, 2], becoming socio-technical systems. These socio-technical systems are composed of complex intelligent sub-systems with a vast degree of autonomy and tendentiously configured as collaborative systems.

In this direction, the work presented in this paper proposes an approach to bridge the gap between the technological and social aspects. The introduction of the concept of collaborative emotions to complex collaborative systems, contributes to a new generation of hyper-connected smart socio-technical systems [5].

3 Emotions and Computational Models of Emotion

Emotions are unique to each human being and deviations from person to person are the result of each person's genes and the involved environment in conjunction. Emotions can be distinguished from feelings, affects, moods, and sentiments. *Emotions* are driven by specific events, actions or objects. They are more dynamic and episodic processes than *moods*, which are generally less intense [6, 7], longer lasting [8] and not directed at specific stimuli or event[9], although this distinction is more often made theoretically than empirically [10]. *Affect* is a broader term and can be defined as a valence evaluation in reference to the self [11]. Put simply, affect is an umbrella concept that covers a broad range of feelings, indicating if something is good or bad for oneself. Affect is often used as the denominator for both emotion and mood [12]. *Sentiments* are, according to Gordon: "*socially constructed pattern[s] of sensations, expressive gestures, and cultural meanings organized around a relationship to a social object, usually another person... or group such as a family*" [13].

Numerous theories involving the origins, mechanisms and nature of emotions have been generated over the years. This is a challenge since emotions can be analyzed from many different perspectives. All of the classic theories of emotion have fallen under criticism at various times, though many modern theorists still use them as a basis to work from. The most known theoretical models of emotion are [14]:

1. **Physiological or Somatic Emotion Theories** [15-17]: concede that emotions are primary to cognitive processes [17]. Prior to analyzing a perceived object, and even before recording any impressions, the (human) brain is able to immediately invoke an emotion associated with this object.
2. **Basic Emotion Theories** [3, 18-22]: adopt a certain number of basic emotions. The fundamental assumption is that a specific event triggers a specific affect corresponding to one of the basic emotions producing physiological response mostly through facial expressions.
3. **Appraisal Theories of Emotion** [23-27]: suggest that before the occurrence of emotion, there are certain cognitive processes that analyze stimuli [25, 28]. In such a way, the emotions are related to a certain history of a human (agent or robot). The relation to the history should follow the process of recognition (since the objects and their relations to the agent's emotion should be first recognized).

Thus, the appraisal theory postulates a certain priority of cognitive processes over emotions.

4. **Dimensional Emotion Theories** – providing a suitable framework for representing emotions from a structural perspective. These theories established that emotions can be differentiated on the basis of dimensional parameters, such as *arousal* and *valence*. Russell [29, 30] proposes a two-dimensional framework consisting of pleasantness and activation to characterize a variety of affective phenomena such as emotions, mood and feelings. Another approach is the three-dimensional framework proposed by Russell and Mehrabian [31], which describes emotions based on their level of pleasantness, arousal, and dominance. This model is known as the PAD model [32].

Furthermore, there are also a number of psychological theories of emotion that do not fit exactly into the ones outlined above, focusing on a **specific aspect** or **component of emotion**, such as *motivation* or *action preparation*, or **combined features from the major theoretical orientations** (see [33]).

Computational Models of Emotion are complex software systems conceived to embrace design decisions and assumptions, inherited from the psychological and computational traditions from where they emerged, and synthesize the operations and architectures of some components that constitute the process of human emotions [34]. In general, computational models of emotion include mechanisms for the evaluation of emotional stimuli, the elicitation of emotions, and the generation of emotional responses, creating means for the recognition of emotions from human users and artificial agents, the simulation and expression of emotional feelings and the execution of emotional responses (or behaviors) [35]. Table 1 illustrates some computational models of emotion according to some theoretical models of emotion. For other reviews of computational models of emotion consult [34, 36, 37].

Table 1. Some computational models of emotion

Computational Model	*Theoretical Model*	*Computational Techniques*
CATHEXIS[38]	Physiological theory by Damasio [3] and Appraisal theories by Roseman [39]. Marvin Minsky's Paradigm [40].	Synthetic Agents
FLAME [41]	Combination of OCC [27] and Roseman's [39] appraisal theories.	Software Agent (does not incorporate group behavior); Fuzzy logic
ALMA [42]	OCC appraisal theory [27] and PAD dimensional theory [32].	Virtual Character or Agent
WASABI [43]	OCC [27] and Scherer [44] appraisal theory and PAD dimensional theory [32].	Software Agents; BDI
KISMET[45]	Physiological theories of Tinbergen and Lorenz and PAD dimensional theory.	Robotic Agent

The work presented in this paper is based on a combination of the WASABI and KISMET's computational models, applied to organizations in a collaborative environment, as presented in the following sections.

4 Proposed Modeling Framework

In this work, the C-EMO modeling framework is proposed, which was developed to simulate dynamically changing *emotions* in virtual agents representing members of a CN. As known, members of a CN are organizations that might be dispersed geographically with different purposes and competences, and not human beings, yet they are managed by humans. Emotions are without any doubt related to humans and it is unquestionable that organizations cannot feel emotions in the same way humans do. Nevertheless, the authors believe that a kind of *individual emotional state* of an organization can be appraised once it makes part of a virtual environment that presupposes interaction and collaboration among its members.

In this context, the main challenges herein are twofold: first what aspects of the emotion theories should be applicable to organizations and second how to capture the stimulus, the evidences and the concepts that should be used in order to mount a model based on human-related emotional theories but applied to organizations. Furthermore we should take into consideration that the applied methods should be non-intrusive, i.e., preserving the privacy of each organization. Another aspect that is also developed, but out of this paper's scope, is the concept of *collaborative emotional state* that represents the CN's emotional state as a whole.

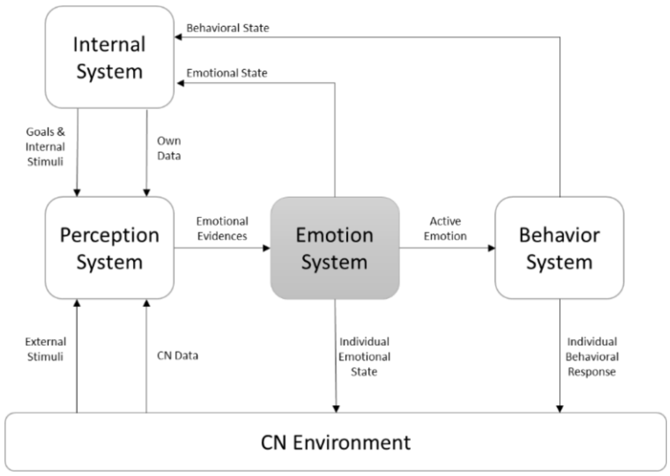

Fig. 1. C-EMO Modeling Framework

In order to accomplish the proposed challenges, the C-EMO Modeling Framework illustrated in Fig. 1 was designed, comprising four main systems:

- ***Perception System***: Collects the external events, environmental states and stimuli from the CN environment in conjunction with the internal state of the member agent in order to prepare an emotional evidences vector of the individual agent.
- ***Internal System***: Maintains the information about the individual agent updated.

- ***Emotion System***: Responsible for assessing the emotional evidences, activating the corresponding agent's emotion and making the emotion manifest to the CN environment.
- ***Behavior System***: According to the activated emotion, a behavioral response(s) is designated to the agent and made available to the CN environment.

Due to the complexity and dynamic nature of emotions, the C-EMO framework was modeled using the Agent-Based and System Dynamics methodologies. In *Agent-Based Modeling (ABM)*, a complex system is modeled as a collection of autonomous decision-making entities called agents (either individual or collective entities such as organizations or groups). Each agent individually evaluates its situation and makes decisions on the basis of a set of rules. According to Siebers et al. [46], an Agent-Based Modeling system should be used when the problem has a natural representation of agents, i.e., when the goal is modeling the behavior and interactions of individual entities in a diverse population in the form of a range of alternatives or futures. In this line, the individual entities are the CN members and the diverse population is the collection of individual members that belong to the collaborative network. Thus, each CN individual member is represented by an agent and the collection of members are represented by a population of agents that "live" inside the agent that represents the Collaborative Network as illustrated below (Fig. 2).

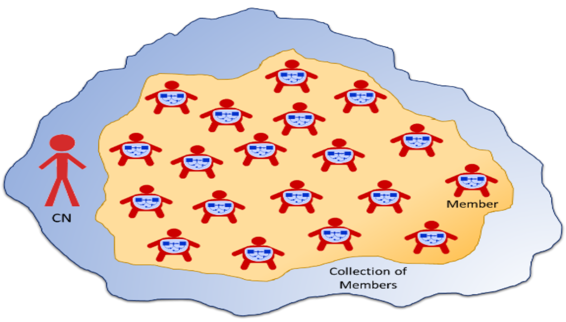

Fig. 2. Agent-Based Model of the Collaborative Network Environment

The model is then composed of two different types of agents; *(i)* the *Individual Member Agent (IMA)*, which represents each participating member of the CN, and *(ii)* the *CN Agent (CNA)*, which represents the CN itself and thus the collection of IMA agents that belong to the CN.

The focus of this paper is on the modeling and simulation/estimation of IMA agent's emotions. In the C-EMO Framework it is the Emotion System that is responsible for it.

Emotion System. The Emotion System is composed of two main modules. The first one is responsible for the emotional appraisal and the second one is in charge of activating the corresponding emotion for the individual agent, as depicted in Fig. 3.

The Emotional Assessment module receives, from the Perception System, an emotional evidences vector that is composed of different parameters relative to the IMA agent own data and also with information about the CN environment, through the CNA agent. For this paper purposes, the interactions of the IMA agent and the CNA agent are not taken into consideration. Table 2 describes the parameters composing the emotional evidences.

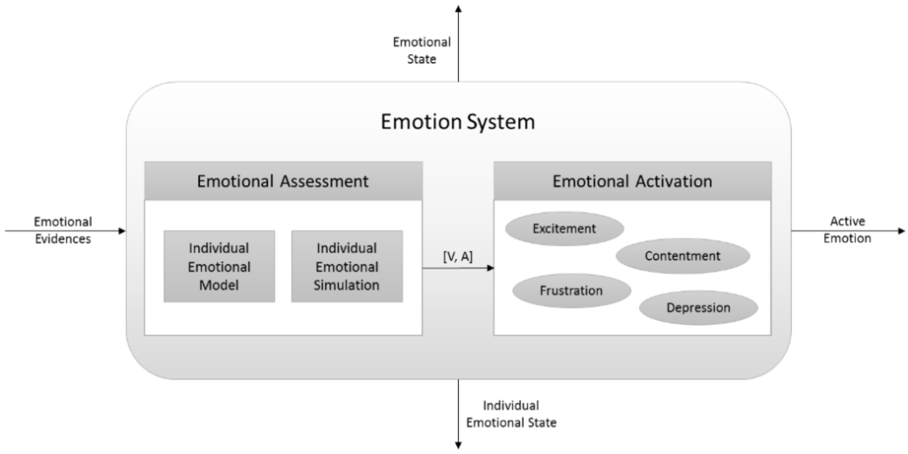

Fig. 3. Emotion System

The two modules composing the Emotional Assessment are the Individual Emotional Model and the Individual Emotional Simulation. Due to uncertainty of how emotions emerge in a virtual collaborative network and how they influence the collaboration itself, a qualitative approach for modeling emotions is proposed using the methodology of System Dynamics.

Table 2. Emotional Evidences Vector

Parameters	*Description*
Past Valence	The previous value of Valence. Represents one dimension of the past emotional state of the Member and assumes the initial value of the Valence variable.
Past Arousal	The previous value of Arousal. Represents the other dimension of the past emotional state of the Member and assumes the initial value of the Arousal variable.
VBE Total VOs	The total number of VOs operating within the VBE. Parameter given by the VBE Management System.
# VOs as Planner	The number of VOs a Member belongs to as a Planner. Parameter given by the VBE Management System.
# VOs as Partner	The number of VOs a Member belongs to as a Partner. Parameter given by the VBE Management System.
Net Income Value	The total earnings or profit of a Member. This is the result of the difference between the total *revenue* and the total *expenses*. Parameter calculated by the VBE Management System.
Member Satisfaction	Represents the level of satisfaction of the Member. This parameter is calculated through a questionnaire that is sent to the VBE Members periodically.
Member Needs & Expectations	Represents the level of expectancy a Member has achieved/met regarding its involvement in the VBE. This parameter is calculated through a questionnaire that is sent to the Member when it joins the VBE and whenever the Member wishes, during the VBE lifecycle.

Performance Evaluation	The performance evaluation value of the Member. This parameter is given by the VBE Management System
Belonging Groups	The percentage of groups a Member belongs to in a certain time. This parameter is calculated by the VBE Management System and is the difference between the number of groups joined and the number of groups left by the Member in relation to the total number of existing groups within the VBE.
Shared Knowledge & Resources	The percentage of knowledge and resources a Member shares within the VBE. This parameter is estimated by the VBE Management system and represents the relation between the knowledge and resources a Member shares and the generation of knowledge that result from it.
Communication Frequency	The rate at which the Member communicates with others within the VBE. This parameter is based on a social network analysis of the VBE environment and is given by the VBE Management System.
Communication Intensity	The measure of the effectiveness of communication within the collaborative VBE environment. This parameter, which is also based on the theory and analysis of social networks, is delivered by the VBE Management System.
Invitations to Form VOs	The percentage of invitations to form VOs a Member has, in relation to the total of existent VOs in preparation phase within the VBE.

System Dynamics Modeling (SDM), initially proposed by Jay Forrester[47], is a methodology and set of modeling tools that allows the understanding of the behavior of complex systems over time. It deals with internal feedback loops and time delays that affect the behavior of the entire system. It has two model representations: *i) causal loop diagrams (qualitative)*, which are used to depict the basic cause-effect mechanisms of the system and also the circular chains of those mechanisms that form a feedback or closed loop; and *ii) stock and flow diagrams (quantitative)* that show relationships between variables that have the potential to change over time and distinguishes between different types of variables. The resulting structure of the system, built with stocks and flows, determines the behavior of the system. The corresponding emotion causal loop diagram and stock and flow diagram of the IMA agent is illustrated in Fig. 4 and **Fig. 5** respectively.

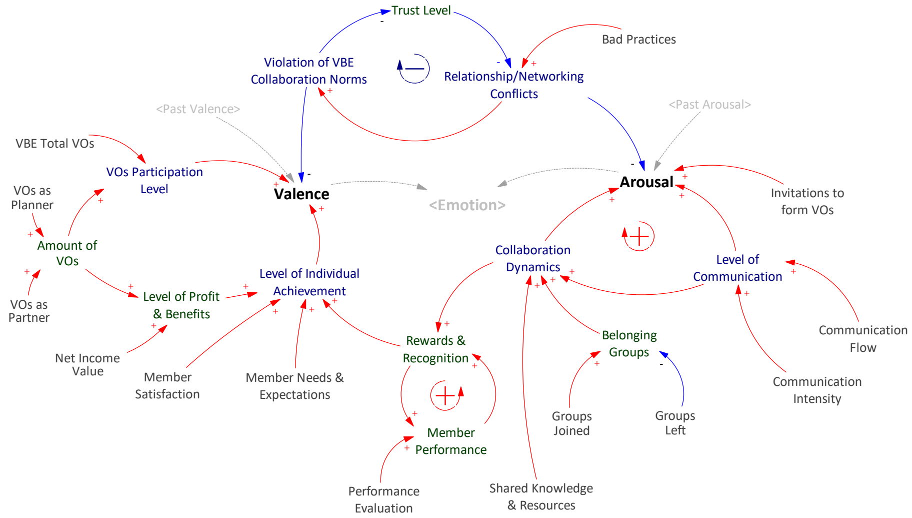

Fig. 4. Emotion Causal Loop Model

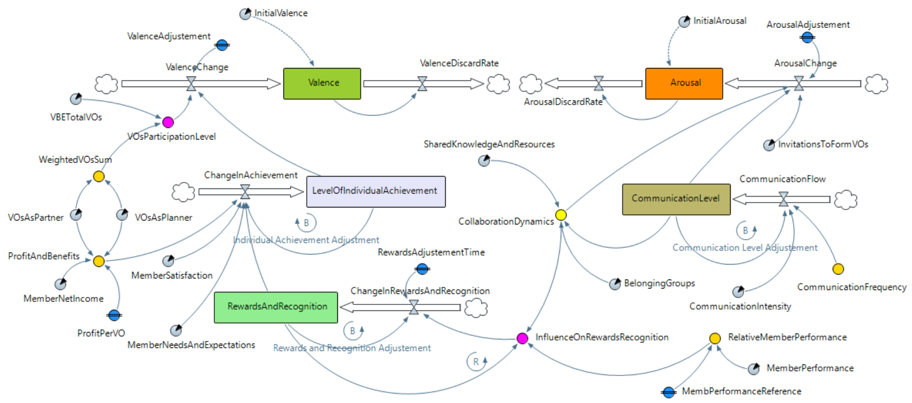

Fig. 5. Emotion Stock and Flows Model

The dynamic model proposed for the representation of individual emotion in CNs is based on the Russell's pair of variables and follows the agent dynamics of Garcia's baseline model for emotional dynamics[48]. Russell's circumplex model [29], states that all affective states arise from two fundamental variables: *Valence*, a pleasure-displeasure continuum, and *Arousal* that is related to the level of activation, uncertainty, novelty, expectation and complexity of the stimuli. Therefore, each individual emotion can be understood as a linear combination of these two dimensions and the IMA agent emotional state described as:

$$e_i(t) = < V_i(t), A_i(t) > \quad (1)$$

In this way, the IMA agent expresses its emotional state according to the tuple of values of valence and arousal. Both variables ranging between -1 and 1.

Taking into consideration that members of collaborative networks are organizations, four individual emotions were adopted, two positives and two negatives as described in Table 3. Following the Russell's dimensional approach there is one possible active emotion for each circumplex quadrant that is the result of the equation **(1)**.

Table 3. The Adopted Emotions and their dimensional placement

Emotions	*Synonyms*	*Dimensions*
Excitement	Active, enthusiastic	Valence >0; Arousal >0
Contentment	Relaxed	Valence >0; Arousal<0
Frustration	Afraid, nervous, angry	Valence <0; Arousal >0
Depression	Apathy, miserable	Valence<0; Arousal<0

5 Model Implementation and Simulation Results

The first developments of the Emotional System were conducted within the GloNet project [4], which was extremely helpful because it was possible to present the concept and the main ideas behind this work to end-users and get some feedback in what concerns its practical usefulness and find alternative approaches [49, 50]. One of the principal insights was that due to the inexistence of available data to validate the work, there is a need for a notable amount of experimentation, and this is the reason why the work evolved to develop, in a second step, a modeling framework based on System Dynamics Modeling and Agent-Based Modeling. In this context, this second implementation was developed using the AnyLogic multi-method simulation tool [51], which comprises, on a single object-oriented platform, three modeling and simulation methods: System Dynamics [47], Agent-Based, and Discrete Event [52].

In order to make a preliminary evaluation of the proposed emotion model, a scenario was designed for a given Company A. The idea behind the scenario consists in a simulation of the daily life of the company during 100 days. Having into account the lack of a real data set, some assumptions were taken in order to have the first results of the proposed model, as follows.

Table 4. Simulation assumptions

Assumptions	
A_1	A company when invited to form a VO gets enthusiastic.
A_2	A company seeing its expectations met tends to stay comfortable.
A_3	A company whose performance evaluation is high tends to be pleased.
A_4	A company that shares its knowledge and resources and maintains working groups is more energetic.
A_5	A company that is satisfied keeps engaged.

During the simulation period, several parameters of the emotional evidences vector change according to the previous assumptions, as shown in Table 5. The initial emotional state of the member company is neutral. The values in bold are the ones that change in order to cope with the assumptions.

Table 5. Adopted simulation scenario for a Company A

Parameters	*Day 0 - 15* *(A_2+A_3)*	*Day 15 – 30* *(all)*	*Day 30 - 50* *(A_2+A_3 +A_5)*	*Day 50-70* *(none)*	*Day 70* *(A_4)*
Past Valence	0	0.4	0.7	-0.3	-0.3
Past Arousal	0	-0.3	0.2	-0.1	0.3
VBE Total VOs	3	3	3	3	3
VOs as Planner	1	1	1	1	1
VOs as Partner	1	1	1	1	1
Net Income Value	100 000	100 000	100 000	100 000	100 000
Member Satisfaction	50%	**100%**	100%	**20%**	20%
Member Needs & Expect.	**100%**	100%	**20%**	20%	20%
Performance Evaluation	**5**	5	**2**	**0.5**	0.5
Belonging Groups	50%	**100%**	100%	**20%**	**100%**
Shared Knowledge & Resou.	50%	**100%**	100%	**20%**	**100%**
Communication Frequency	0.2	0.2	0.2	0.2	0.2
Communication Intensity	2.5	2.5	2.5	2.5	2.5
Invitations to Form VOs	0	**1**	1	**0**	0
Emotion Activation	Contentment	Excitement ↑	Excitement ↔	Depression	Frustration

The implementation of the model and the simulation results are presented in **Fig. 6**. On the left hand side the evolution of the tuple (Valence, Arousal) is presented. On the right hand side, a representation of the circumplex model.

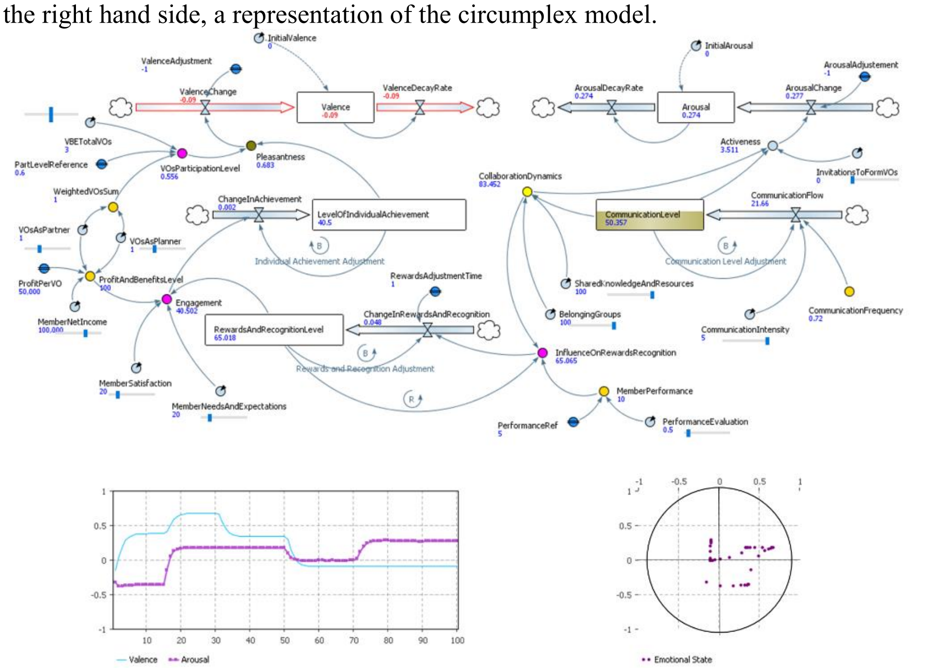

Fig. 6. Simulation runs and results

In a first overall analysis, the proposed model provided promising indications. Nevertheless, it was found that some adjustments are needed on two main aspects: a) the weight of some of the parameters and, b) the time of the emotion decay.

6 Conclusions and Future Work

The C-EMO Modeling Framework is introduced with the aim to conceptualize the notion of Collaborative Emotions within the context of a collaborative environment. A model based on Agent-Based and System Dynamics Modeling and Simulation is presented in order to model and simulate individual emotions generated by IMA agents. At the end some simulations results for a partial validation of the model are shown.

Future work relies on developing the *Behavior System* of the C-EMO Modeling Framework and developing a model to estimate the Collective Emotional State of the CN.

Acknowledgments. This work has been funded in part by the Center of Technology and Systems and the Portuguese FCT-PEST program UID/EEA/00066/2013 (Impactor project), and partly by the GloNet project funded by the European Commission.

References

1. Baxter, G. and I. Sommerville, Socio-technical systems: From design methods to systems engineering. Interacting with Computers, 2011. 23(1): p. 4-17.
2. Morris, A., W. Ross, and M. Ulieru. A system dynamics view of stress: Towards human-factor modeling with computer agents. in IEEE International Conference on Systems, Man and Cybernetics. 2010. Istanbul, Turkey: IEEE.
3. Damasio, A.R., Descarte's Error: Emotion, Reason, and the human Brain. 1994: Gosset/Putnam Press.
4. Ferrada, F. and L.M. Camarinha-Matos, An Emotional Support System for Collaborative Networks, in Technological Innovation for Cloud-Based Engineering Systems, DoCEIS'15 6th Socolnet/IFIP/IEEE Advanced Doctoral Conference on Computing, Electrical and Industrial Systems, L.M. Camarinha-Matos, et al., Editors. 2015, Springer. p. 43-53.
5. EPoSS, Smart Systems in the Multi-Annual Strategic Research and Innovation Agenda of the JTI ECSEL. 2014.
6. Mandler, G., The nature of emotion, in States of mind: Conversations with psychological investigators, J. Miller, Editor. 1983, BBC: London. p. 136-153.
7. Siegert, I., R. Böck, and A. Wendemuth, Modeling Users' Mood State to Improve Human-Machine-Interaction, in Cognitive Behavioural Systems. 2012, Springer Berlin Heidelberg. p. 273-279.
8. Ekman, P., Expression and the nature of emotion, in Approaches to Emotion, K.R. Scherer and P. Ekman, Editors. 1984, Erlbaum: Hillsdale, NJ. p. 319-344.
9. Parrott, W., Emotions in Social Psychology. 2001, Philadelphia: Psychology Press.
10. Fredrickson, B.L., The broaden-and-build theory of positive emotions. Philosophical Transactions of the Royal Society of London, 2001. 359(Series B): p. 1367- 377.

11. Baumeister, R.F., et al., How emotion shapes behavior: Feedback, anticipation, and reflection, rather than direct causation. Personality and Social Psychology Review, 2007. 11: p. 167-203.
12. Robbins, S.P. and T.A. Judge, Organizational Behavior. 15th ed. 2013: Pearson. 258-297.
13. Gordon , S.L., The sociology of sentiments and emotion, in Social Psychology: Sociological Perspectives M. Rosenberg and R.H. Turner, Editors. 1981, Basic Books: New York. p. 562-92.
14. Scherer, K.R., Emotions are emergent processes: they require a dynamic computational architecture. Philosophical Transactions of the Royal Society B: Biological Sciences, 2009. 364(1535): p. 3459-3474.
15. James, W., What is an Emotion? Mind, 1884. 9(34): p. 188-205.
16. Schachter, S. and J.E. Singer, Cognitive, social and physiological determinants of emotional state. Psychological Review, 1962. 69: p. 379-399.
17. Zajonc, R.B., On the primacy of affect. American Psychologist, 1984. 39: p. 117-123
18. Darwin, C., Expression of the emotions in man and animals. 1979: J Friedmann.
19. Izard, C.E., Human emotions. 1977, New York: Plenum Press.
20. Izard, C.E., Basic emotions, relations among emotions, and emotion–cognition relations. Psychological Review, 1992. 99: p. 561-565.
21. Tomkins, S.S., Affect as amplification: some modification in theory, in Emotion: Theory, research, and experience R. Plutchik and H. Kellerman, Editors. 1980, Academic Press, Inc. p. 3-33.
22. Ekman, P., An argument for basic emotions. Cognition and Emotion, 1992. 6: p. 169-200.
23. Arnold, M.B., Emotion and Personality. 1960, New York: Columbia University Press.
24. Lazarus, R.S., Thoughts on the relations between emotions and cognition. American Psychologist, 1982. 37: p. 1019-1024.
25. Lazarus, R.S., Emotion and Adaptation. 1991, New York: Oxford University Press.
26. Scherer, K.R., A. Schorr, and T. Johnstone, Appraisal Processes in Emotion: Theory, Methods, Research. 2001, New York and Oxford: Oxford University Press.
27. Ortony, A., G.L. Clore, and A. Collins, The Cognitive Structure of Emotions. 1988, Cambridge, UK: Cambridge University Press.
28. Frijda, N.H., The Emotions. 1986, Cambridge: Cambridge University Press.
29. Russell, J.A., A Circumplex Model of Affect. Journal of Personality and Social Psychology, 1980. 39: p. 1161-1178.
30. Russell, J.A., Core affect and the psychological construction of emotion. Psychological Review, 2003. 110: p. 145-172.
31. Russell, J.A. and A. Mehrabian, Evidence for a three-factor theory of emotions. Journal of Research in Personality, 1977. 11(3): p. 273-294.
32. Mehrabian, A., Pleasure-Arousal.Dominance: A General Framework for Describing and Measuring Individual Differences in Temperament. Current Psychology, 1996. 14(4): p. 261-292.
33. Moors, A., Theories of emotion causation: A review. Cognition and Emotion, 2009. 23(4): p. 625-662.
34. Marsella, S., J. Gratch, and P. Petta, Computational models of emotion, in Blueprint for affective computing: a source book, K.R. Scherer, T. Bänziger, and E.B. Roesch, Editors. 2010, Oxford University Press: Oxford.
35. Rodríguez, L.-F. and F. Ramos, Development of Computational Models of Emotions for Autonomous Agents: A Review. Cognitive Computation, 2014. 6(3): p. 351-375.
36. Handayani, D., et al., Systematic review of computational modeling of mood and emotion. Information and Communication Technology for The Muslim World (ICT4M), 2014.
37. Kowalczuk, Z. and M. Czubenko, Computational Approaches to Modelling Artificial Emotion - An Overview of the Proposed Solutions. Frontiers in Robotics and AI, 2016. 3(21).

38. Velásquez, J.D., Cathexis: A Computational Model for the Generation of Emotions and their Influence in the Behavior of Autonomous Agents, in Department of Electrical Engineering and Computer Science. 1996, Massachusetts Institute of Technology (MIT).
39. Roseman, I.J., M.S. Spindel, and P.E. Jose, Appraisals of Emotion-Eliciting Events: Testing a Theory of Discrete Emotions. Journal of Personality and Social Psychology, 1990. 9(5): p. 899-915.
40. Minsky, M., The Society of Mind. 1986, New York: Simon & Schuster.
41. El-Nasr, M.S., J. Yen, and T.R. Ioerger, FLAME-Fuzzy Logic Adaptive Model of Emotions. Autonomous Agents and Multi-Agent Systems, 2000. 3: p. 219-257.
42. Gebhard, P., ALMA - A Layered Model of Affect. In:, in Proceedings of the Fourth International Joint Conference on Autonomous Agents and Multiagent Systems (AAMAS'05). 2005: Utrecht. p. 29-36.
43. Becker-Asano, C., WASABI: Affect Simulation for Agents with Believable Interactivity. 2008, University of Bielefeld: Bielefeld.
44. Scherer, K.R., What are emotions? And how can they be measured? Social Science Information, 2005. 44(4): p. 695-729.
45. Breazeal, C., Emotion and sociable humanoid robots. International Journal of Human-Computer Studies, 2003. 59(1-2): p. 119-155.
46. Siebers, P.-O., et al., Discrete-Event Simulation is Dead, Long Live Agent-Based Simulation! Journal of Simulation, 2010. 4(3): p. 204-210.
47. Forrester, J.W., Industrial Dynamics. 1961, Cambridge, MA: The M.I.T. Press.
48. Garcia, D. and F. Schweitzer, Emotions in Product Reviews - Empirics and Models., in Proceedings of 2011 IEEE International Conferenceon Social Computing, SocialCom 2011. p. 483-488.
49. Camarinha-Matos, L.M., et al., Collaborative Enterprise Networks for Solar Energy, in ICCCT'15 - IEEE International conference on Computing and Communications Technologies. 2015, IEEE: Chennai, India.
50. Camarinha-Matos, L.M., A.I. Oliveira, and F. Ferrada, Supporting Collaborative Networks for Complex Service-Enhanced Products, in Risks and Resilience of Collaborative Networks. Proceedings of PRO-VE 2015, L.M. Camarinha-Matos, F. Bénaben, and W. Picard, Editors. 2015, Springer. p. 181-192.
51. AnyLogic. AnyLogic: Multimethod Simulation Software. 2000 [cited 2015; Available from: http://www.anylogic.com/.
52. Gordon, G., A General Purpose Systems Simulation Program., in Proceedings of EJCC: Computers - a key to total systems control. 1961, McMillan: Washington D.C. p. 87-104.