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Abstract

People react differently to stress. According to the Cognitive Motivational Relational Theory by Lazarus and Folkman, the appraisal of stress and the emotions related to it determine whether people cope with stress by focussing on altering the situation (problem focussed) or on changing the emotional consequences of the events (emotion focussed). These different coping strategies have different effects on the long term. The coping process can be described in a formal dynamic model. Simulations using this model show that problem focussed coping leads to better coping skills and higher decrease of long-term stress than emotion focussed coping. These results also follow from a mathematical analysis of the model. The presented model can form the basis of an intelligent support system that uses a simulation of cognitive processes in humans in stressful conditions.

Keywords: virtual human agent model; stress; cognitive and behavioral modeling; temporal dynamics.

Introduction

Stress is simply a reality of nature where forces from the outside world affecting the individual. It comes in many forms and affects people of all ages and all walks of life. The individual responds to stress in ways that affect the individual as well as their environment. Hence, all living creatures are in a constant interchange with their surroundings, either physically or behaviorally. In general, stress is generally considered as being synonymous with distress and dictionaries defined it as “physical, mental, or emotional strain or tension” or “a condition or feeling experienced when a person perceives that demands exceed the personal and social resources the individual is able to mobilize” (Beck, 1987; Folkman, 1984).

However, human has its own mechanism to adapt with this adversity. Through a process known as coping, our cognitive skill will evaluate the situation mentally. If the situation is threatening, then the human will decide how to deal with the situation, and what skills can be used. If the demands of the situation outweigh the resources human has, then it will be labeled as “stressful” and he or she will react with the classical stress response and vice versa (Carver et al., 1989). It is essential to consider that everyone sees situations differently and has different coping skills. For this reason, no two people will respond exactly the same way to a given situation. Understanding this coping ability is an essential ingredient for developing a software agent that is capable of providing the right intervention towards stressed individuals (Aziz et al., 2010). Therefore there is a need for a virtual human agent model that has this capability. In this paper, virtual human agents are computer model of people that can be used as substitutes for “the real person” in a virtual environment, with a specific focus on simulating human coping behaviors during the formation of stressful events. Although there has been several work in computational models of human stress, little work has been done in modeling coping strategies, with a few exceptions in (Marsella and Gratch , 2003; Marsella et al., 2009).

This paper focuses exclusively on the formal model for dynamics in coping process, as it is one of the essential components in the development of a software agent that is able to monitor individuals’ conditions during stressful events (Aziz & Treur, 2009). In the next section, the underlying principles in coping during stress are discussed (Section 2). From this perspective, a formal model is designed and formulated (Section 3). Later, in Section 4, simulation traces are presented to illustrate how this model satisfies the expected outcomes in long-term stress. In Section 5, a detailed mathematical analysis is performed, to identify equilibria in the model. Finally, Section 6 concludes the paper

Underlying Concepts in Coping

The cognitive theory that governs the underlying principle of this work is based on Cognitive Motivational Relational Theory (CMRT) as in Lazarus and Folkman (1984). This theory explains the role of distinctive positive and negative emotions in the stress appraisal process. Essentially, it conceptualized a transactional process in which the person and the environment are viewed as being in a dynamic and bidirectional relationship, where the essence of cognitive appraisal and coping provides a critical mediator between stressful person-environment and health outcomes.

Dynamics in Cognitive Appraisal Process and Coping Strategies

The cognitive approach to coping is based on a mental process of how the individual appraises the situation. Cognitive appraisal can be viewed as the evaluation of the significance of what is happening in the person-environment relationship (Lazarus, 1991). Normally, it is also related to the *intensity of the stressful events*, a condition where several factors such as *situational demands* (pressure), *personal resources* (i.e; support), and *negative events* play important roles (Aziz et al., 2009; Lazarus & Folkman, 1984). Having the stressful events in motion, individual appraises two types of appraisals; the primary and the secondary. The primary appraisal is made when the individual makes a conscious evaluation of the matter at hand of whether it is a sense of harm or a loss, a threat or a challenge. It is an evaluation process of what is at stake for a person's well being. From this first process, the situation can be appraised either as harm/loss, threatening, challenging or benign (Folkman et al., 1986). *Harm* or loss refers to a condition where damage has already occurred, while *threat* refers to damage, but an anticipated one (*imminence of harm*) and it is more to a risk assessment part (Kessler, 1997). *Challenging* differs from threat in term of how persons are viewing it where it has a positive tone compared to threat. When stressful events were appraised as irrelevant or as *benign*, it will offer the chance to preserve or enhance wellbeing as it does not initiate the stress process as there is no potential threat to overcome. In addition, this appraisal process also involves an array of *personality attributes* such as values, commitments, and beliefs about oneself and the environment in defining the condition that the individuals are facing through (Uehara et al., 1999). Later this process will determine individuals' emotion perception; *negative, positive* or *neutral* emotion (Folkman, 1984). Negative emotion is related to perceiving *harm* and *threat*, while position emotion is attributed to perceiving *challenge* (Lazarus, 1991). Neutral emotion is triggered when individual perceives the condition as *benign* (Noh, 2003).

In the second appraisal, the persons evaluate whether they have the resources to deal with the incoming stressors. It is commonly related to the emotional attribution, where a positive and neutral emotion results in *acceptance* and *change*, while the negative emotion triggers *holdback* behavior (Lazarus, 1991). During this stage, several coping strategies are evaluated. Coping strategies refer to the specific efforts, both behavioral and psychological, that people employ to either be in charge of, tolerate, reduce, or minimize stressful events. According to the CMRT model, there are two types of coping strategies have been distinguished, namely; *problem-focused coping* and *emotion-focused coping*. A problem-focused coping is associated with aggressive interpersonal efforts to alter the situation, as well as rational efforts to get the problem solved (Carver et al., 1989). Contrary to this, emotion-focused coping strategies (thinking rather than acting to change the person-environment relationship) entail efforts to regulate the emotional consequences of stressful or potentially stressful events (Pruchno & Resch, 1989). It is typically include distancing, escape avoidance, and seeking for social comforts.

Several findings showed that the type of coping strategies can be derived, depending on what was at stake (primary appraisal) and what the coping options were (secondary appraisal) (Lazarus, 1991; Ntoumanis et al. 2009). It means, when people feel that they are capable of changing the situation into something better (high perception of acceptance and change), and then a problem-focused coping is chosen. In contrast, when the conditions are considered not amenable to change (high perception in holdback) then emotion-focused coping is used. In addition to this, problem focused coping strategies may give an individual greater perceived control over their problem, while emotion focused coping strategies may more often lead to a reduction of control over the perceived events. All these strategies can be proven useful, but many individuals feel that problem-focused coping represent a more effective means of coping in adversities (Uehara, 1999). In addition to this, in a long run, emotion focused coping is associated with outcomes that people found unsatisfactory (*exhaustion in coping*) that later will increase long-term stress, and problem focused coping is associated with satisfactory outcomes (*improved coping skills*) (Clarke & Tanya, 2009). Furthermore, in psychological distress, problem focus coping strategies appear reliably to produce better emotional adjustment to chronically stressful events than do emotional focused strategies (Pruchno & Resch, 1989; Uehara, 1999).

In short, the following dynamics can be identified from the literature; *(1)* the intensity of the stressful events will lead to coping appraisal, *(2)* the perception of event regulates emotional attribution, *(3)* the emotional attribution will trigger a coping strategy, *(4)* a long-term overwhelming dependency in emotion-focused coping will lead to the exhaustion in coping, and *(5)* a problem-focused coping will improve the coping ability.

The Virtual Human Agent Model

Based on the analysis of the cognitive dynamics in coping appraisal and strategy as given in the previous section, it is possible to specify computational properties for the virtual human agent model. These computational properties are represented in a way that allows simulating how an individual is coping when experiencing stressors, and what are the consequences of that action. All of these concepts (and their interactions) are discussed in the following paragraphs in this section.

Formalizing the Cognitive Model Relationships

In the formalization, the dynamic concepts discussed in the previous section are translated into several interconnected nodes. Figure 1 depicts the global interaction between these nodes. The nodes are represented as variables that can have values ranging from 0 (low) to 1 (high). The interaction will determine the new value of it, either by a series of accumulations or an instantaneous interaction for each node.

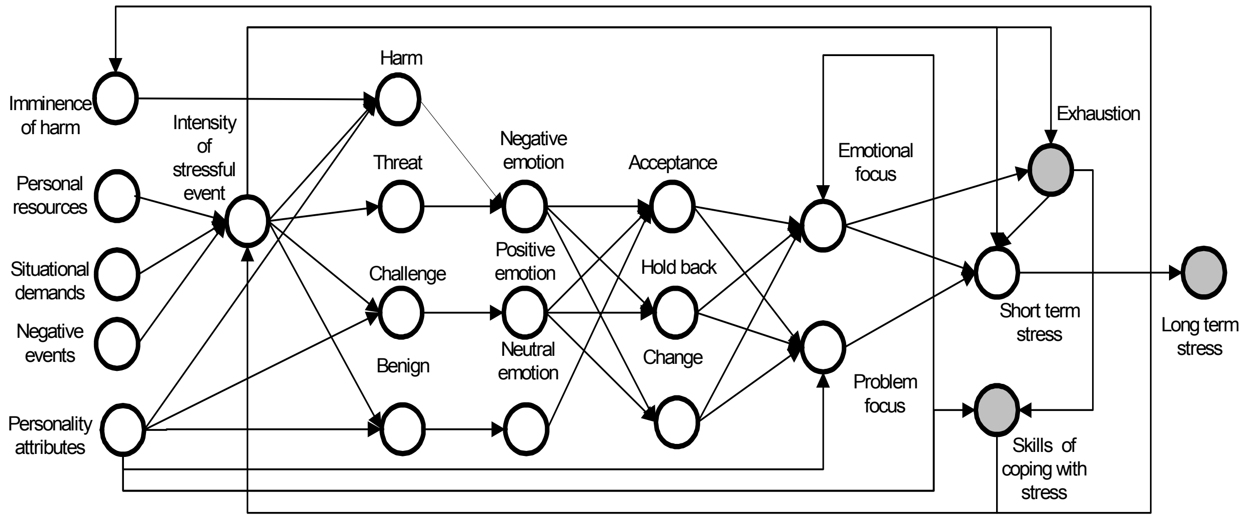

Figure 1: Global relationships of variables involved in the coping process

The description of these formalizations is described in the following. Together, this results in a dynamic model. This model involves a number of instantaneous and some temporal relations. The dark nodes represent concepts that have temporal relationships with the incoming nodes, in which the change is specified for a time interval between t and $t+\Delta t$

Stressor Events, Intensity of Stressful Event, and Imminence of Harm In the model, the stressor events *(e)* (negative events) are generated by simulating potential effects throughout t time using w weighted sum of three types of events; life (*le*), chronic (*ce*), and daily (*de*) events. The role of these factors in the model is to represent a series of events. The intensity of stressful event (*IsE*) represents the degree of stress encountered by a person related to his or her situational demands (*SiD*), and stressor events (*NeVt*), regulated by the proportion factor β_e. In addition, the intensity of a stressful event will be reduced if the coping skills (*ScS*) and personal resources (*PeS*) are high. Imminence of harm (*ImH*) can be measured by combining both concepts in perceived harm (*PeH*) (from the environment), and coping skills (*ScS*).

$$NeV(t) = w_1.le(t) + w_2.ce(t) + w_3.de(t), \ \sum w=1 \quad (1)$$

$$IsE(t)= [\beta_e.NeV(t)+(1-\beta_e).SiD(t)].(1-ScS(t)).(1-PeS(t)) \quad (2)$$

$$ImH(t) = PeH(t).(1-ScS(t)) \quad (3)$$

Harm, Threat, Challenge, and Benign The level of harm (*HrM*) is determined by the proportional contribution φ_h on the imminence of harm, and intensity of the stressful event. The intensity of the stressful event also related to threat (*ThT*). For both cases, in harm and threat, there is a negative relation with personality attributes. On the contrary, challenge (*ChL*) and benign (*BnG*) are positively related with good personality attributes (*PrA*), and negatively with the intensity of stress. Here parameters α_c and ψ_b represent the proportional factor for both challenge and benign respectively.

$$HrM(t) = [\varphi_h.ImH(t) + (1-\varphi_h).IsE(t).ImH(t)].(1-PrA(t)) \quad (4)$$

$$ThT(t) = IsE(t).(1-PrA(t)) \quad (5)$$

$$ChL(t) = \alpha_c.PrA(t) + (1-\alpha_c).(1- IsE(t)).PrA(t) \quad (6)$$

$$BnG(t) = \psi_b.(1-IsE(t)) + (1-\psi_b).PrA(t) \quad (7)$$

Negative, Neutral, and Positive Emotion When the harm and threat is perceived, a fraction from those two parts (by a proportional factor β_n) is contributed as a negative emotion (*NgE*). The notion of positive (*PsE*) and neutral (*NuE*) emotion is represented through a proportional factor of τ_p in challenge and ρ_e in benign respectively.

$$NgE(t) = \beta_n.HrM(t) + (1-\beta_n).ThT(t) \quad (8)$$

$$PsE(t) = \tau_p.ChL(t) \quad (9)$$

$$NuE(t)= \rho_e.BnG(t) \quad (10)$$

Acceptance, Holdback, and Change Positive and neutral emotion increases the acceptance (*AcP*) level by a proportional factor γ_a, while negative emotion works in a opposite way. Holdback (*HdB*) depends on the relation between negative and positive emotion. Change (*ChG*) uses the same concepts as in holdback but with the opposite relation.

$$AcP(t) = \gamma_a.PsE(t) + (1-\gamma_a).NuE(t).(1-NgE(t)) \quad (11)$$

$$HdB(t) = (1-PsE(t)).(NgE(t)) \quad (12)$$

$$ChG(t) = PsE(t)).(1-NgE(t)) \quad (13)$$

Emotional and Problem Focused Coping Emotional focused coping (*EmF*) is determined using the presence of acceptance, holdback and change. Using this relation, emotion focused coping decreases when either acceptance or change increases. However in problem focused coping (*PrF*), coupled with personality attributes, those factors provide a positive effect. Parameters η_e and γ_p regulate the contribution preferences for both specifications respectively.

$$EmF(t) = [\eta_e.(1\text{-}AcP(t)).HdB(t) + (1\text{-}\eta_e).HdB(t)].(1\text{-}ChG(t)) \quad (14)$$

$$PrF(t) = [\gamma_p.PrA(t) + (1\text{-}\gamma_p).AcP(t)].(1\text{-}HdB(t)).ChG(t) \quad (15)$$

Short-term stress, Long-term stress, Exhaustion, and Coping Skills The notion of short-term stress (*StS*) models a relation between coping styles (regulated by μ_s), and a combination of exhaustion and intensity in stressful events (regulated by a proportional rate γ_s) and will influence the level of long-term stress (*LtS*) in a long run. The formation of exhaustion (*ExH*) is modelled using the presence of emotion-focused coping and the intensity of stressful events. The level of coping skills (*ScS*) is influenced by the exhaustion and personality attributes. The rates of change for all temporal relationships are determined by flexibility parameters β_{lts}, ψ_e, and ϕ_s respectively.

$$StS(t)=[1\text{-}(\mu_s.EmF(t)+(1\text{-}\mu_s).PrF(t))].(\gamma_s.ExH(t)+(1\text{-}\gamma_s).IsE(t)) \quad (16)$$

$$LtS(t+\Delta)t=LtS(t)+\beta_{lts}.[\mathrm{Pos}(StS(t)\text{-}LtS(t)).(1\text{-}LtS(t))\text{-}\ \mathrm{Pos}(\text{-}(StS(t)\text{-}LtS(t))).LtS(t)].\Delta t \quad (17)$$

$$ExH(t+\Delta t)=ExH(t)+\psi_e.[(\mathrm{Pos}((IsE(t)\text{-}ExH(t)).(1\text{-}ExH(t)))\text{-}\ \mathrm{Pos}(\text{-}(IsE(t)\text{-}xH(t)).ExH(t))].EmF(t).\Delta t \quad (18)$$

$$ScS(t+\Delta t)=ScS(t) + \phi_s.[\mathrm{Pos}(ExH(t) - ScS(t)).(1\text{-}ScS(t))\text{-}\ \mathrm{Pos}(\text{-}(ExH(t) - ScS(t)).ScS(t)].PrA(t).\Delta t \quad (19)$$

The operator Pos for the positive part is defined by Pos$(x) = (x + |x|)/2$, or, alternatively; Pos$(x) = x$ if $x \geq 0$ and 0 else.

Example Simulation Traces

In this section, the virtual human agent model of coping has been executed to simulate a number of scenarios with a variety of different conditions of individuals. Two example scenarios are shown: an individual with a tendency to choose problem focused coping (***A***), and an individual with a tendency to choose emotional focused coping ***(B)***. The initial settings for the different individuals are the following (*PrA, PeH, SiD, PeS*); ***A*** (*0.8, 0.5, 0.5, 0.8*), and ***B*** (*0.2, 0.5, 0.8, 0.1*). In all cases, the long term stress, exhaustion, and coping skill value are initialized at 0.3.

Corresponding to these settings, the level of severity is set at 0.5, defining that any individuals scoring higher than 0.5 in their long-term stress and exhaustion levels will be considered as experiencing difficulties in coping. These simulations used the following parameters settings: $t_{max}=1000$ (to represent a monitoring activity up to 42 days), Δt=0.3, all proportional and flexibility rates are assigned as 0.5 and 0.9 respectively. These settings were obtained from several systematic experiments to determine the most suitable parameter values in the model.

Result # 1: Simulation Trace for Repeated Stressor Events During this simulation, each type of individual has been exposed to an extreme stream of stressor events, with a moderate alteration between each corresponding event. Figure 2 depicts the comparison between the conditions of individual *A* and *B* during repeated stressors. In this simulation trace, it is visible that individual *A* has developed better coping skills. For this reason, an individual A recovers much faster from long-term stress compared to other individuals.

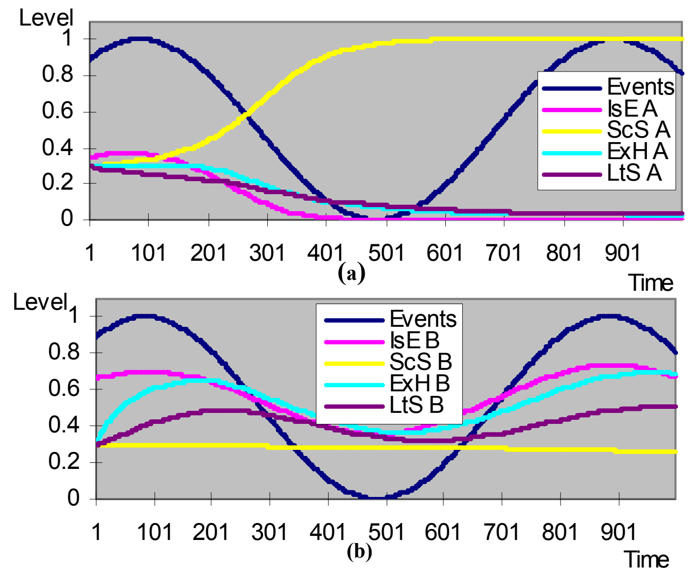

Figure 2. Simulation traces for repeated stressor in (**a**) individual *A* (**b**) individual *B*

Note that the individual *B* shows a repeated increasing pattern that may lead to potential long-term stress. As a consequence of this condition, an individual B will experience difficulty if that individual is having constant exposure towards stressors in a long run

Result # 2: Simulation Trace for Fluctuated Stressor Events This simulation trace shows two types of periods, one with a very high constant and with a very low constant stressor event. These events occurred in a constant behaviour for a certain period of time (approximately within 20 days).

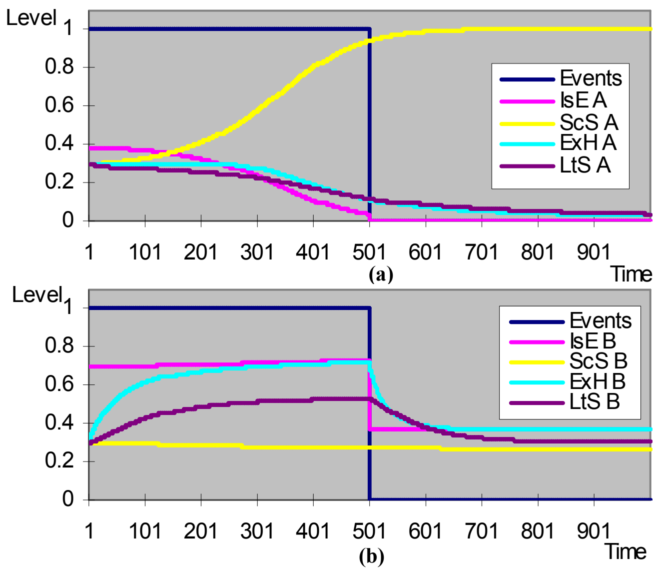

Figure 3. Simulation traces for fluctuated stressor in (**a**) individual *A* (**b**) individual *B*

Also here it can be seen (in Figure 3) that individual *B* gets into long-term stress much faster than individual *A*. Moreover, even at the end of the simulation time, the long term stress level of individual *B* is still slightly higher than individual *A*. Furthermore, in contrast with individual *B*, individual *A* has his/her coping skills improved throughout time.

Mathematical Verification

This section addresses the formal analysis of the agent model and the simulation results presented above by means of a mathematical analysis of the equilibria of the model. The equilibria describe situations in which a stable situation has been reached. Those equilibria are interesting as it should be possible to explain them using the knowledge of the domain that is modelled [2]. As such, the existence of reasonable equilibria is an indication for the correctness of the model. To analyze the equilibria, the available temporal and instantaneous equations are filled with values for the model variables such that the derivatives or differences between time point t and $t + \Delta t$ are all *0*. The dynamic part of the model written in differential equation format is as follows:

$$dLtS(t)/dt = \beta_{lts}.[\,\mathrm{Pos}(StS(t)-LtS(t)).(1-LtS(t)) - \mathrm{Pos}(-(StS(t)-LtS(t))).LtS(t)] \quad (20)$$

$$dExH(t)/dt = \psi_e.[\mathrm{Pos}(IsE(t)-ExH(t)).(1-xH(t)) - \mathrm{Pos}(-(IsE(t)-ExH(t))).ExH(t))].EmF(t) \quad (21)$$

$$dScS(t)/dt = \phi_s.[\mathrm{Pos}(ExH(t) - ScS(t)).(1-ScS(t)) - \mathrm{Pos}(-(ExH(t) - ScS(t)).ScS(t)\,].PrA(t) \quad (22)$$

For an equilibrium it has to hold that all of the derivatives are zero:

$$dLtS(t)/dt = d\,ExH(t)/dt = d\,ScS(t)/dt = 0$$

Assuming β_{lts}, ψ_e and ϕ_s nonzero, this provides the following equilibrium equations:

$$\mathrm{Pos}(StS-LtS).(1-LtS)-\mathrm{Pos}(-(StS-LtS)).LtS = 0\,. \quad (23)$$

$$[\mathrm{Pos}(IsE-ExH).(1-ExH)-\mathrm{Pos}(-(IsE-ExH)).ExH].EmF = 0 \quad (24)$$

$$[\mathrm{Pos}(ExH - ScS).(1-ScS)-\mathrm{Pos}(-(ExH - ScS)).ScS].PrA = 0 \quad (25)$$

Table 1 shows which cases can be distinguished. For example, notice that always $\mathrm{Pos}(x) \geq 0$, so (23) is equivalent to;

$$\mathrm{Pos}(StS-LtS).(1-LtS) = 0$$
$$\mathrm{Pos}(-(StS-LtS)).LtS = 0$$

This provides cases;

$$(StS \leq LtS \;\vee\; LtS = 1) \;\wedge\; (StS \geq LtS \;\vee\; LtS = 0) \quad (26)$$

This can be logically rewritten into;

$$(StS \leq LtS \wedge StS \geq LtS) \vee (StS \leq LtS \wedge LtS = 0) \vee (LtS = 1 \wedge StS \geq LtS) \vee (LtS = 1 \wedge LtS = 0)$$

The latter case cannot exist, and as $0 \leq StS \leq 1$ the other three cases are equivalent to $StS = LtS$. Similarly the cases for (24) and (25) can be found as shown in Table 1.

Table 1: Equilibrium Equations

(1)	(2)	(3)	Combined
StS = LtS	*EmF =0*	*PrA = 0*	*StS = LtS*, *EmF = PrA = 0*
		ExH = ScS	*StS = LtS*, *EmF = 0*, *ExH = ScS*
	IsE = ExH	*PrA = 0*	*StS = LtS*, *IsE = ExH*, *PrA = 0*
		ExH = ScS	*StS = LtS*, *IsE = ExH = ScS*

Note that for each of the distinguished cases, further information can be found about the equilibrium values of other variables using the other non-dynamic-equations. For example, from *EmF = 0* by (14) it follows that *ChG = 1* or *HdB = 0*. This condition illustrates the generic condition that a problem-focused individual that encounters stressful events will never develop long term stress that typically caused by a prolonged dependency on emotion-focused focus coping (Aziz & Treur, 2009; Ntoumanis et al, 2009; Pruchno & Resch, 1989). From another condition *PrA = 0,* by (6) it follows that *ChL* = 0 represents a condition when an individual with negative personality attributes tend to appraise stressful events not as a challenge later will trigger emotion-focused coping (Clarke & Tanya, 2009; Uehara et al. 1999). Both of these conditions can be found in our simulation results.

Conclusion

In this paper, we have presented a formal temporal model for the cognitive process of coping with stress as described in the informal Cognitive Motivational Relational Theory by Lazarus and Folkman. This theory explains the role of positive and negative emotions in the stress appraisal process, which results in either a problem focused coping strategy or an emotional focused coping strategy. The theory also describes the effect of the different strategies on the long term stress.

The resulting model has been used for two simulations of two persons with different personality characteristics in two different scenarios that describe the level of external sources of stress over time. The simulation traces exhibit patterns that are expected in this domain: problem focused coping leads to better coping skills and higher decrease of long-term stress than emotion focused coping. These results also follow from a mathematical analysis of the model, in which the equilibria of the model are determined to identify the stable situation in the model.

The resulting model can be considered as a virtual human agent model, in the sense that it is a computer models of a person that can be used as a substitute for the real person in a virtual environment. This could provide the basis for a intelligent support system, in which the system should be able to understand the coping process of the persons to which support is provided.

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