Design of an Intelligent Support Agent Model for People with a Cognitive Vulnerability

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Abstract—This paper presents the design of an intelligent agent application aimed at supporting people with a cognitive vulnerability to prevent the onset of a depression. For this, a computational model of the cognitive processes around depression is used. The agent application uses the principles of Rational Emotive Behavioural Therapy. The effect of the application is studied using software simulation. The simulation shows that a person that responds to REBT therapy develops less cognitive vulnerability than people that are not supported.

Keywords: cognitive modeling, human-ambience agent, rational emotive behavioral therapy

I. INTRODUCTION

Cognitive vulnerability is, from a broad perspective, a defect belief, or a set of structures that is persistently related to later emerging psychological problems. With in this context, it means that the cognitively vulnerable individuals could show negative cognitions, but that these cognitions are not accessible until they experience an activating event [1]. Several studies in affective disorders have pointed out that cognitive vulnerability is one of the precursors for future onset in unipolar depression [4]. Unipolar depression is a mood disorder characterized by a depressed mood, a lack of interest in activities normally enjoyed, fatigue, feelings of worthlessness and guilt, difficulty concentrating and thoughts of death and suicide [4]. If a person experiences the majority of these symptoms for longer than a two-week period then he may be diagnosed with major depressive disorder. Depression will also lead to a higher cognitive vulnerability. Normally, under a certain degree of stressors exposure, an individual with a history of depression will develop a negative cognitive content (cognitive distortion), associated with the past experiences [9]. When this has happened, the individual is vulnerable and in a high risk to develop future onsets.

The risk of future onset can be reduced through appropriate support from other members within the social support network. Social support network is made up of friends, family and peers. Some of them might be professionals and support individuals in very specific ways, or other people in this network might be acquaintances in people in contact with them every day [6]. Several studies have suggested that social support is capable to diminish stress through positive inferences, which will later restrain the formation of a cognitive vulnerability. However, some studies have shown that certain types of support provide contrasting effects. Rather than attenuating the negative effects from stressors, it will eventually amplify the individual's condition to get worse [8][9]. Therefore it is important for an individual with a high level of cognitive vulnerability to be supported by a specific mean of intervention in order to prevent future onset.

The goal of this research is to develop an intelligent agent application that can support people with a cognitive vulnerability to prevent the onset of a depression. In the past, intelligent agent technology has become an important means for increasing analysis, decision making ability and communication. To realise a supportive human agent application, it is required to integrate within the application a dynamical model of the human (domain model) that describes how an individual might experience cognitive vulnerability or could stay healthy. With that aim, a model of an ambient agent to support individuals with cognitive vulnerability is described, in which the domain model (cognitive model) is embedded [3]. The resulting integrative ambient agent is able to reason about the state of the human and the effect of possible actions. In case of vulnerability is predicted, the agent can provide to support by providing adequate remedies in an early stage. The aim of this paper is to present the basis of an intelligent ambient agent application that complements the existing approaches by providing support to individuals with cognitive vulnerability using Rational Emotive Behavioural Therapy (REBT). This ambient agent application is expected to have capabilities to understand its environment and the individual, providing a better monitoring and assessment of the situation.

This paper is organized as follows. The first section introduces main concepts used in the dynamic model of cognitive vulnerability. Later it follows by a REBT concept. Thereafter, an ambient model is described and simulated (Section IV and V). The model has been verified by checking several properties of simulation traces (Section VI). Finally, Section VII summarizes the paper with a discussion and future work for this model.

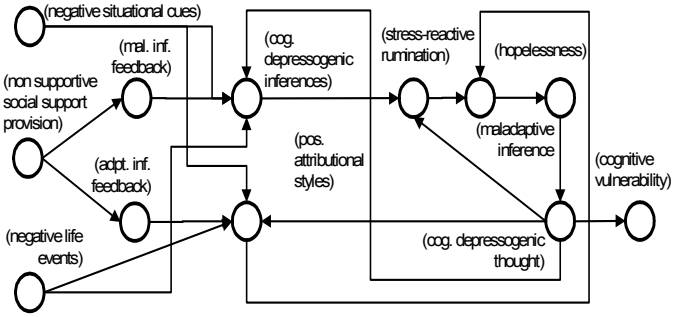

Figure 1. Overview of the Domain (Cognitive) Model in Cognitive Vulnerability.

II. DYNAMIC MODEL OF COGNITIVE VULNERABILITY

This section discusses some of the details of the dynamic cognitive model, which has already been presented in earlier work [2]. In this model, three major components can be identified, namely: the environment, inferential feedbacks, and thought formation. These will represent the dynamic of interactions between environmental feedback and individuals involved in negative thought formation during the beginning of relapse and recurrence in depression. The model has been developed based on the Extended Hopelessness Theory of Depression [9]. In this theory, people who exhibit a negative inferential style, in which they describe, attribute negative events (*NvT*) to stable (likely to persist over time) and global (likely to affect many aspects of life) will most likely to infer themselves as fundamentally useless and flawed [1][7]. One of the important concepts from this theory is the analysis on how social support mitigates a risk of relapse (positive feedback (*AiF*)), and indirectly escalates the risk of relapse (maladaptive inferential feedback (*MiF*)) [7][9]. Both of these concepts are derived from the negative effect of received social support or non-supportive social support provision (*NsP*). As indicated in several previous works, inferential feedbacks provide one of the substantial factors towards the development of cognitive vulnerability (*CoV*) over time. By combining either one of these two factors together with situational cues, it leads to the formation of either cognitive depressogenic inferences (*CdI*) or positive attributional styles (*PtS*) [1].

Situational cues (*SiC*) refers to a concept that explains individuals' perception that highly influenced by cues from events (environment). Individuals under the influence of negative thought about themselves will tend to reflect these negative cognitions in response to the occurrence of stressors [7]. These later develop the conditions called "stress-reactive rumination". Stress reactive rumination (*SrR*) reflects a situation where individuals have trouble in accessing positive information, and further increase a negative bias towards future inference (maladaptive inference (*MdI*)) [14]. After a certain period, both conditions are related to the development of hopelessness (*HpS*). Hopelessness is defined by the expectation that desired outcome will not occur, or there is nothing one can do to make it right [9]. Prolong and previous exposure from hopelessness will lead to the development of cognitive depressogenic thought (*DyT*) and later influence the formation of cognitive vulnerability. The detailed discussion of the domain model can be found in [2].

III. RATIONAL EMOTIVE BEHAVIORAL THERAPY

The intelligent agent application will provide support based on the ideas in the Rational Emotive Behavioural Therapy (REBT). This section will describe this therapy. In general, REBT is a comprehensive amd active-directive psychotherapy which focuses on resolving emotional and behavioral problems and disturbances and enabling people have positive belief in their life [10]. One of the most important concepts in REBT is that humans, in most cases, do not merely get upset by unfortunate adversities, but also by how they construct their beliefs the events, themselves and other [11].

Important Concepts in REBT

REBT suggests that human beings defeat or distub themselves in two main ways: (1) by holding irrational beliefs about their self (ego disturbance) or (2) by holding irrational beliefs about their emotional, social, or physical comfort (discomfort disturbance) [10]. To overcome these disturbances, REBT employs the 'ABC framework' to clarify the relationship between activating events and individual's beliefs (A); individual's beliefs about them (B); and the cognitive, emotional or behavioural consequences of our beliefs (C) [10][11].

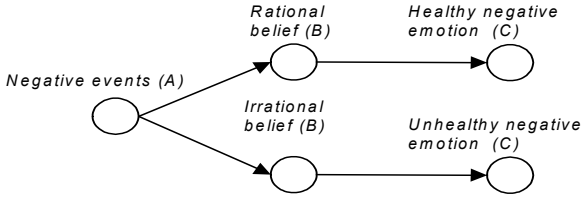

Figure 2. Interactions in ABC framework.

In practise, if a individual's evaluative B, belief about the A, activating event is dysfunctional, therefore the C, the emotional and behavioral consequence, is likely to be self-defeating and destructive.

Alternatively, if a individual's evaluative B, belief is and constructive, then the emotional and behavioral consequence (C) is likely to be constructive. Fig. 2 depicts the effects of rational beliefs about negative events, which give rise to healthy negative emotions, and the effects of irrational beliefs about negative events, which lead to unhealthy negative emotion [10].

In addition the existing framework, REBT has also employed additional steps to provide prevention towards irrational belief. These steps are dispute irrational beliefs

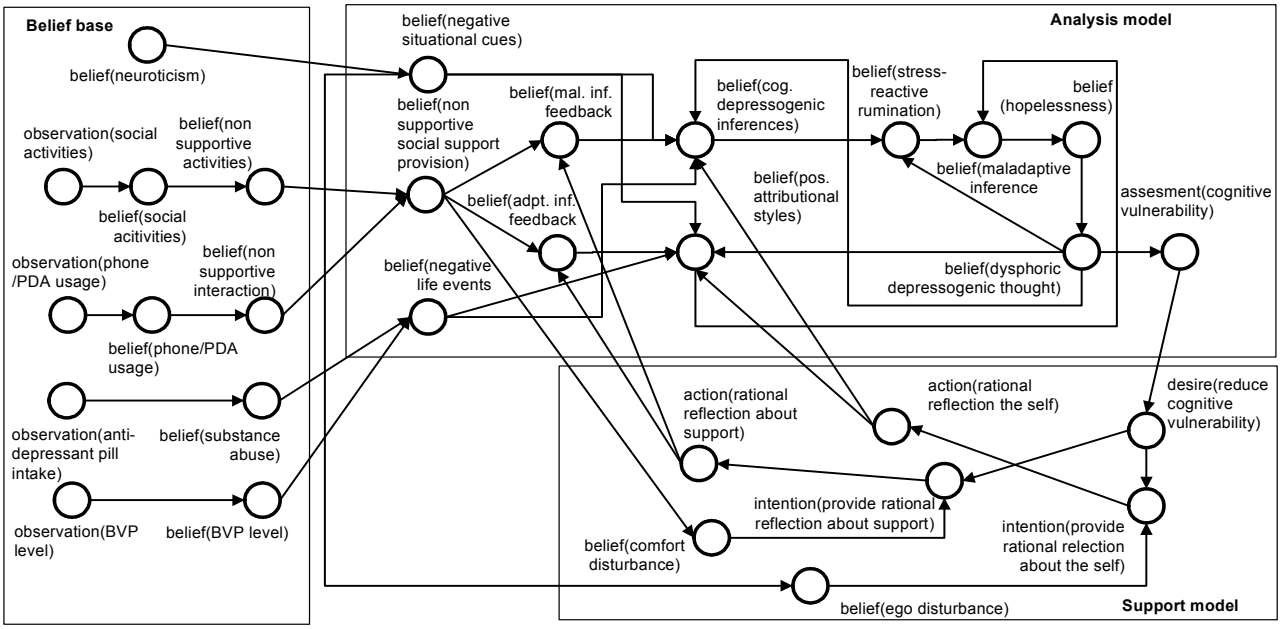

Figure 3. Detailed Interactions within an Ambient Agent Model

(D), and implement new effective thinking (E). Using this extended concept, individual will try to understand the role of their mediating, evaluative over unrealistic interpretations and assumptions in upset. Later, he or she often can learn to identify their irrational beliefs, challenge and question them. It will allow individual to distinguish them from unhealthy scenarios, and use more constructive and self-helping constructs.

Techniques

There are several techniques that can be adopted to alter irrational belief about the events, namely; cognitive, behavioural, and imaginary techniques. Cognitive techniques focus to detect irrational beliefs, to separate the rational from the irrational and to change one's way of thinking, while behavioural approaches are used to develop more effective ways of thinking by entering feared situations that individual would normally avoid. Imaginary techniques are designed to show that one's life and the world in general, continue after a feared or unwanted event has come and gone by visualizing the future outcomes of it. A complete description of these techniques is available in [10].

IV. AMBIENT AGENT MODEL

In order to achieve an intelligent agent, an approach has been followed in which the dynamical domain model for depression is integrated in the model that describes the functioning of the ambient agent. By integrating the domain model, the ambient agent will be able to reason about the human and environmental processes. It is important to have such capabilities, since an ambient agent should be aware of human behaviours and states [3]. Through this mechanism, the agent will use this vital knowledge to provide related actions related to the predicted state of the human and the environment.

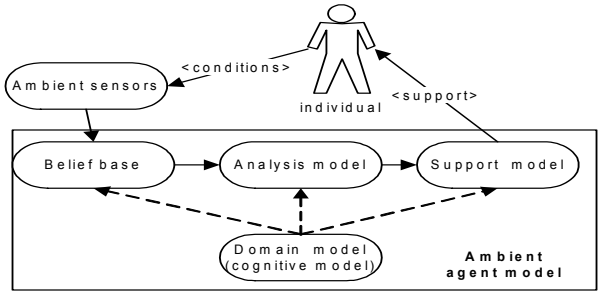

Figure 4. Overview of the ambient agent model

In Fig. 4, the solid arrow indicates information exchange between processes, and the dotted arrow represents the integration process of the domain model within the ambient agent models. The detailed view of the model is shown in Fig. 3.

Belief Base

The main purpose of the belief base is to produce primary beliefs (basic and derived beliefs) from the ambient agent's observation about the individual's condition. Information about individual's condition can be obtained from several ambient sensors and devices. For example, Basic beliefs refer to beliefs related to the sensors (from the environment), while derived beliefs are based on derivations using the domain model. One of the advantages to have such concept is it allows future extension of the model. For example, if there is a new method (or sensors) can be used to measure belief in substance abuse, it is easily can be added as a basic belief for a new observation, and append it with the existing substance abuse belief. In addition, another belief model

can make use this set of related beliefs without having to generate a new one.

Using pervasive and wearable technologies, such conditions can be observed through several ambient sensors and devices. For example, a medicine box that registers medication intake (MEMS) and passive alcohol sensor can used to observe potential substance abuse while a mobile phone / personal digital assistant (PDA), digital planner, and email interaction provide essential cues to monitor social interactions [3][12][13]. In addition to this, using blood pressure sensor provides important information to infer those individuals are experiencing potential stress [13]. These devices can potentially be integrated to support the real world application. However, a detailed discussion on these devices and signals is beyond the scope of this paper.

Analysis Model

One of the very important features to determine the level of cognitive vulnerability is the continuous assessment of changes in selected physiological and behavioural features within the individual. This assessment is highly related to the cognitive model encapsulated within the analysis model [3]. Using this cognitive model in the analysis model, the progression of the important features is analyzed. If the individual cognitive vulnerability level (from the assessment) is above the accepted threshold level for certain individual (*baseline threshold*), then the model will consider he/she is in the risk of experiencing an onset. By analyzing this condition, an agent will interfere this maladaptive progression by trigger desire to reduce an individual's cognitive vulnerability. This later will trigger the support model.

Support Model

For an individual at a high risk of cognitive vulnerability, necessary actions are needed to curb the onset stage. The ambient agent can use the results from analysis model to generate support actions for the individual. Information about beliefs in non-supportive social support provision and negative situational cues can used to select an appropriate action. This important information will lead to the agent's beliefs either an individual is experiencing ego-disturbance (from belief in negative social cues) or comfort disturbance (non-supportive social support provision). For example, if the belief non-supportive social support provision holds true, then the agent perceives the individual is experiencing comfort disturbance.

By triggering belief in comfort disturbance, an agent generates an intention to support an individual. Later, by combining this intention with the desire to reduce an individual's cognitive vulnerability, an agent will provide a RBET intervention for both actions (to support action in rational reflection about support or about the self). As a result from this intervention process, it will curb the development of future irrational beliefs, and later provides effective new thinking on individual experienced conditions. In the domain model, the intervention effect from beliefs in comfort disturbance is calculated as follows.

$$MiF^{+}(t) = NsP(t).(1\text{-}RtO(t)) \quad (1)$$

$$AiF^{+}(t) = (1\text{-}(1\text{-}RtO(t)).NsP(t)) \quad (2)$$

where $MiF^{+}(t)$ and $AiF^{+}(t)$ *represent individuals condition* during intervention process for comfort disturbance. Moreover, the effect of intervention on beliefs in ego disturbance can be seen in these formulations.

$$PtS^{+}(t) = [\eta.AiF(t) + (1\text{-}\eta).\ (1\text{-}\ (SiC(t).\ DyT(t).NvT(t)(1\text{-}RtS(t)))].AiF(t) \quad (3)$$

$$CdI^{+}(t) = [\alpha.MiF(t) + (1\text{-}\ \alpha).\ SiC(t)\ DyT(t).MiF(t)].(1\text{-}RtS(t)).NvT(t) \quad (4)$$

where *RtO* and *RtS* functions represent the conditions to simulate the effects of intervention when any individual is experiencing distorted beliefs and receiving the support provided by an ambient agent. $PtS^{+}(t)$ and $CdI^{+}(t)$ computes the effect of this intervention in ego disturbance cases. These functions simulate three conditions; *(1)* an individual with a good skill to dispute the irrational belief, *(2)* an individual in a learning process and later acquired the skills, *(3)* an individual without any therapy skills and avoiding help.

V. SIMULATION TRACES

The intervention as described in the previous section has been implemented in simulation environment. Using this simulation environment, we mimicked the intervention process to see its effect under several cases. Three scenarios are shown: an agent supports a individual with good skills in using cognitive techniques to the dispute distorted belief (***A***), an agent support with a individual who is new with RBET, learns the techniques, and later acquire the important skills to dispute the distorted belief ***(B)***, and a individual who refuse to accept help and incapable to acquire important skills to dispute the belief (***C***). These scenarios are studied under several negative events, namely; prolonged, repeated, and fluctuated events. In all cases, the temporal relations are initialized at 0.5. Corresponding to these settings, the level of severity (baseline to consider as a cognitive vulnerably condition) is set at 0.3, defining that any individuals scoring higher than 0.3 in their cognitive vulnerability level will be considered as experiencing difficulties and need help.

In addition, 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.

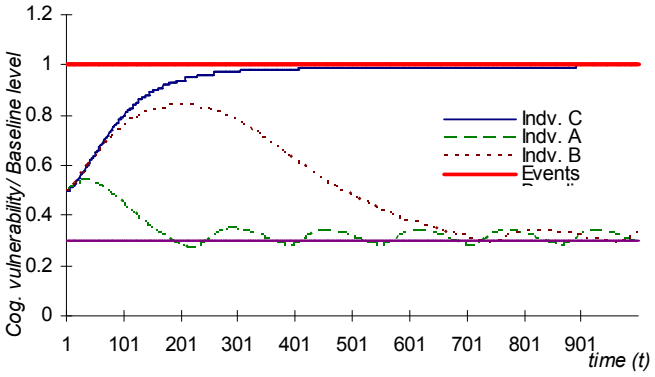

Figure 6. Cognitive Vulnerability Level for Each Individual (prolonged stressors)

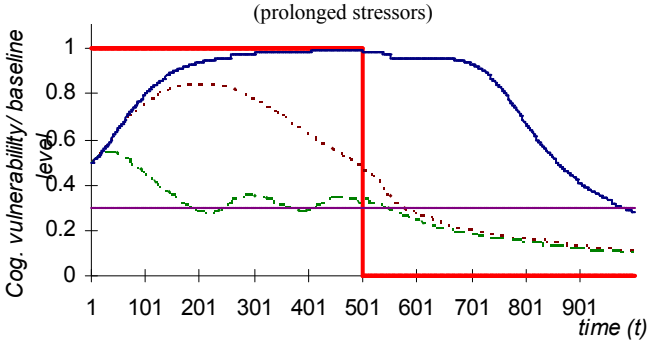

Figure 7. Cognitive Vulnerability Level for Each Individual (fluctuated negative events)

Prolonged Negative Events

During this simulation, each type of individual has been exposed to the highly extreme and constant negative events. In this simulation trace it shown that an individual *C* tends to experience cognitive vulnerable condition much faster compared to other people. Furthermore, the individual *C* also experienced persistent cognitive vulnerability throughout the development of negative events. As for the individual *B*, in the beginning of the simulation, individual *B* is experiencing the increasing effect towards cognitive vulnerability. However, after certain time point, note that an individual *B* shows a gradual decreasing level from potential cognitive vulnerability. Individual *A* is capable to lower the risk of cognitive vulnerability within the baseline boundary. The simulation results for these conditions are shown in Fig. 6.

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). Fig. 7 illustrates how each individual reacts with these conditions. Although all individuals show a full recovery state during the end of the simulation period, but for individual *C* it takes longer period to reach that particular state and it is only happens after the negative events (stressors) have diminished. Both individuals *A* and *B* show faster progression towards recovery compared to an individual *C*.

Repeated Stressor Events

During this simulation, all individuals are exposed to repeated negative events, that later will decline gradually. These conditions represent an individual is experiencing an extreme stream of stressor events, with a rapid alteration between each corresponding event.

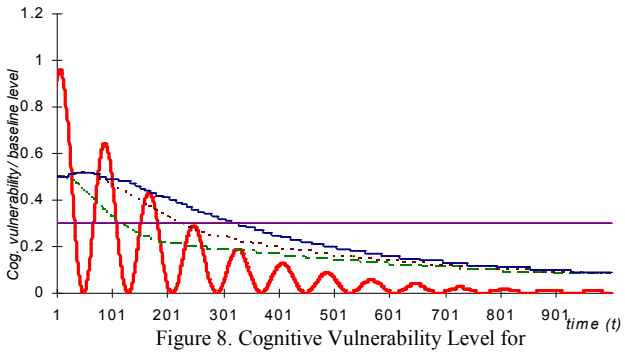

Figure 8. Cognitive Vulnerability Level for Each Individual (repeated negative events)

As can be seen from Fig. 8, when the stressors decrease, all individuals show decreasing patterns in their cognitive vulnerability. However, an individual *C* has shown a slow decline progression towards a full recovery stage.

VI. AUTOMATED VERIFICATION

This section deals with the verification of relevant dynamic properties of the cases considered in the ambient agent model. It is important to verify whether the model produces results that are coherent with the literature and appropriate to help the patient. The Temporal Trace Langue (TTL) is used to perform an automated verification of specified properties against generated traces. This language allows formal specification and analysis of dynamic properties using a combination of a qualitative and a quantitative representation [5].

VP1: Individuals with Good Skills in RBET will Reduce the Risk of Future Cognitive Vulnerability

When an individual capable to perform good skills in RBET, then the individual will unlikely to develop further cognitive vulnerability in future.

VP1 ≡ ∀γ:TRACE, t, t':TIME, R1,K1,V1,V2, MIN_LEVEL_SELF, MIN_LEVEL_SUPPORT:REAL, X:AGENT
[state(γ, t) |= rational_reflection_self (X, R1) &
R1 ≥ MIN_LEVEL_SELF &
state(γ, t) |= rational_reflection_support (X, K1) &
K1≥ MIN_LEVEL_SUPPORT & state(γ, t) |=
cognitive_vulnerability (X,V1) & V1 > 0] ⇒ ∃t':TIME > t:TIME
[state(γ, t') |= cognitive_vulnerability (X,V2) & V1 < V2]

In some simulation traces, a condition was added to the antecedent of the formal property, namely t=200 so the property only checked at the given time step. In general, this property can be used to verify future condition of an

individual if the individual capable to infer positive (rational) interpretations of experienced events throughout time.

VP2: Monotonic Increase of Cognitive Vulnerability for Individual without Good Skills and Experiencing Prolonged Stressors

When an individual is incapable to perform RBET, then the individual will prone to develop further cognitive vulnerability in future

VP2 ≡ ∀γ:TRACE, t, t':TIME, D1,D2,F1,F2:REAL, X:AGENT
[state(γ, t) |= stressors (X, D1) &
state(γ, t') |= stressors (X, D2) &
state(γ, t) |= cognitive_vulnerability (X,F1) &
state(γ, t')|= cognitive_vulnerability (X,F2) & t' > t &
D2 ≥ D1] ⇒ F2 ≥ F1

By checking property VP2, one can verify whether any individual (without good skills in RBET) increase monotonically in his/her cognitive vulnerability after experiencing prolonged stressors.

VP3: Monotonic Decrease of Cognitive Vulnerability for Any Individual When Stressors are Reduced

When an individual is experiencing lesser stressors throughout time, then the individual will reduce the level of cognitive vulnerability in future.

VP3 ≡ ∀γ:TRACE, t, t':TIME, D1,D2,F1,F2:REAL, X:AGENT
[state(γ, t) |= stressors (X, D1) &
state(γ, t') |= stressors (X, D2) &
state(γ, t) |= cognitive_vulnerability (X,F1) &
state(γ, t')|= cognitive_vulnerability (X,F2) & t' > t &
D2 ≤ D1] ⇒ F2 ≤ F1

Property VP3 can be used to verify individual's condition when negative events (stressors) are decreasing throughout time.

VII. CONCLUSION

Depression is a serious mood disorder that influences the life of the patient enormously. Unfortunately, the disease has a high rate of relapse. The occurrence of depression and the rate of relapse are probably related to the cognitive vulnerability of the patients. In this paper a cognitive model has been described that specifies the dynamics of the mood and thought according to the theory of cognitive vulnerability. This model is used as the basic component of an intelligent agent application aimed at supporting people to prevent the onset of a depression. The application uses the model to analyze patients and detect risk full situations.

When such situations are detected, a intervention is taking place following the principles of Rational Emotive Behavioural Therapy (based on changing the underlying thoughts). A software simulation has been implemented to study the effect of the application. In these simulations, three cases are compared: a not cognitive-vulnerable person, a person that responds to REBT therapy, and a person that does not respond to the therapy. Finally, using several generated traces, the model has been verified using a number of important properties in the literature.

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