

An Integrative Ambient Agent Model for Unipolar Depression Relapse Prevention

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Abstract. One of the challenges for persons with a history of unipolar depression is to stay healthy throughout their lifetime. In principle, with more stressing prior onset cases, it escalates the risk of the persons to fall into a relapse. In this paper, a domain model and an integrative ambient agent model to support persons from relapse is presented. First, based on several personal characteristics and a representation of events (i.e., life events or daily hassles) the domain model can simulate whether a human that recovered from a depression will fall into a relapse or recurrence. A number of well-known relations between events and the course of depression are summarized from the literature and it is shown that the domain model exhibits those patterns. The domain model has been mathematically analyzed to find out which stable situations exist. Second, by incorporating this domain model into an ambient agent system, the resulting integrative ambient agent model is able to reason about the state of the human and the effect of possible actions. Several simulation experiments have been conducted to illustrate the functioning of the proposed model in different scenarios. In addition, an automated verification method using Temporal Trace Language (TTL) is used to verify that the ambient agent model satisfies a number of relevant properties. Finally, it is pointed out how this model can be used in depression therapy, supported by an ambient agent.

Keywords: Human-Ambient Agent, Temporal Dynamics, Relapse in Unipolar Depression, and Decision Support Systems.

1. Introduction

Unipolar depression is a mental disorder distinguished by a persistent low mood, and loss of awareness or contentment in usual activities. In many cases, depression is a recurring condition; a subsequent depressive episode is called a relapse or recurrence. In principle, the depressive relapse stage can be defined as “episode of major depressive disorder that occurs within six months after either response or remission (no longer meeting the depression criteria)”, while, recurrence is a depressive episode occurring after six months have elapsed [9][12]. Despite the modern era of pharmaceutical and holistic intervention, one of the primary problems with unipolar depression (i.e., a depression not related to other mental disorders) is that it has a very high rate of recurrent and relapse cases [18]. Reviewing studies of lifetime course of depression concluded that at

least 60 percent of individuals who have had one depressive episode will have another, 70 percent of individuals who have had two depressive episodes will have a third, and 90 percent of individuals with three episodes will have a fourth episode [12][17]. Although the risk of relapse may decline with time, even for those who remain well for 5 years after an index episode, the rate of recurrence/relapse is 58 percent [5]. The relapse nature and high rates among individuals with a history in depression have motivated many researchers on effective maintenance therapies. However, despite the recognized magnitude of the problem of recurrence and relapse, little attention has been focused on the symptom pattern in recurrent episodes of major depression, and the related possibilities for support in an early stage, in order to prevent further development of the depressive episode. When a mechanism to monitor the condition of individuals who have had a previous

encounter with unipolar depression would be available, this eventually would improve the quality of life for a large group of persons [10].

In the past, intelligent agent technology has become an important means for increasing analysis, decision making ability and communication. This technology has not only shaped the landscape of artificial intelligence work, but also pushes the frontiers in other field, like in medical informatics. Examples can be seen in communication and cooperation between agents to manage patient care, information agents that retrieve medical information from the Internet, and multi-agent systems that assist the doctors in the tasks of monitoring and diagnosis [3]. With the advent of wearable devices, and mobile applications, new ways are created for agents to obtain more human-awareness, by human-related information gathered from sensors and based on this enhanced human-awareness will interact and react in a more knowledgeable manner [4]. Such human-aware ambient agents will be able to contribute towards the development of personal care and human wellbeing applications by harnessing vital information from human itself [1]. In order to achieve this objective, the aim of the work reported here is to develop an ambient agent model on that is able to support humans with depression history in the long term. This ambient agent model is expected to have capabilities to understand its environment and the individual, providing a better monitoring and assessment of the situation.

To realise this capability in an ambient agent, it is required to integrate within the agent model a dynamical model of the human that shows how he or she might fall into relapse / recurrence, or stay healthy. In case a relapse or recurrence is predicted, the agent can provide to support by providing adequate remedies in an early stage. This ambient agent model was designed using a set of dynamic properties, takes observations as input, and uses a belief-desire-intention concept to determine its internal function and actions. A dynamical model has been developed and formalized for the way in which humans are developing and experiencing relapse. This domain model was a crucial basic building block, comprised from a set of equations to model the dynamics of relapse and recurrence.

This paper is structured as follows. After an introduction of the area, first the dynamical model for relapse and recurrence of unipolar depression is described in some detail and its behaviour analyzed by means of simulation and a mathematical analysis. Next, the integrative ambient agent model is de-

scribed. It covers a number of sub-models used as building blocks. The main concepts of this model are specified, and results from simulation experiments are discussed and verified. Finally, a discussion concludes this paper.

2. The Domain of Relapse and Recurrence of Unipolar depression

For the individuals at high risk of relapse and recurrence, there are several factors that may lead to these both stages. The combinations of these factors will lead to the sudden onset, and usually is a manifestation associated with major stress.

2.1. Underlying Factors Used to Monitor Relapse and Recurrence in Unipolar Depression.

Generally, prior to relapse there might be changes in the usual symptoms of the illness, or changes in behaviour, thoughts or feelings. These changes (or symptoms) are useful warning signs. Symptoms may develop over days to weeks, though there potentially leads to fearfulness, anxiety, and lowered mood over preceding months [18]. Thus, by analyzing related factors, one will be able to determine the potential risk of individuals is having a potential onset. Thus, the earlier those symptoms can be identified, the better chance there is of stopping a relapse / recurrence or reducing the severity of it. The main characteristics of recurrence and relapse of depression as known from the literature are described. First, the effect of repeated stressful events is explained. Then, the knowledge about the causes of relapse and recurrence are discussed.

Frequent stressful events (stressors) are correlated with a positive contribution to the development of recurrence and relapse [20]. Contrary to popular belief, repeated strikes, even when they are low, can have almost the same effect as a similar single instantaneous stressful event [20][25]. This can be explained by an analogy of striking a bell. Imagine when a bell is struck once, it emits a sound that is loud at first, and then decays in intensity. However, if each subsequent strike is applied before the sound of the preceding strike has diminished: the loudness will increase each time. Applying this to the real world, a single and low stressor event may initially be so miniscule that it is considered to cause no effect. However, many repeated and small stressor events will eventually lead to a higher level of potential stress than a single major stress-producing

event. Therefore, the intensity of a single stressor event faced by an individual is not the only important factor, because if negative events are persistently present, they can have a stronger effect than an initial event with a higher intensity [25].

A key step in the development of a model to represent potential onset of relapse and recurrence is to understand how this condition may recur. Stressors from the environment are the dominant components that will lead to recurrence or relapse of depression. This primary mechanism however is regulated by two main apparent predisposing factors, which influence the process as moderators that can neutralize each other. These two components are simplified as *immunity* and *neuroticism* (vulnerabilities in the personality) [16][19]. These factors are induced by the observed evidences that there are personal differences and conditions that will increase or decrease the onset of recurrence or relapse in any individual [13]. In addition, in many works, these two components are assumed to influence not only the possibility of onset of a depression, but also affect the duration of it. On the other hand there are many factors that eventually help people to sustain their well-being. These factors are closely related to: (a) *coping skills*, (b) *being assertive*, and (c) *knowing when to seek help* [1][5][9][24]. The first is the ability to cope with the adversities. *Coping skill* is a behavioural and biologically wired tool which may be used by individuals to offset stressor events without correcting or eliminating the underlying condition [21].

On the basis of many theories in depression, coping responses and strategies have been most frequently divided into problem focused coping and avoidant coping responses. *Problem focus coping* responses allow an individual to increase the perceived control over their problem; it is proven in many studies that they are able to reduce the risk of onset of a depression [17]. They involve attempts to do something constructive about the stressful conditions that are harming an individual, rather than to make it worsen. In contrast, *avoidance coping* is detrimental in nature. When feelings of discomfort appear through stressor events, people find ways of not experiencing them [24]. Such a strategy may work in a very short term, but it is mostly considered as an inadequate approach of coping. The second component is being *assertive*. Individuals who are assertive tend to be aware of their emotions and communicate these in clear-cut manner and are able to make and meet goals and challenges through respect and perseverance [9][17]. In many cases, peo-

ple with a high assertive level are more likely to be more proactive and problem focused rather than unassertive individuals.

The last component is the ability to seek *social support*, (“having positive interaction of helpful behaviour provided to a person in need of support”). As a multidimensional concept in nature, social support also includes many other facets that may finally determine if social support is constructed such as having the ability to create a support network [24]. There are many characteristics of individuals that influence their potential abilities of seeking support or vice versa. For example, an individual who is highly neurotic, using more avoidant coping and having a lack of self esteem may not be able to request support, and later it may disengage him/herself from potential social support [9][14]. Table 1 summarizes several important features that potentially used to understand the formation of relapse.

Table 1. Features in Relapse and Recurrence

Factors	Evidences
Neurotics	Poor respond to the environmental stress, and tends to exaggerate ordinary situations as threatening.
Low in immunity	Residual symptoms, history with depression onset, family history with mood disorders.
Lack of social support	Disengaging from social activities and interaction with others.
Low in assertiveness	Lack of self-esteem and poor control over anger.
Relying on avoidance coping skills	Lack in problem-focus coping skills, prone to comorbidities (substance abuses).
Stressful events	Events that can escalate or provoke relapse / recurrence. This can be divided into three categories, namely; life, chronic, and daily.

Using these factors as a foundation, the following relations can be identified from the literature: (1) a series of smaller stressor events can lead to the recurrence or relapse; (2) stressor events directly affect the potential onset of relapse /recurrence; (3) neuroticism aggravates the effect of stressor events on the potential onset of a depression;(4) assertiveness and immunity will diminish the potential of onset, and (5) a combination of good social support and coping skills will reduce the risk of having future relapse/recurrence.

2.2. Potential Sensing Devices within the Domain

The field of pervasive and wearable technologies has recently witnessed an explosion of new

inexpensive and distributed at all scales throughout everyday life which utilize personal-cues and information. These devices can be used in any combination of three main system environments either in a physical world, human-centred environments, or distributed computing environments [4]. Those devices are either loosely-bound to users, or can be more tightly-bound to users. To take advantage of these new findings, an ambient agent model can be developed to support people that have recovered from a depression to maintain a healthy state. This model will be provide a building block to develop a system that continuously monitors the person and takes measures when there the risk on a relapse or recurrence is too high. Such technologies complement the ambient agent capability to understand about human conditions and providing solution if necessary.

In depression, a typical cause of relapse is a condition called the stressors. These stressors may derive from life, chronic, or daily events. The culmination of these factors will become overwhelming and leave a person feeling that they have lost control of their life. Using pervasive and wearable technologies, such conditions can be observed through several ambient sensors and devices. Table 2 summarizes related wearable or personal devices that can be potentially used to provide useful information for the proposed model

sion on these devices and signals is beyond the scope of this paper.

3. A Dynamical Domain Model of Relapse and Recurrence in Unipolar Depression

The domain model is used to provide a basic reference to understand the whole function of a selected domain. In general, the domain model could be used to describe physical phenomena, physiological and cognitive phenomena, or behavioural process of human interaction within environment. By incorporating domain model with an ambient agent model, the agent gets an understanding of the processes of its environment. The model is designed in a way to be tailored with several other sub-models.

In this domain model, there are four major components that will represent dynamic interactions of human agent abilities involved in recurrence/relapse namely; *environment*, *personality*, *social support*, and *coping strategies*. By combining these characteristics together, it will allow a hypothesis or expected behaviour for the human agent to be monitored [2]. Once the dynamical relationships in the domain model have been determined, the model can be formalized.

Table 2. Potential Sensors and Devices

Factors	Signals/ Activities / Information Measured	Sensory Devices / Source
Neuroticism	Heart rate, skin conductance, self report.	Blood volume pressure (BVP), galvanic skin response (GSR) [17] [22]
Avoidance coping	Alcohol level in sweat, medicine intake, drug intake	Passive alcohol sensor, medicine box (MEMS), transdermal alcohol sensor (TAS), sweat patch. [3][8][23]
Social support and interaction	Interaction with friends, acquaintances, colleagues.	Mobile phone, personal digital assistant (PDA), e-mail application [6][10]
Immunity	Prior onset, clinical history, self report.	Record from related database, web-based questionnaires (mobile phone, PDA). [3][26]
Assertiveness	Self report, personal information	Web-based questionnaires (mobile phone, PDA) [6] [26]

As shown in Table 2, these devices can potentially be integrated to support the real world application. These devices are non-obtrusive and technically adequate to observe selected needed features needed. A stream of continuous physiological and behavioural information can be collected from these sensors and devices [6][15]. Furthermore, in near future, this technology will be available for personal usage at affordable cost. A detailed discus-

In the formalization, all nodes are designed in a way to have values ranging from 0 (low) to 1 (high). Figure 1 depicts the global interaction between these nodes. The interaction will determine the new value of it, either by a series of accumulations or an instantaneous interaction for each node. The description of these formalizations is described as the following.

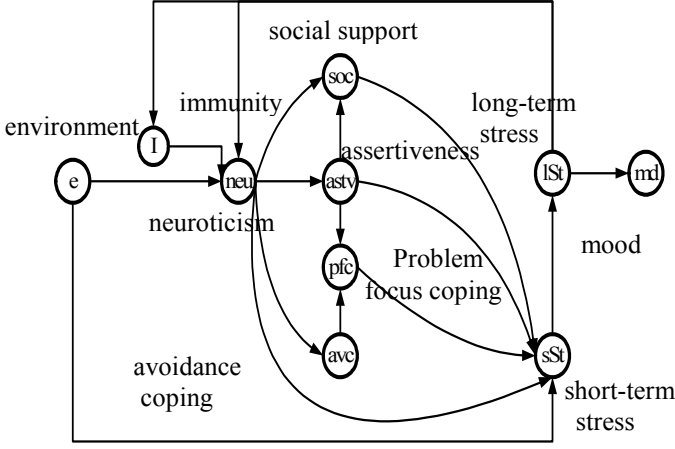


Fig. 1. Global Relationships of Variables Involved in the Domain Model.

Stressor Events

In the model, the stressor events (e) are generated by simulating potential effects throughout t time using weighted sum of three types of events; life (le), chronic (ce), and daily (de) events.

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

The role of these factors in the model is to represent a series of events. Stressors are seen as very intense when $e(t) \rightarrow 1$, and no stressors are represented by $e(t) \rightarrow 0$.

Dynamics of Neuroticism

In this model, the neurotic level (neu) describes the interactions between environment (e), personal immunity trait (I), and prior exposure to long-term stress (lSt), in a time interval between t and $t+\Delta t$. Here, α_{neu} is a parameter for a change rate, and β_{neu} is a parameter for the contribution effect of the previous neurotic rate in this equation.

$$neu(t+\Delta t) = neu(t) + \alpha_{neu} \cdot (1 - eu(t)) \cdot [f(e(t), I(t)) \cdot lSt(t) - \beta_{neu} \cdot neu(t)] \cdot \Delta t \quad (2)$$

where, $f(e(t), I(t))$ is a logistic unit function,

$$f(e(t), I(t)) = 1 / (1 + \eta e^{-\alpha(e(t)-I(t))})$$

Social Support, Problem Focus Coping, Assertiveness, and Immunity

Social support (soc) is computed by multiplying the factor of being assertive by the ability of less or non-neurotic. Problem focus coping (pfc) is also computed with the same approach, but with a negative association in avoidant coping (avc). The α_{avc} is

proportional rate for the effect of neurotic level in avc .

$$soc(t) = astv(t) \cdot (1 - neu(t)) \quad (3)$$

$$pfc(t) = astv(t) \cdot (1 - avc(t)) \quad (4)$$

$$avc(t) = \alpha_{avc} \cdot neu(t) \quad (5)$$

Assertiveness ($astv$) depends on the interaction between the normal assertive value within an individual and the condition of being less or non-neurotic. The immunity (I) level interaction also having a similar behavior, but it is related to the interaction in a long term stress level.

$$astv(t) = \alpha_{astv} \cdot astv_{norm} + (1 - \alpha_{astv}) \cdot (1 - neu(t)) \cdot astv_{norm} \quad (6)$$

$$I(t) = \alpha_I \cdot I_{norm} + (1 - \alpha_I) \cdot (1 - lSt(t)) \cdot I_{norm} \quad (7)$$

Dynamics of Short Term Stress, Long Term Stress, and Mood

Short term stress (sSt) is modeled by instantaneous relationships between the environment, neurotic level, and reducer components, ψ (a combination of social support, assertiveness, and problem focus coping). Long term stress (lSt) is primarily contributed the accumulation exposure towards short term stress and later will influence the level of mood (md) in a time interval between t and $t+\Delta t$.

$$sSt(t) = \beta_{sSt} \cdot e(t) + (1 - \beta_{sSt}) \cdot neu(t) \cdot (1 - e(t)) \cdot (1 - \psi) \quad (8)$$

$$lSt(t+\Delta t) = lSt(t) + \alpha_{lSt} \cdot (1 - lSt(t)) \cdot (sSt(t) - \beta_{lSt} \cdot lSt(t)) \cdot \Delta t \quad (9)$$

$$md(t+\Delta t) = md(t) + \eta_{md} \cdot (1 - md(t)) \cdot (lSt(t) - \beta_{md} \cdot md(t)) \cdot \Delta t \quad (10)$$

where η_{md} , β_{md} , α_{lSt} , β_{sSt} and β_{lSt} denote the proportion change rates for all respective equations.

4. Simulation Results for the Domain Model

In this section, it is described how the dynamical domain model for relapse and recurrence of unipolar depression was executed to simulate a number of scenarios with a variety of different conditions of individuals. To this end software to generate simulation traces was developed in Visual Basic.NET.

Three example scenarios are shown: a healthy individual (A), an individual with a potential risk of relapse and recurrence (B), and an individual with severe conditions (C). The initial settings for the different individuals are the following ($neu(t=0)$, $astv_{norm}$, I_{norm}); A (0.1, 0.8, 0.8), B (0.5, 0.5, 0.4), and C (0.8, 0.2, 0.1). In all cases, the initial long term stress and mood value is initialized as 0.3, 0.1

respectively. Corresponding to these settings, the level of severity (or potential onset) is measured, defining that any individuals scored more than 0.5 in their mood level (within more than 336 time steps) will be considered as reaching the recurrent or relapse stage. These simulations used the following parameters settings: $t_{max}=1000$ (to represent a monitoring activity up to 42 days), $\Delta t=0.3$, $\alpha_{st}=0.3$, $\eta_{md}=0.2$, $\beta_{sst}=0.3$, $\alpha_f=0.7$, $\alpha_{astv}=0.5$, $\alpha_{avc}=0.5$, $\alpha_{neu}=0.4$, and with all decay terms are assigned as 0.02.

Result # 1: Simulation Trace for Prolonged-Fluctuating Stressor Events

During this simulation, each type of individual has been exposed to an extreme stream of stressor events, with a rapid alteration between each corresponding event. This kind of pattern is comparable to the repeated strike event, where stressor events always occur when the previous events were ended.

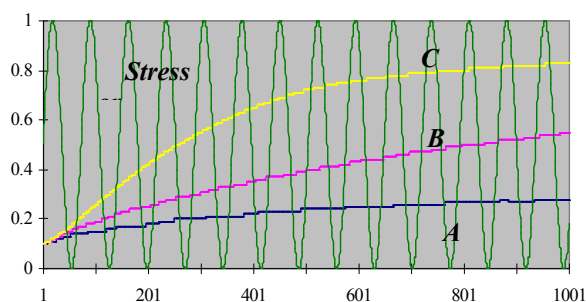


Fig.2. Relapse / Recurrent Onset for Each Individual in Prolonged Stressor Events.

In this simulation trace, it shown that an individual *C* (*high neurotic, low in assertive and immunity*) tends to get into onset much faster compared to other individuals. Note that the individual *B* (*moderate neurotic, assertive, and immunity*) shows a gradual increasing level of potential onset and possibly will experience relapse / recurrent if that individual is having constant exposure towards stressors. Individual *A* however is less prone to develop a potential onset condition within a short period of time.

Result # 2: Simulation Trace for Decrease 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). Also here it can be

seen that individual *C* gets into a bad mood much faster than the others. Moreover, even at the end of the simulation time, the mood of individual *C* is worse than the mood of the other two individuals. Using a similar experimental setting, with $t_{max}=10,000$, the end of the experimental results show all individuals will have a normal mood level.

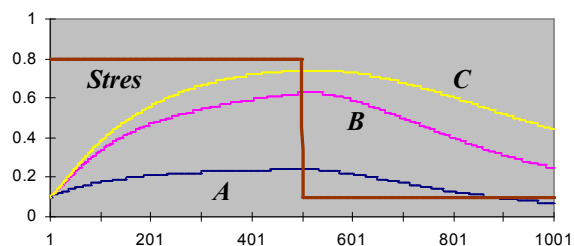


Fig.3. Relapse / Recurrent Onset for Each Individual in Fluctuated Stressor Events.

Result # 3: Simulation Trace with Social Support, and Problem Focus Coping Skills (Reducer)

As initially discussed in Section 2.1, a combination of social support, and problem focus coping skills is expected to help any individuals to reduce potentially risk in relapse / recurrence. The combination of these factors will be represented by R_A , R_B , and R_C for the respective human agents. To visualize the effect of these, frequently repeating low stressor events were simulated. Figure 4 illustrates how these combinations, mood levels and stressor events are influencing each other.

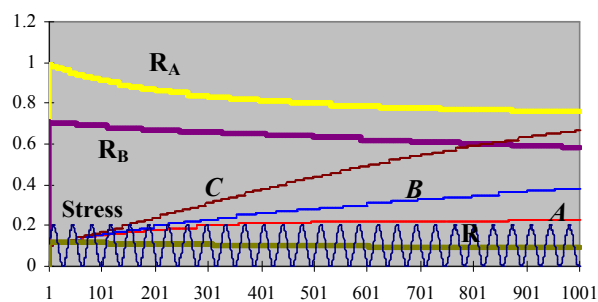


Fig.4. Relapse / Recurrent Onset for Each Individual with a Combination of Reducer .

Figure 4 shows that a healthy individual (*A*) has much higher reducer factors than less healthy individuals. These reducing factors limit the effect of the incoming stressors. Also it can be seen that the reducer factors decrease over time, due to the relatively low but frequent stressors. The patterns for the different individuals are the same as in Figure 2,

although the final mood level is lower in Figure 4 because of the less intense stressors fluctuation.

To wrap up these experimental results, the simulation traces described above satisfactorily explain the relations as summarized in Section 2. In all simulation traces, it is shown that individuals with higher assertiveness, immunity and less neurotic levels develop less often a relapse compared those who are not. In addition, a higher neurotic level eventually aggravates the potential risk of onset, as illustrated in all simulation traces. The effects of stressor events on relapse/ recurrence onset are also exemplified. It is apparent that frequent or high stressor events contribute to the potential risk of onset. Furthermore, the effect of the reducers is also examined, where in Figure 4, it depicts that when the reducer level is decreasing, the person is also prone to a relapse, or vice versa. This distillation of above evidences and traces illustrates that this model reflects the basic relations that are known to influence relapse and recurrence, given certain criteria of events and personality attributes.

5. Mathematical Analysis of the Domain Model

In this section the equilibria are analyzed that may occur under certain conditions. 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 modeled. 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 (in particular for neuroticism, long term stress and mood). Moreover, for an equilibrium, the external input is also assumed to be constant. To start, for an equilibrium for neuroticism it holds as ;

$$(1-neu) \cdot (f(e,I) \cdot lSt - \beta_{neu} \cdot neu) = 0$$

This is equivalent to;

$$neu = 1 \text{ or } neu = f(e,I) \cdot lSt / \beta_{neu} ,$$

$$\text{where } f(e,I) = 1 / (1 + \eta e^{-\alpha(e-1)}) .$$

Assuming high steepness of the threshold function provides the cases $e \leq I$ (where $f(e,I) = 0$) or $e > I$ (where $f(e,I) = 1$). Under this assumption the cases are $neu = 1$ or $neu = 0$ and $e \leq I$ or $neu = lSt / \beta_{neu}$ and $e > I$.

For an equilibrium for assertiveness it holds:

$$astv = astv_{norm} - (1 - \alpha_{astv}) \cdot neu \cdot astv_{norm}$$

Meanwhile, for an equilibrium for immunity it holds:

$$I = \alpha_I \cdot I_{norm} + (1 - \alpha_I) \cdot (1 - lSt) \cdot I_{norm}$$

$$= I_{norm} - (1 - \alpha_I) \cdot lSt \cdot I_{norm}$$

For an equilibrium for long term stress it holds $(1 - lSt) \cdot (sSt - \beta_{lSt} \cdot lSt) = 0$, which is equivalent to $lSt = I$ or $sSt = \beta_{lSt} \cdot lSt$. For an equilibrium for mood it holds $(1 - md) \cdot (lSt - \beta_{md} \cdot md) = 0$ which is equivalent to $md = I$ or $md = lSt / \beta_{md}$. Table 3 provides a summarization of these equilibria.

From the equilibria analysis, it turns out that all values can be expressed in terms of either neu or lSt . In Table 3, the values $astv$, soc , avc , pfC have been expressed in neu , and the values md , sSt , I have been expressed in lSt . Then by the equation for short term stress the value lSt can be expressed in neu .

$$\beta_{lSt} \cdot lSt = \beta_{sst} \cdot e + (1 - \beta_{sst}) \cdot neu \cdot (1 - e) \cdot (1 - (w_1 \cdot (astv_{norm} - (1 - \alpha_{astv}) \cdot neu \cdot astv_{norm})) (1 - neu))$$

$$+ w_2 (astv_{norm} - (1 - \alpha_{astv}) \cdot neu \cdot astv_{norm})$$

$$(1 - \alpha_{avc} \cdot neu) + w_3 \cdot (astv_{norm} - (1 - \alpha_{astv}) \cdot neu \cdot astv_{norm}))$$

From the equation for neuroticism two cases occur; $e \leq I$ and $neu = 0$, or $e > I$, and $\beta_{neu} \cdot neu = lSt$. These cases will be addressed in some more detail.

Analysis of Case $e \leq I$ and $neu = 0$:

In this case, the following values are found:

$$neu = 0, astv = astv_{norm} ,$$

$$soc = astv_{norm}, avc = 0,$$

$$pfC = astv_{norm}$$

$$sSt = \beta_{sst} \cdot e, lSt = \beta_{sst} \cdot e / \beta_{lSt}, I = I_{norm} - (1 - \alpha_I) \cdot \beta_{sst} \cdot e / \beta_{lSt} \cdot I_{norm}$$

$$md = I \text{ or } md = \beta_{sst} \cdot e / \beta_{lSt} \cdot \beta_{md}$$

Here the condition $e \leq I$ is equivalent to:

- $e \leq I_{norm} - (1 - \alpha_I) \cdot \beta_{sst} \cdot e / \beta_{lSt} \cdot I_{norm} ,$
- $e (1 + (1 - \alpha_I) \cdot \beta_{sst} / \beta_{lSt} \cdot I_{norm}) \leq I_{norm} ,$
- $e \leq I_{norm} / (1 + (1 - \alpha_I) \cdot \beta_{sst} / \beta_{lSt} \cdot I_{norm})$

These conditions illustrate the generic condition that an extremely healthy individual (not neurotic at all) that encounters only events that are less intense than its immunity level will never develop a relapse [2][5].

Table 3. Equilibrium Equations

Variable	Equations
neu	$neu = 1$ or $e \leq I$ and $neu = 0$ or $e > I$ and $\beta_{neu} neu = lSt$
$astv$	$astv = astv_{norm} - (1 - \alpha_{astv}) \cdot neu \cdot astv_{norm}$
soc	$soc = astv \cdot (1 - neu) = (astv_{norm} - (1 - \alpha_{astv}) \cdot neu \cdot astv_{norm}) (1 - neu)$
avc	$avc = \alpha_{avc} \cdot neu$
$pf\hat{c}$	$pf\hat{c} = astv \cdot (1 - avc) = (astv_{norm} - (1 - \alpha_{astv}) \cdot neu \cdot astv_{norm}) (1 - \alpha_{avc} \cdot neu)$
I	$I = I_{norm} - (1 - \alpha_I) \cdot lSt$, $I_{norm} = I_{norm} - (1 - \alpha_I) \cdot lSt$, I_{norm}
sSt	$sSt = \beta_{sst} \cdot e + (1 - \beta_{sst}) \cdot neu \cdot (1 - e) \cdot (1 - \psi)$ [where $\psi = w_1 \cdot soc + w_2 \cdot pf\hat{c} + w_3 \cdot astv$] $= \beta_{sst} \cdot e + (1 - \beta_{sst}) \cdot neu \cdot (1 - e) \cdot (1 - (w_1 \cdot (astv_{norm} - (1 - \alpha_{astv}) \cdot neu \cdot astv_{norm}) (1 - neu)) + w_2 (astv_{norm} - (1 - \alpha_{astv}) \cdot neu \cdot astv_{norm}) (1 - \alpha_{avc} \cdot neu)) + w_3 \cdot (astv_{norm} - (1 - \alpha_{astv}) \cdot neu \cdot astv_{norm})))$
lSt	$lSt = 1$ or $sSt = \beta_{lst} \cdot lSt$
md	$md = 1$ or $md = lSt / \beta_{md}$

Analysis of Case $e > I$ and $\beta_{neu} neu = lSt$:

In this case the equation becomes:

$$\begin{aligned} \beta_{lst} \beta_{neu} neu = & \\ \beta_{sst} \cdot e + (1 - \beta_{sst}) \cdot neu \cdot (1 - e) \cdot (1 - & \\ (astv_{norm} - (1 - \alpha_{astv}) \cdot neu \cdot astv_{norm}) & \\ (1 - neu)) + w_2 (astv_{norm} - (1 - \alpha_{astv}) \cdot neu \cdot & \\ (1 - \alpha_{avc} \cdot neu)) + w_3 \cdot (astv_{norm} - (1 - \alpha_{astv}) \cdot & \\ neu \cdot astv_{norm})) & \end{aligned}$$

Rewriting this equation in general, provides an equation of third degree, which for given values of the parameters can be solved in an algebraic manner or numerically. For some special cases of parameter values the equation becomes simpler. For example, when $\alpha_{astv} = 1$, it becomes a quadratic equation:

$$\begin{aligned} \beta_{lst} \beta_{neu} neu = & \\ \beta_{sst} \cdot e + (1 - \beta_{sst}) \cdot neu \cdot (1 - e) \cdot (1 - & \\ w_1 \cdot astv_{norm} (1 - neu)) & \\ + w_2 \cdot astv_{norm} (1 - \alpha_{avc} \cdot neu)) & \\ + w_3 \cdot astv_{norm} \cdot neu \cdot astv_{norm})) & \end{aligned}$$

This situation describes how an individual that encounters events which are more intense than its immunity level will not change, if his long-term stress level is in balance with his level of neuroticism [16].

6. The Integrative Ambient Agent Model

One of the key contributions of this paper is the design of an integrative model for an ambient agent to support persons recovered from a depression. In order to achieve this, 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 [1][4]. Through this mechanism, the agent will use this knowledge to provide related actions related to the predicted state of the human and the environment.

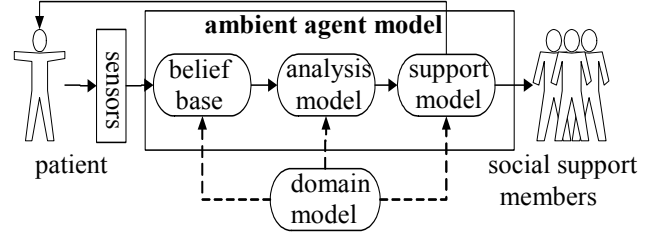


Fig. 5. Integrative Ambient Agent Model.

In Fig. 5, 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 following sub-sections will discuss in more detail the different elements within the integrative ambient agent model.

6.1. Belief-Desire-Intention Structure

Basically, the Belief-Desire-Intention (BDI) structure represents the beliefs as corresponding to information the agent has about the world, while desires correspond to states of actions that the agent would wish to be executed, and intentions represent actions that the agent has committed to accomplish [7]. Figure 6 depicts the overall functioning of the BDI model

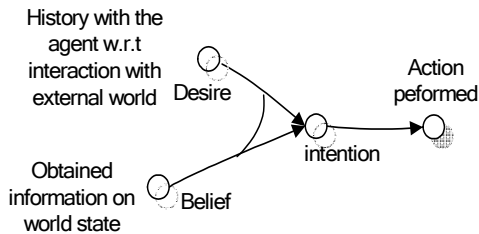


Fig. 6. The BDI Structure.

The term *belief* represents that what an agent believes about the world (or another agent) may not necessarily be true all the time and may change over time. As for the integrative agent model, the BDI structure will be used as a foundation for most of the properties.

6.2. Belief Base

The main function of the belief base is to generate initial beliefs (basic and derived beliefs) from the ambient agent's observation about the person's condition (refer to Figure 7). From this perspective, the observed beliefs and its interdependencies can be distinctively known and grouped.

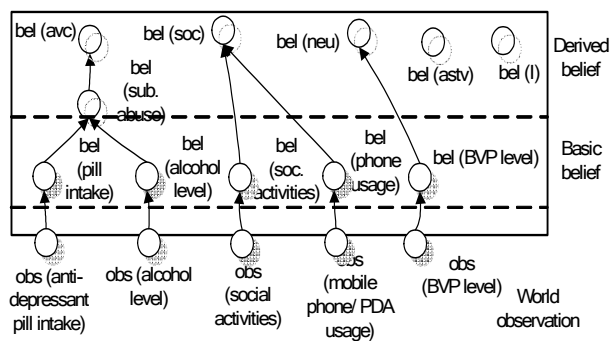


Fig. 7. Basic and Derived Belief in Belief Base.

Basic beliefs refer to beliefs related to the observation, while derived beliefs are based on derivations using the domain model [2]. 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 sensor) can be used to measure avoidant coping, it is easily can be added as a basic belief for a new observation, and append it with the existing avoidant coping belief. In addition, another model can make use this set of related beliefs without having to generate a new one.

6.3. Analysis Model

A very important aspect to determine the risk of relapse or recurrence is the continuous evaluation of changes in selected physiological and behavioural features within the person. In the analysis model, a set of different combination of several generated beliefs is analyzed. By analysing these combinations, the person's potential risk in relapse or recurrence can be monitored and predicted. Three important steps were taken to design this model. First, the information from the domain model has been captured and abstracted. This information provides the dynamic relations in the model. The relationships can be grouped as follows [3][5][17]:

- (1) relations from observable features in person to beliefs about observable states,
- (2) relations affecting beliefs about human conditions, such as avoidance coping, social support interaction, neurotic, assertiveness and immunity, and
- (3) relations from beliefs on human condition to an assessment of his state w.r.t. relapse risk.

Figure 8 depicts these relationships in a causal graph.

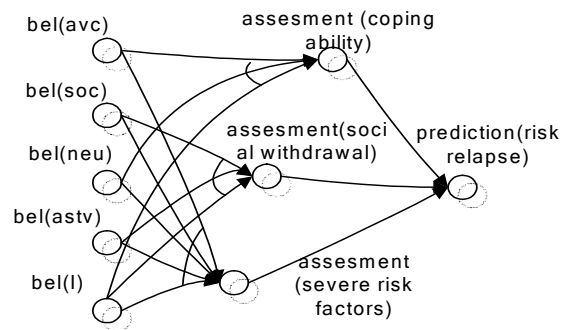


Fig. 8. Causal Graph of the Analysis Model.

The next step was to formalize these concepts in logical atoms. Once these concepts have been identified, the temporal relations and properties for these concepts within the ambient agent can be formally described [1]. These properties were designed to predict the risk of relapse / recurrence in the analysis model and to provide the basis for specific action selection in the support model

6.4. Support Model

For a person at a high risk of relapse or recurrence, 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 person. The implementation of BDI in the support model provides an action selection process, dedicated to decide which action should be chosen. On the conceptual level, the implementation of the BDI mechanism in the support model is illustrated in Figure 9.

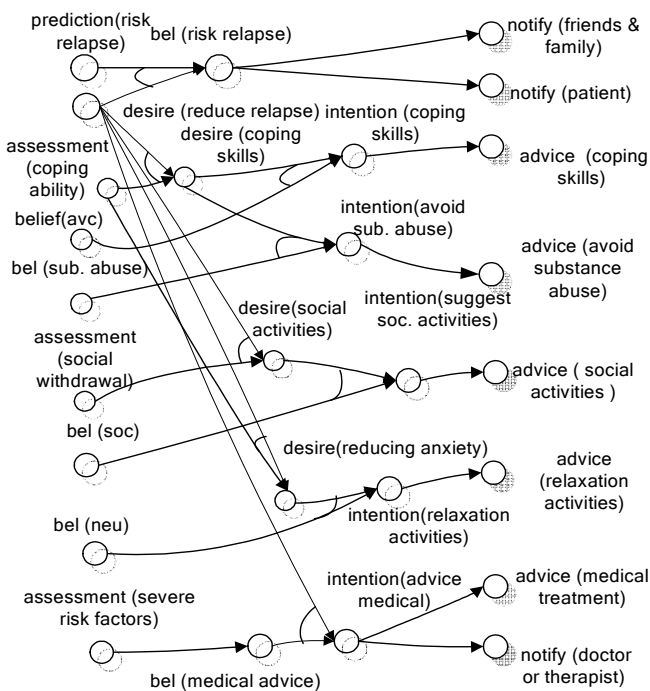


Fig. 9. Action Selection Process in the Support Model using the BDI Concept.

This has been obtained by compiling the combination of relations in the domain model between risk factors and long term mood into direct relations between the assessment of a specific risk and specific interventions.

6.5. Ontology and Specifications

To specify properties on dynamics relationship, an ontology of the model was designed using predicate calculus. For example, any agent ability to observe the frequency level of pill intake can be expressed as

`observed(X:AGENT, pill_intake,(F:FREQ_LEVEL)).`

Ontology for Agent's Observation: Observation using several sensors (input from person-world interaction). The agent observes human's condition through pill intake activities, alcohol compound in a blood stream, blood pressure level, phone usages, and social interaction with the social group.

```
observed(X:AGENT, pill_intake(F:FREQ_LEVEL))
observed(X:AGENT, alcohol_level(L:LEVEL))
observed(X:AGENT, BVP_level(L:LEVEL))
observed(X:AGENT, phone_usage(T:TYPE))
observed(X:AGENT, social_activity(T:TYPE))
```

Ontology for Belief Base: *Basic belief* (generated belief after several observations on pill intake, alcohol level reading, social activities, phone usage, and blood volume pressure reading)

```
belief(X:AGENT, pill_intake(F:FREQ_LEVEL))
belief(X:AGENT, alcohol_level(L:LEVEL))
belief(X:AGENT, BVP_level(L:LEVEL))
belief(X:AGENT, phone_usage(T:TYPE))
belief(X:AGENT, social_activity(T:TYPE))
```

Derived belief (belief on substance abuse, avoidant coping, neurotic, social support, immunity and assertiveness)

```
belief(X:AGENT, sub_abuse(L:LEVEL))
belief(X:AGENT, avoidant_coping(L:LEVEL))
belief(X:AGENT, neurotic(L:LEVEL))
belief(X:AGENT, social_support(T:TYPE))
belief(X:AGENT, immunity(L:LEVEL))
belief(X:AGENT, assertiveness(L:LEVEL))
```

Ontology for Analysis Model: There are three levels of analysis used; evaluation on coping skills, social withdrawal, and severe risk factors. These distinctive features provide important information to execute a specific action in the support model.

```
assessment(X:AGENT, coping_skill(L:LEVEL))
assessment(X:AGENT, social_interaction(L:LEVEL))
assessment(X:AGENT, all_factors(L:LEVEL))
prediction(X:AGENT, stage(C:COND, T:TYPE))
```

Ontology for Support Model: Two main actions are used to intervene the risk of relapse namely; notify and advice. The BDI approach regulates action selection process (internal processing) [9]. An action to be taken by an ambient agent is represented using *performed* as its predicate.

```
belief(X:AGENT, seek(K:TASK))
desire(X:AGENT, improved(K:TASK))
desire(X:AGENT, reduced(C:COND))
intention(X:AGENT, advice(K:TASK))
intention(X:AGENT, notify(R:ROLE))
performed(X:AGENT, advice(K:TASK))
performed(X:AGENT, notify(C:COND, R:ROLE))
belief(X:AGENT, stage(C:COND, T:TYPE))
```

The formalization of some properties makes use of sorts. These sorts are presented in Table 4.

Table 4. Sort Used in the Models

Sort	Elements
LEVEL	{low, medium, high}
TYPE	{positive, negative}
FREQ LEVEL	{normal, not taken, overdose}
TASK	{avoid_substance_abuse, social_activities, relaxation_activities, coping_skills, meet_doctor_therapist}
ROLE	{patient, friends_family, doctor_therapist}
AGENT	{low, medium, high}
CONDITION	{risk_relapse, anxiety, healthy}

Using this pre-determined ontology, the Belief-Desire-Intention (BDI) approach regulates action selection process (internal processing). To utilize the specification, a forward reasoning method for belief generation is used. It follows the time sequence and causality, to generate new beliefs from previous properties. The ambient agent functionality is described by three actions: belief generation in the belief base, evaluation of risk, and action selection for the support. Below a number of related specifications for social withdrawal case are shown.

BB4: Generating basic belief on phone/PDA usage

When the ambient agent observes there is no phone/PDA usage,
then the agent will believe that the person is not using phone/PDA to communicate with the others.
observed(agent, phone_usage(negative)) →
belief(agent, phone_usage(negative))

DB5: Derived belief on social support from the phone usage belief

If the ambient agent believes that there is no phone usage,
then the agent will believe there is no social interaction between social support network members.
belief(agent, phone_usage(negative)) →
belief(agent, social_support(negative))

GE2: Evaluation on social withdrawal condition

If it is believed that the person is not interacting with any social network support members, and having difficulty to control anger and it is believed that the person is vulnerable for the future onset,
then the agent will conclude that the condition of the person is having social withdrawal.
belief(agent, social_support(negative)) ∧ belief(agent, assertiveness(low)) ∧ belief(agent, immunity(low)) →
assessment(agent, social_interaction(low))

PCB2: Predicting the risk of relapse from social withdrawal condition

If the person is having social withdrawal,
then the ambient agent will assess the person as having potential risk of relapse.
assessment(agent, social_interaction(low)) →
prediction(agent, stage(risk_relapse, positive))

BOR: Belief on relapse

When the ambient agent predicts that the person is having a risk in relapse,
then the ambient agent will believe that the person is in the risk of relapse.
prediction(agent, stage(risk_relapse, positive)) →
belief(agent, stage(risk_relapse, positive))

ANR1: Action to notify social support networks

When the ambient agent believes that the person is in the risk of relapse,
then the ambient agent will notify all friends and family within the social support network.
belief(agent, stage(risk_relapse, positive)) →
performed(agent, notify(risk_relapse, friends_family))

ANR2: Action to notify the person

When the ambient agent believes that the person in the risk of relapse,
then the ambient agent will notify the person.
belief(agent, stage(risk_relapse, positive)) →
performed(agent, notify(risk_relapse, person))

DSI: Desire to improve social interaction

If the ambient agent assesses that the person is having social withdrawal,
then the ambient agent will desire to improve person's social interaction by advising the person about suitable social activities.
assessment(agent, social_interaction(low)) ∧ desire(agent, reduced(risk_relapse)) →
desire(agent, improved(social_activities))

ISIA: Intention to advice on social interaction

When the ambient agent desires to improve the person's social interaction through social activities and the ambient agent believes there is no social interaction between a person and social support network members, then the ambient agent will have an intention to advice the person on suitable social activities.
desire(agent, improved(social_activities)) ∧ belief(agent, social_support(negative)) →
intention(agent, advice(social_activities))

ASIA: Action to advice on social interaction activities

When the ambient agent intends to advice the person regarding to social activities to the person, then the ambient agent will advice the person about those social activities.

intention(agent , advice(social_ activities)) →
performed(agent , advice(social_ activities))

7. Simulation Results for the Integrative Agent Model

For the integrated model, a temporal specification language called LEADSTO and its supporting software environment has been used. LEADSTO enables one to model direct temporal relationship between two state properties (dynamic properties). Consider the format of $\alpha \xrightarrow{e,f,g,h} \beta$, where α and β are state properties in form of a conjunction of atoms (conjunction of literals) or negations of atoms, and e,f,g,h represents non-negative real numbers. This format can be interpreted as follows;

If state α holds for a certain time interval with duration g, after some delay (between e and f), state property β will hold a certain time interval of length h.

Here, atomic state properties can have a qualitative, logical format to represent certain observed conditions. In addition, this representation also holds a temporal trace γ , denoted by

$$\begin{aligned} \gamma \models \alpha \xrightarrow{e,f,g,h} \beta, \text{ if} \\ \forall t_1 [\forall t_1 [t_1 - g \leq t < t_1 \Rightarrow \alpha \text{ holds in } \gamma \text{ at time } t] \\ \Rightarrow \exists d [e \leq d \leq f \ \& \\ \forall t' [t_1 + d \leq t' < t_1 + d + h] \Rightarrow \beta \text{ holds in } \gamma \text{ at time } t']] \end{aligned}$$

For a more detailed discussion of this language, see [27]. Note that LEADSTO is used as a modeling instrument. It also possible to implement the model within any other software environment. Based on the proposed model, using the specified temporal rules to determine the stage of person, several simulations have been performed. For this paper, three examples of simulation runs were chosen. In the figures below, timeline is shown on the horizontal axis, the state properties are on the vertical axis and a dark box indicates that a state property is true.

Simulation # 1: Deficiencies in Social Interaction

This condition occurs when the ambient agent observes no activities in social interaction, low in assertiveness, and highly vulnerable towards future onset. The person is highly advised to engage social interaction with others. Having this in motion, social support network members will be informed by an ambient agent (see Figure 10)

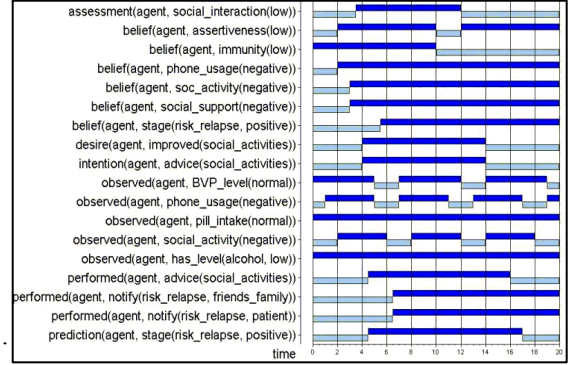


Fig. 10. Simulation Trace in Social Withdrawal.

Simulation #2: Deficiencies in Coping Skills

In this simulation, the ambient agent observes several risks, such as: a high blood volume pressure, high alcohol level, and overdose pill intake. Based on this, the agent assesses that the person is facing a risk of relapse, subject to coping skills problem. Therefore, the agent desires to give advice to improve coping skills, specifically to reduce anxiety and later to eliminate substance abuse are translated into intentions. Prior to this, the beliefs about the conditions must hold true. Figure 11 depicts the simulation trace of this condition.

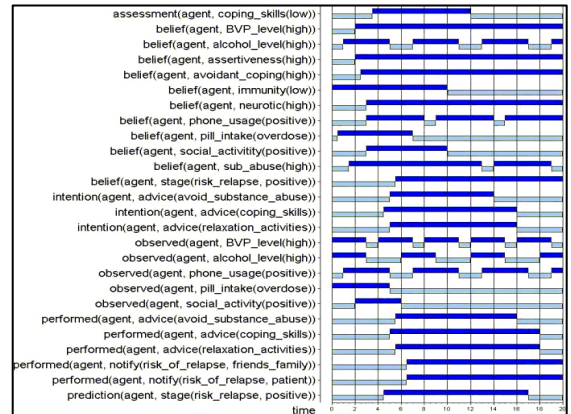


Fig. 11. Simulation Trace in Coping Skills Deficiencies.

Simulation # 3: Severe Risk Factors

The severe risk factors occur when all observed risk factor features show a positive contribution towards the future onset. Normally, seeking medical advice is the only best option. When an ambient agent evaluates a person is having all severe risk factors, the doctor or the therapist will be notified. The person will receive a notification to seek for medical advice. The result of this condition is shown in Figure 12.

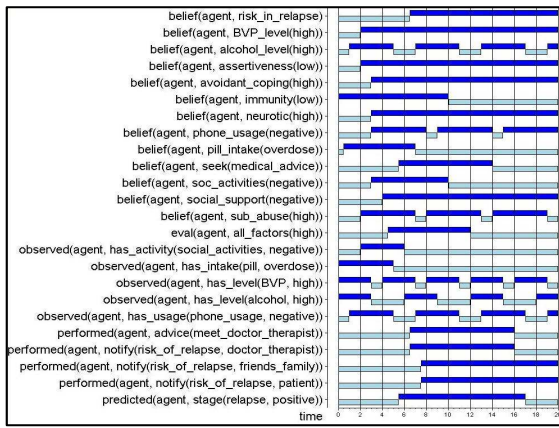


Fig. 12. Simulation Trace for All Severe Risk Factors.

8. Verification of the Integrative Agent Model

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 coherence with the literatures. It deals with building the model *right*. Several properties have been identified from related works in relapse management. The Temporal Trace Language (TTL) is used to perform an automated verification of specified properties against generated traces. This language allows formal specification and analysis of dynamic properties; it is either a qualitative or a quantitative representation [27].

TTL is designed on atoms, to represent the states, traces, and time properties. This relationship can be presented as a $state(\gamma, t, output(R)) \models p$, means that state property p is true at the output of role R in the state of trace at time point t . Based on that concept, dynamic properties can be formulated using a sorted predicate logic approach.

VP1: Advice to avoid substance abuse during the risk of relapse

When a person is believed to have a problem in substance abuse, prolong high neurotic level and vulnerable towards relapse (low in immunity), then the ambient agent provides advice to avoid substance abuse.

$$\begin{aligned} &\forall \gamma: \text{TRACE}, t: \text{TIME} \\ &[state(\gamma, t) \models \text{belief}(\text{agent}, \text{sub_abuse}(\text{high})) \wedge \\ &state(\gamma, t) \models \text{belief}(\text{agent}, \text{neurotic}(\text{high})) \wedge \\ &state(\gamma, t) \models \text{belief}(\text{agent}, \text{immunity}(\text{low}))] \\ &\Rightarrow \exists t': \text{TIME} > t: \text{TIME} [state(\gamma, t') \models \text{performed}(\text{agent}, \\ &\text{advice}(\text{avoid_substance_abuse}))] \end{aligned}$$

Substance abuse advice needs to be delivered if the persons are showing the risk of relapse, and with the combination of substance abuse problem, vulnerable to the onset, and prolong exposure to the anxiety [13]. It is vital since by prolong exposure towards substance abuse will increase the risk of future onset [17].

VP2: Warn for medical help if all risk conditions have been observed

When the doctor or therapist has been informed, the person has already had all severe risk factors observed.

$$\begin{aligned} &\forall \gamma: \text{TRACE}, t: \text{TIME} \\ &[state(\gamma, t) \models \text{performed}(\text{agent}, \text{notify}(\text{risk_relapse}, \\ &\text{doc_tor_therapist}))] \\ &\Rightarrow \exists t': \text{TIME} < t: \text{TIME} \\ &[state(\gamma, t') \models \text{belief}(\text{agent}, \text{sub_abuse}(\text{high})) \wedge \\ &state(\gamma, t') \models \text{belief}(\text{agent}, \text{neurotic}(\text{high})) \wedge \\ &state(\gamma, t') \models \text{belief}(\text{agent}, \text{immunity}(\text{low})) \wedge \\ &state(\gamma, t') \models \text{belief}(\text{agent}, \text{assertiveness}(\text{low})) \wedge \\ &state(\gamma, t') \models \text{belief}(\text{agent}, \text{social_support}(\text{negative}))] \end{aligned}$$

VP3: Social support networks as a buffer for negative life events

When the ambient agent predicts a person is having a risk in relapse, then the ambient agent sends a notification message to related friends and family within the social support network members.

$$\begin{aligned} &\forall \gamma: \text{TRACE}, t: \text{TIME} \\ &state(\gamma, t) \models \\ &\text{prediction}(\text{agent}, \text{stage}(\text{risk_relapse}, \text{positive})) \\ &\Rightarrow \exists t': \text{TIME} > t: \text{TIME} [state(\gamma, t') \models \\ &\text{performed}(\text{agent}, \text{notify}(\text{risk_relapse}, \text{friends_family}))] \end{aligned}$$

Friends and family within social support networks need to be informed if the person is developing the risk of relapse in future. Ability to have social support is one of the crucial elements to reduce the risk of relapse [24].

VP4: Relaxation training to reduce high comorbidity between anxiety and future onset

If the ambient agent observes a person is having a high reading in blood volume pressure,

then the ambient agent provides advice on relaxation activities

$$\begin{aligned} &\forall \gamma: \text{TRACE}, t: \text{TIME} \\ &\text{state}(\gamma, t) \models \text{observed}(\text{agent}, \text{BVP_level}(\text{high})) \\ &\Rightarrow \exists t': \text{TIME} > t: \text{TIME} [\text{state}(\gamma, t') \models \\ &\quad \text{performed}(\text{agent}, \text{advice}(\text{relaxation_activities}))] \end{aligned}$$

Anxiety can be reduced through a series of relaxation activities [9][16]. By reducing the level of anxiety (neurotic), it will deplete the risk of having a relapse .

VP5: Involvement in several social activities to reduce the risk of relapse in the case of social withdrawal

When the ambient agent evaluates a person is having social withdrawal and the ambient agent believes that a person is having no social support, then the ambient agent will provide advice to engage with suitable social activities.

$$\begin{aligned} &\forall \gamma: \text{TRACE}, t: \text{TIME} \\ &[\text{state}(\gamma, t) \\ &\quad \models \text{assessment}(\text{agent}, \text{social_interaction}(\text{low})) \wedge \\ &\quad \Rightarrow \exists t': \text{TIME} > t: \text{TIME} [\text{state}(\gamma, t') \models \text{performed} \\ &\quad \quad (\text{agent}, \text{advice}(\text{social_activities}))] \end{aligned}$$

Deficits in social activities increase the chance of relapse. Positive social activities mitigate between stressful life events and onset [24].

9. Conclusion

The grand challenge addressed in the research that is reported in this paper is to develop an ambient intelligent agent that is capable of monitoring individuals' condition in certain events and providing appropriate suggestions. In this paper, two steps have been taken. Firstly, a dynamical (domain) model was presented for automated relapse and recurrence of unipolar depression in humans. This model forms the basis for the monitoring function within the ambient agent model; through this domain model it acquires its awareness of the human's state. The proposed domain model is heavily inspired by scientific findings about the relapse and recurrence. A model has been developed that is able to explain the onset of recurrence and relapse based on personal characteristics and stressor events. Having this foundation, a formal model has been developed that can be used to simulate and analyse different individuals' situations, in relation to their personality and characteristics. A mathematical analysis has been performed to demonstrate the occurrence of equilibrium conditions, fundamentally beneficial

to describe convergence and stable states of the model.

Secondly, by compiling knowledge from the domain model into an ambient agent model, an integrative ambient agent model was obtained which is able to reason about the state of the person. Thus, it is capable to predict the risk of relapse based on several observable features and beliefs, mainly using a belief-desire-intention mechanism. The integrative agent model has been specified using a hybrid formal modelling approach, which enables both qualitative and quantitative specification. Within this integrative ambient agent model, some subcomponents are used to provide basic understanding based on monitoring the person's conditions, evaluating the risk, and to decide on actions to sustain the persons' wellbeing. The integration takes place by encapsulating the domain model in these subcomponents. A set of formal temporal properties were specified to allow intelligent reasoning to take place. From this formally specified ambient agent model, several simulation runs were executed using the LEADSTO software environment.

The simulation results have been verified based on several properties using Temporal Trace Language (TTL) environment. The presented model provides a basic design on how an ambient model can be used to monitor person in a risk of relapse and recurrence in unipolar depression. It was shown that the ambient agent model indeed through simulation is capable to provide a support for persons. Future work of this integrative agent model will be specifically focus on how interactions and sensing properties can be further developed and enriched, to promote a better way to fluidly embedded this into any monitoring and ambient health system. In addition to this, apart from a more thorough evaluation of the proposed model, future work will focus on generalizing the proposed model to a generic model for risk assessment and support in other domains.

References

- [1] A. Sharpanskykh, and J. Treur, An Ambient Agent Model for Automated Mindreading by Identifying and Monitoring Representation Relations. In: PETRA'08, ACM Pub. Athens, 2008.
- [2] A. A. Aziz, M.C.A. Klein, and J. Treur, An Agent Model of Temporal Dynamics in Relapse and Recurrence in Depression. In: Ali, M., Chen, S.M., Chien, B.C., Hong, T.P. (eds.), IEA-AIE 2009. LNAI, Springer Verlag, 2009. 36-45).
- [3] A. A. Aziz, M.C.A. Klein, and J. Treur, An Ambient Intelligent Agent Model for Relapse and Recurrence Monitoring

- in Unipolar Depression. In: Combi, C., Shahar, Y., Abu-Hanna, A. (eds.), Proceedings of the 12th Conference on Artificial Intelligence in Medicine, AIME'09, LNAI, Springer Verlag, 2009, 186-190.
- [4] A. A. Aziz, M.C.A. Klein, and J. Treur, Modeling An Ambient Agent To Support Depression Relapse Prevention. In: Proceedings of the Third International Workshop on Human Aspects in Ambient Intelligence, HAI'09. IEEE Computer Society Press, 2009, to appear.
- [5] A. A. Neirenberg, T.J. Petersen, and J.E. Alpert, Prevention of Relapse and Recurrence in Depression: The Role of Long-Term Pharmacotherapy and Psychotherapy. *J.Clinical Psychiatry* 64(15), (2003), 13-17.
- [6] A. P. Glascock, and D.M. Kutzik, The Impact of Behavioural Monitoring Technology on the Provision of Health Care in the Home. *Journal of Universal Computer Science* 12(1), (2006), pp.59-79.
- [7] D. Kinny, M. Georgeff, and A. Rao, A Methodology and Modelling Technique for Systems of BDI Agents, Proceedings of the 7 th European Worksgop on Modelling Autonomous Agents in a Multi-Agent World, LNAI Volume 1038, 1999.
- [8] D.J. Green, Real-time Compliance Management Using a Wireless Real-time Pill bottle – A Report on the Pilot Study of SIMPILL. In: Proc. of the International Conference for eHealth, Telemedicine and Health'05, 2005.
- [9] E.I. Brilman, and J. Ormel, Life Events, Difficulties, and Onset of Depressive Episodes in Later Life, *Psychological Medicine* 31, (2001).
- [10] F. Both, M. Hoogendoorn, M.C.A. Klein, and J. Treur, Design and Analysis of an Ambient Intelligent System Supporting Depression Therapy. In: Luis Azevedo and Ana Rita Londral (Eds), Proceedings of the Second International Conference on Health Informatics, HEALTHINF'09. INSTICC Press, 2009,142-148.
- [11] F. Both, M. Hoogendoorn, M.C.A. Klein, and J. Treur,, Formalizing Dynamics of Mood and Depression, In: M. Ghallab, C.D. Spyropoulos, N. Fakotakis and N. Avouris (Eds.), Proc. of the 18th European Conf. on Artificial Intelligence, ECAI'08. IOS Press, 2008, 266-270.
- [12] G. Belsher, and C.G. Costello, Relapse after Recovery from Unipolar Depression: A Critical Review. *Psychological Bulletin*. 104, (1988).
- [13] G. Shahar, J. Joiner, D.C. Zuroff, and S.J. Blatt, Personality, Interpersonal Behavior, and Depression: Co-Existence of Stress-Specific Moderating and Mediating Effects, *Personality and Individual Differences* (36), (2004), 1583-1596.
- [14] J. Ormel, and T. Wohlfarth, How Neuroticism, Long Term Difficulties, and Life Situation Change Influence Psychological Distress: A Longitudinal Model. *Journal of Personality and Social Psychology* 60(5), (1991), 744-75.
- [15] J. Zhai, and A.B. Barreto, Instrumentation for Automatic Monitoring of Affective State in Human-Computer Interaction, In 18th International Florida Artificial Intelligence Research Society Conference, (2005), 207-212.
- [16] K.C. Gunthert, L.H. Cohen, and S. Armeli, The Role of Neuroticism in Daily Stress and Coping, *Journal of Personality and Social Psychology* 77, (1999), 1087-1100.
- [17] L.V. Kessing, M.G. Hansen, P.K. Andersen, and J. Angst, The predictive effect of episodes on the risk of recurrence in depressive and bipolar disorders - a life-long perspective. *Acta Psychiatrica Scandinavica* 109, (2004), 339-344.
- [18] M.B. Keller, Long-Term Treatment of Recurrent and Chronic Depression, *J.Clinical Psychiatry* 62(24), 2001.
- [19] P.M. Lewinsohn, H. Hoberman, L. Teri, and M. Hautzinger, An integrative theory of depression, In S.Reiss & R.R. Bootzin (Eds.), *Theoretical Issues in Behavior Therapy*, (1985), 331-352.
- [20] R.C. Kessler, The Effects of Stressful Life Events on Depression, *Annual Review of Psychology* 48, (1997), 191-214.
- [21] R.E. Ingram, and D.D. Luxton, Vulnerability-Stress Models, In J.Abel (Ed.).*Development of Psychopathology: Stress-Vulnerability Perspectives*, New York, 2005.
- [22] R.W. Picard, and K.K. Liu, Relative Subjective Count and Assessment of Interruptive Technologies Applied to Mobile Monitoring of Stress, *International Journal of Human-Computer Studies*, Vol 65(4), (2007).
- [23] R.W. Picard, E. Vyzas, and J. Healey, Towards Machine Emotional Intelligence: Analysis of Affective Physiological State, *IEEE Transactions on Pattern Analysis and Machine Intelligence*. Vol.23 (10), (2001).
- [24] S. Cohen, and T.A. Wills, Stress, Social Support, and the Buffering Hypothesis, *Psychological Bulletin* 98,(1985), 310-357.
- [25] S.M. Monroe, and K.L. Harkness, Life stress, the kindling hypothesis and the recurrence of depression: consideration from a life stress perspective, *Psy. Review* 112:2, (2005), 417-445.
- [26] T. Bickmore, A. Gruber, and R. Picard, Establishing the Computer-Patient Working Alliance in Automated Health Behavior Change Interventions. *Patient Education and Counseling* 59 (1) , (2005), 21-30.
- [27] T. Bosse, , C.M. Jonker,, L. van der Meij, and J. Treur, A Language and Environment for Analysis of Dynamics by Simulation. *International Journal of Artificial Intelligence Tools*, vol. 16, (2007), 435-464.