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An Adaptive Multi-Agent Model for Dynamics of Emotion Contagion in Groups

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ABSTRACT

In this paper a multi-agent model is proposed that can simulate emotion contagion processes within groups. The obtained dynamical multi-agent model is integrated with the environment in an adaptive manner by use of specific characteristics of a group's emotion contagion. The model dynamically adapts the values of these parameters to the characteristics of the group. It is implemented in Java®

KEY WORDS: Adaptive, Multi Agent, Emotion, Contagion

1. INTRODUCTION

Agents are often used in environments that have a highly dynamic nature. In many applications of agent systems, varying from robot contexts to virtual world contexts, some form of world model plays an important role; e.g., [1, 11, 14, 15, 17]. Usually in such applications a world model represents a state of the world that is built up by using different types of inputs and is updated with some frequency. Examples of challenges addressed are, organizing data, producing local/global models, integrating sensor information etc. (cf. [14, 15]). Such agents can provide more dedicated support when they have a certain level of human-awareness see also [1, 11, 17]. This may require awareness not only of personal characteristics such as preferences, but also of (dynamically changing) states of the human. Examples of such states are emotion and stress, fatigue and exhaustion, goals and intentions, and attention states [7, 12, 18]. Acquiring awareness of such states is a nontrivial challenge but some sensors may be used.

Such sensor information can be used in a more indirect manner in dynamical models that express temporal relationships between a number of variables including these human's states and the sensor information; e.g., [16]. As humans may show substantial individual differences in characteristics in cognitive functioning, such a dynamical model usually includes a number of parameters for a number of specific characteristics of the human. Therefore they only can be used in a dedicated manner when sufficiently accurate estimations can be made for the values of these parameters as representations for the characteristics of the human considered. For applications in software agents this implies that such an agent does not only need a dynamical model of the human's processes, but also an adaptation model e.g [2, 13, 20]describing how the parameter values of the former model can be adapted over time to the characteristics of the human e.g. [1, 11, 14, 15, 17].

A dynamical system model usually involves two different types of concepts: "*state variables*" and "*parameters*" [2, 13, 20]. A particular problem here is that values for parameters often are not completely known initially by the agent. So the agent needs to be able to perform parameter estimation or tuning either off-line or on the fly. The proposed agent model is based on the results of mathematical analyses from the literature such as [19]. Thus, the agent can adapt its beliefs about the environmental characteristics (represented by the model parameters) to the real characteristics [2, 13, 20]. The agent's adaptation model was designed and implemented in a generic manner, but for this paper it is applied to the dynamical model for emotion contagion as a case study e.g. [7, 12, 18]. Interestingly this adaptation is carried out for eighteen parameters simultaneously.

The paper is organised as follows. In Section 2 the example model for the emotion contagion is briefly introduced. Section 3 presents the background ideas of the parameter adaptation approach used. Section 4 presents the method by which the agent adapts to the environmental characteristics with implementation details. In Section 5 some simulation results are discussed. Finally, Section 6 is a discussion.

2. Dynamical Model for Emotion Contagion

In this section, inspired by the theories [3, 10] and approaches used in [12, 18] a computational model of emotion contagion is described. First a number of aspects are distinguished that play a role in the contagion, varying from aspects related to the sender, the channel between sender and receiver and the receiver of the transferred emotion. Accordingly, the

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model (for detail description see [4, 5, 8]) distinguishes three parts in the process of transfer of emotion and related parameters: a sender S, a receiver R, and the channel from S to R (see Table 1).

Table 1: Parameters for aspects of emotion contagion

	Emotion state		Characteristics	
Sender	current level of the sender's emotion	q_S	extent to which the sender expresses the emotion	ε_S
Channel			the strength of the channel from sender to receiver	α_{SR}
Receiver	current level of the receiver's emotion	q_R	openness or sensitivity for received emotion	δ_R
			tendency to adapt emotions upward or downward	β_R
			tendency to amplify emotions	η_R
			collective positive impact of received emotion from group members	PI
			collective negative impact of received emotion from group members	NI
			the strength of which an emotion is received from sender	γ_{SR}

As a first step, all aspects have been formalized numerically by numbers in the interval [0, 1]. The following given set of equations describes the dynamics of emotions produced by individual(s) and emotion contagion among the group members. The detail explanation of this dynamic model can be found in [4, 5, 8].

$$\gamma_{SR} = \varepsilon_S \, \alpha_{SR} \, \delta_R$$
$$\gamma_R = \Sigma_{S \in G \backslash \{R\}} \; \gamma_{SR}$$
$$dq_R/\,dt = \gamma_R \, [\eta_R \, (\beta_R \, PI \; + (1\text{-}\beta_R) \, NI) + (1\text{-}\eta_R) \, q_R^* \; - \; q_R]$$
$$q_R^* = \Sigma_{S \in G \backslash \{R\}} \; w_{SR} \, q_S$$
$$w_{SR} = \varepsilon_S \, \alpha_{SR} \, / \, \Sigma_{C \in G \backslash \{R\}} \; \varepsilon_C \, \alpha_{CR}$$
$$PI = 1 - (1\text{-}q_R^*) \, (1\text{-}q_R)$$
$$NI = q_R^* \, q_R.$$
$$dq_R/\,dt = \gamma_R \, [\eta_R \, (\beta_R \, (1 - (1\text{-}q_R^*) \, (1\text{-}q_R)) \; + (1\text{-}\beta_R) \, q_R^* q_R \,) + (1\text{-}\eta_R) \, q_R^* \; - \; q_R]$$

The collective emotional state of a group is calculated as:

$q = \Sigma_i \, \rho_i \, q_i$ where $i = \{0..n\}$ and "n" is total members in the group.
"ρ" is relevance factor

Some simulation results for "*Amplification*" and "*Absorption*" [5, 9] cases of the model are given in Fig. 1(a) and (b) respectively.

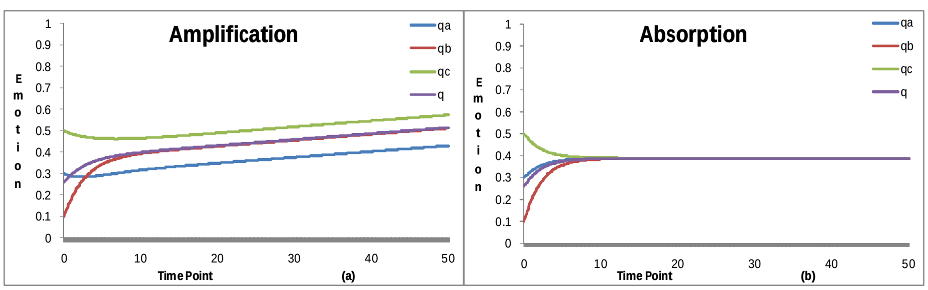

Fig. 1: (a)- β= (0.2, 0.4, 0.7), δ_R=0.5, η_R = (0.5, 0.3, 0.8) **(b)**-β= (1, 0.3, 0.8), δ_R=0.9, η_R = 0

3. The Adaptation Approach

As we have already mention in section 1 that an agent does not only need a dynamical model of the human's processes, but also an adaptation model [2, 13, 20]describing how the parameter values of the former model can be adapted over time to the characteristics of the human's states such as "*emotion*" [7, 12, 18].As often it is not possible to determine accurate values at forehand, this section presenting a method by which the agent adapts its beliefs concerning human characteristics to the real characteristics. The main idea is as follows. The agent initially assumes rough estimations of the values for these human characteristics, and maintains them as beliefs. Using the dynamical model with parameter values as represented by these initial beliefs, the agent [1, 15, 17] predicts the human state, up to a certain time point. When at that time point, for example by observation, information is obtained that can be related to the target of one or more state variables of the model, this can be used as input for the adaptation process. The agent then tries to minimize the difference between predicted and target by adjusting the beliefs on the human characteristics (i.e., the parameter values which were initially assumed). This process of adaptation is kept going on until the difference is low enough, i.e., until the agent has a sufficiently accurate set of beliefs about the human's characteristics see also [2, 13, 20]. To be able to make reasonable adjustments it is needed to obtain information on how a change in a parameter value affects the difference between predicted and target of the variable that is considered; this is called the sensitivity of the variable value for the parameter value. This "*sensitivity"* based approach is formally described in [7] and to give more focus on the implementation details and the simulation results, only the equations are included here.

As a first step, a small change ΔP in the parameter is tried to make an additional prediction for X, and based on the resulting change ΔX found in the two predicted values for X, we determine the sensitivity as follow for all parameters one by one.

$$S_{(X,P)} = \Delta X / \Delta P$$

After calculating the sensitivity we can calculate the change required in parameter value to make the deviation of predicted value from the target value minimum i.e. ideally "*zero*".

$$\Delta P = \lambda \, (\Delta D / S_{X,P}) \, (1\text{-}W) \qquad \text{when } \Delta D / S_{X,P} \geq 0$$

$$\Delta P = -\lambda \, (-\Delta D / S_{X,P}) \, W \qquad \text{when } \Delta D / S_{X,P} < 0$$

Where λ is the "*speed factor*" to control the adaptation speed, ΔD is the "*deviation*" from the target, "*W*" is the current value of the parameters being adapted and finally "ΔP" is the suggested change in parameter value.

4. Implementation

In this section we will discuss basic architecture of scenario for which we are designing our adaptive multi-agent model, specifications and its implementation in detail. Section 4.1 will give an architectural overview of the implantation and its detail is discussed in section 4.2.

4.1 Architectural View of Implementation

We have divided our proposed system in two main modules. First is the "World State" keeping complete information about the members of group: referred as "Actors", initial values of their emotion levels, initial values of parameters representing the characteristics of human's emotion and the dynamical model "World Model" to determine group emotion level. In other words it constitute the real world for which agent have to adapt its belief accordingly. Second module is "Master Agent" which is further consisting of "Replica World Model" and "Adaptation Model". Former one is just the duplication of dynamical model of the "World Model" as name suggest and is described earlier in section 2. Later one is responsible for the adaptation process in accordance to the approach described section 3. In addition to these models "Master Agent" also has mirror image of the "Actors" referred as "Agents" for this module and self assumption mechanism for its belief to make the system running properly. This is also explained diagrammatically in Fig. 2.

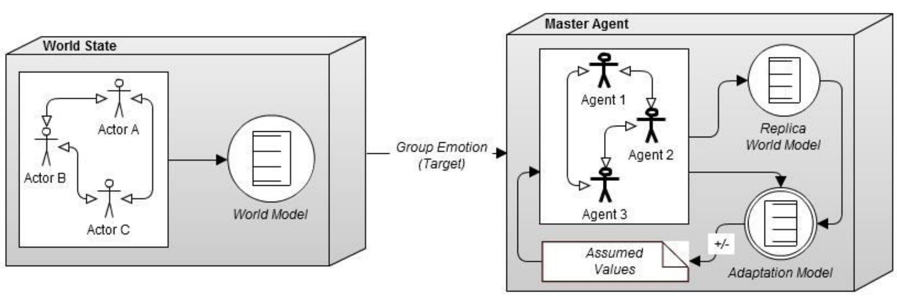

Fig. 2: Architectural View

Moreover from working point of view of system "World State" generates *group emotion level* through its dynamical model of emotion contagion and this is the only information along with time point which available for the "Master Agent" to adapt its belief concerned to the characteristics of human's emotion. This *group emotion level* is considered as a "*target*" to achieve during adaptation process of the agent see also [7, 12, 18]. On other hand "Master Agent" has its own system to make assumptions about the beliefs concerning these characteristics which are later on passed to "Replica World Model" and "Adaptation Model" [2, 13, 20]. On the basis of these initial beliefs "Replica World Model" generates its prediction about the group emotion level at that time point. This predicted value and the "*target*" are compared and beliefs of the agent are updated accordingly to minimize the deviation of prediction from the "*target*". Furthermore "Adaptation Model" does this all through to separate internal modules 1*) sensitivity calculation* and 2) *parameter tuning*. As currently the system is adapting beliefs in "off-line" mode so multiple targets are available. And these multiple targets may be used to make the adaptation process more reliable and accurate one by one.

4.2 Implementation in Java

This section will give the overview of implementation in Java® for whole system. The system initializes all of its data objects through a Microsoft Excel® file and stores its output back to an Microsoft Excel® file. Later one this output file is used to analyse the results. As discussed in previous sections in detail, we might describe the implementation in the following manner.

World Sate

World state is generated by two modules; one for initializing the parameters of the emotion contagion dynamical model and the other to execute the model and generate the emotion levels of its "Actors" and group's emotion level. Fig. 3 gives the pseudo code for both modules.

PopulateWorldState

```
populateWorldState (ActorA, ActorB, ActorC ){

        Read "Δt" from excel sheet;
        Populate Actor(ActorA)
        Populate Actor(ActorB)
        Populate Actor(ActorB)
}

populateActor(ActorX){

        Initialize all parameters value from
        excel sheet one by one.
}
```

ExecuteWorldState

```
ExecuteWorldStateModel(ActorA,ActorB,ActorC) {
   While (TRUE){
        Calculate
                 "emotion level"
                 "openness"
                 "weight_SA , weight_SB, weight_SC"
                 "weighted sum of emotion level"
                 "Positive Impact"
                 "Negative Impact"
                 "Group Emotion"
        for all members ActorA, ActorB, ActorC
        Write back all values in Excel sheet;}
}
```

Fig. 3: Pseudo Code for "World State"

Master Agent

As discuss earlier in this section, "Master Agent" has three main modules "Replica World Model" and "Adaptation Model". "Adaptation Model" is has further two sub modules "*sensitivity calculation*" and "*parameter tuning*". Pseudo codes for these modules are given in Fig 4.

PopulateMasterAgent

```
populateMasterAgent (AgentA, AgentB, AgentC ){

        Read "Δt" from excel sheet;
        Populate Agent(AgentA)
        Populate Agent(AgentB)
        Populate Agent(AgentB)
}

populateAgent(AgentX){

        Initialize all parameters value from excel sheet one
        by one.
}
```

ReplicaWorldModel

```
ExecuteReplicaWorldModel (AgentA,AgentB,AgentC) {
    Initialize all parameters with assumed values from
    excel sheet one by one.
    While (TRUE){
         Calculate
                 "emotion level"
                 "openness"
                 "weight_SA , weight_SB, weight_SC"
                 "weighted sum of emotion level"
                 "Positive Impact"
                 "Negative Impact"
                 "Group Emotion"
         for all members AgentA, AgentB, AgentC
         Return value of "group emotion level";
    }
}
```

SensitivityCalculation

```
calculateMasterAgentSensitivity (AgentA,AgentB,AgentC) {
    Set "ΔP" for sensitivity calculation;
    Initialize all parameters with assumed values from
    excel sheet one by one.
    Calculate "group emotion level (ref)" with assumed
    value
     While (TRUE){
        Make "ΔP" change a parameter
        Calculate "group emotion level (newref)" with
        new value
        Calculate sensitivity using (newref-ref ) /ΔP
        Write back value in Excel sheet
     }
}
```

ParameterTuning

```
ParameterTuning (AgentA,AgentB,AgentC) {
   Initialized with assumed values for all parameters
   While (TARGET){
      Predict group emotion level using "ReplicaWorldModel"
      Calculate deviation
      Make adjustment in all parameters to minimize
      deviation
      set new assumed values
      }
}
```

Fig. 4: Pseudo Code for "Master Agent"

5. Example Simulation Results

To test the behavior of the model to adapt the agent's beliefs on the environmental characteristics (represented by the parameters) to the real characteristics, it has been used to perform a number of simulation runs using Java®. Standard numerical simulation software Microsoft Excel® is used to generate the graph presented in this paper. These simulation runs result in a variety of interesting patterns. As mentioned earlier in section 1, the focus set consist of eighteen parameters for adaptation, six for each *agent*. Which are ε, δ, β, η, α_{SR} and α_{QR}. Table 2 shows the initial setting for both real values for "World State" and assumed values for "Master Agent"

Table 2: Initial settings

		ε	δ	ρ	β	η	αba	αca	αab	αcb	αac	αbc
	a	0.2	0.5	0.2	0.2	0.5	0.5	0.9				
World	b	0.3	0.5	0.5	0.4	0.3			0.9	0.9		
	c	0.6	0.5	0.3	0.7	0.8					0.9	0.5
	a	0.5	0.6	0.2	0.4	0.1	0.7	0.3				
Agent	b	0.3	0.4	0.5	0.6	0.2			0.7	0.6		
	c	0.2	0.7	0.3	0.2	0.1					0.4	0.4

If we compare the execution of model for both "world" and "agent" we can see clear difference in their behavior. We can also observe significant deviation in calculation of group emotion in both cases as shown in Fig 5 below.

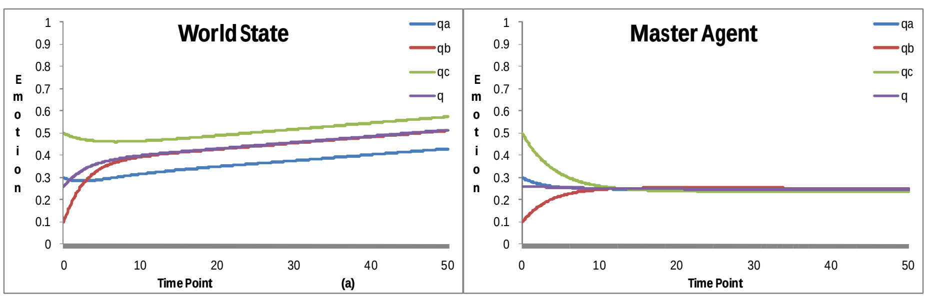

Fig. 5: Model Behavior with initial settings

It is obvious from the Fig. 5 that the assumed values by the agent is not accurate because the group emotion level determine on any time point is significantly deviate from the real group emotion level of the "world State". Table 3 gives an overview of the deviation of predicted values of individual emotion level of group members as well as group emotion level from the targeted values at the end of simulation run for the given time interval. Moreover Fig. 6 shows how much the prediction of different "q_s" deviates over time due to inaccurate initial assumption of parameter values by the agent.

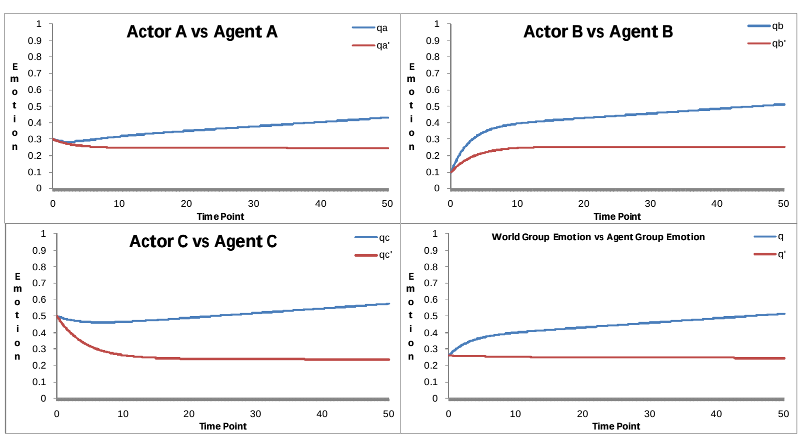

Fig.6: Deviation of "q_s" with initial settings

Similarly these results can be tabulated as follow.

Table 3: Deviation in prediction and real values

	World	Agent	%age Deviation
qa	0.431077639	0.245037137	43
qb	0.512144466	0.251704004	51
qc	0.574713875	0.236406917	59
q	0.514701923	0.245781505	52

Now to minimize this deviation we have to adapt the parameters using approach described in section 2. After using the proposed implementation of adaptation model for parameters agent become able to reduce the deviation and adapt the parameters. Fig. 7 shows the results of an adaptive agent model. It can be seen from the result that the agent model now starts behaving quite similar to the “World State”.

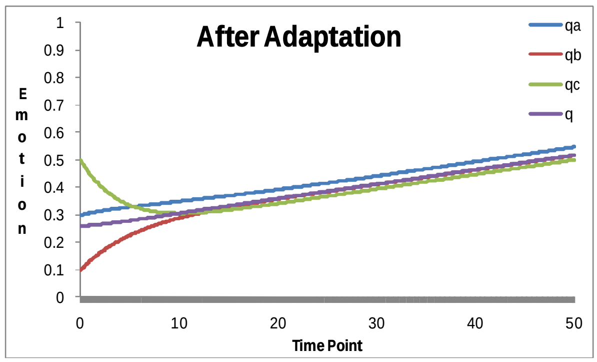

Fig. 7: Model Behavior with adapted values

Fig. 8 gives the adaptation process in more detail and a comparable manner for individual emotion levels of the group member as well as the collective group emotion level

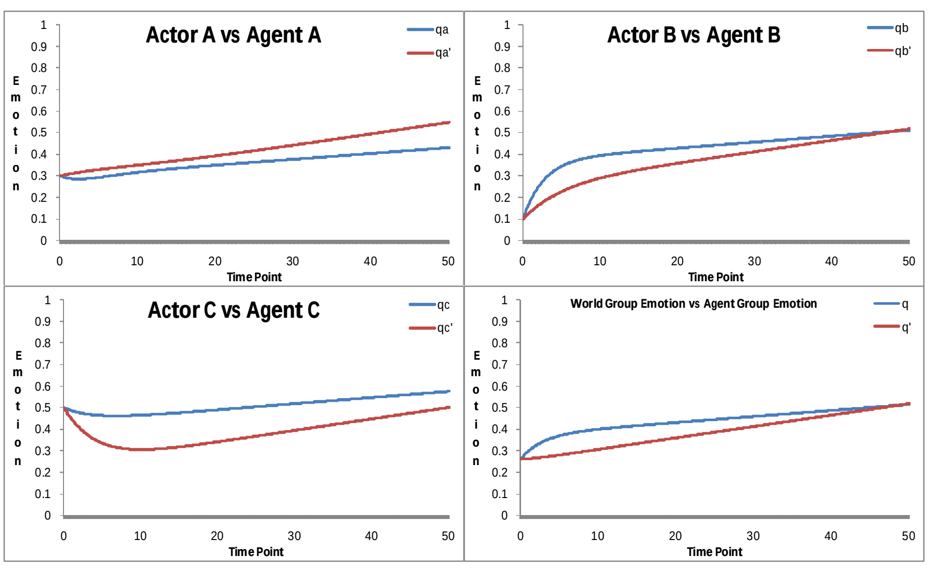

Fig. 8: Deviation of “q_s” after adaptation

Table 4 gives an overview of the deviation in “q_s” after the adaptation process is completed.

Table 3: Deviation in prediction and real values after adaptation

	World	Agent	%age Deviation	%age Improvement
qa	0.431077639	0.547664716	21	22
qb	0.512144466	0.517448884	1	50
qc	0.574713875	0.501122693	13	46
q	0.514701923	0.518594193	1	51

Thus the model is quite successful in achieving the target through adapting the parameters. Due to the space limitation it is impossible to provide the adaptation process for each parameter separately. Fig. 9 shows the adaption process of all parameters over the time. Particularly the adaptation process of η_a is described whose initial value was 0.1 and by the end of adaptation process it attains 0.66 compared to the real value of 0.5.

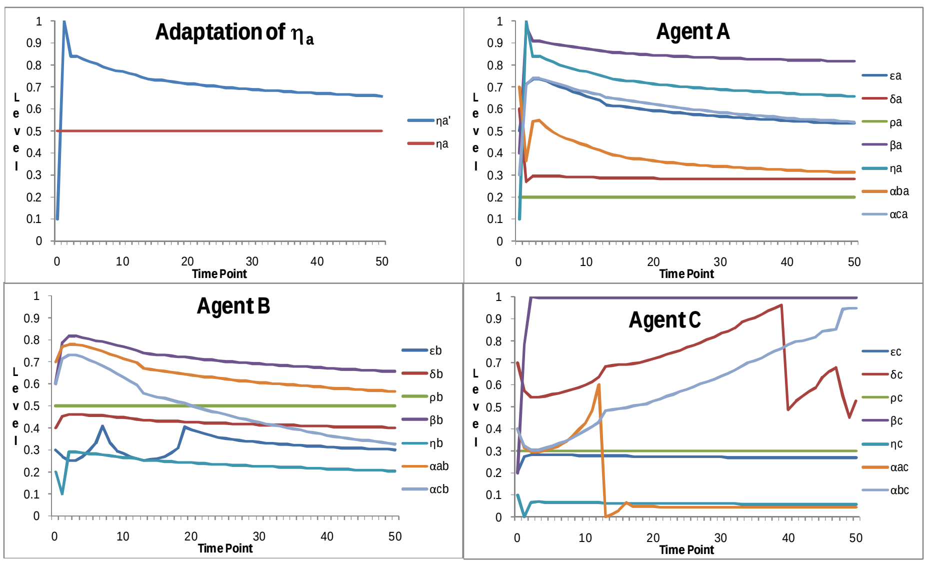

Fig. 8: Adaptation process for all parameters

6. DISCUSSION

The results shown in previous section shows that the target is almost achieved which was set initially. The results show that with the adapted parameters the agent is able to predict the group emotion level with a deviation of only 1% which is quite low and negligible; see [2, 13, 20]. Moreover the results show that the method used is significantly precise and accurate.

In this paper an adaptive multi- agent model is proposed that maintains a model of the emotion contagion dynamics, based on a numerical (dynamical system) see [1, 11, 14, 15, 17]. Moreover, it does so in an adaptive manner by adjusting the parameter values in the environment model that represent believed environmental characteristics, thus adapting these beliefs to the real characteristics of the environment. The described adaptive multi-agent model can be used with an environment (local and/or global) that can be described in a continuous manner by a dynamical system (based on a set of first-order differential equations) [2, 14, 17, 20, 13].

For future research, one of the plans is to validate the model using empirical data within an example domain. Moreover, other approaches for sensitivity analysis will be used to compare the convergence and speed of the adaptation process [2, 13, 20].

Domains for which the presented ambient agent model may be relevant do not only concern natural physical and biological domains but also to human-related autonomic environments for example in logistic, economic, social and medical domains. Such applications of the approach may involve both local information and global information of the environment [1, 14, 17]. An example of the former is monitoring a human's gaze over time and using a dynamical model to estimate the person's attention distribution over time, as described in [6]. Examples of the latter may concern monitoring and analysis of (statistical) population information about (real or virtual) epidemics, gossiping, or traffic flows. This allows to combine in an ambient agent both local (e.g., using information on individual agents) and global (e.g., using information on groups of agents) perspectives on the environment.

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