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RESEARCH ARTICLE

A generic computational model of mood regulation and its use to model therapeutical interventions

Fiemke Both, Mark Hoogendoorn, Michel C.A. Klein, Jan Treur *

VU University Amsterdam, Agent Systems Research Group, De Boelelaan 1081, 1081HV Amsterdam, The Netherlands

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Abstract
As all living organisms, human beings aim at being in some kind of balance (or homeostasis) with their environment. Part of this challenge takes the form of keeping their mood within certain boundaries, and in particular avoiding (too) negative moods when facing negative events from time to time. In this paper a generic computational model for this regulative process is presented. The model serves as a framework or architecture in which various additional elements can be incorporated. To evaluate the suitability of this framework, the model has been extended by incorporating therapeutical interventions for four different types of therapy. The obtained intervention models have been used to model and compare different therapies for a variety of patient types by simulation experiments and by formal verification. Simulation experiments are reported showing that the mood regulation and depression indeed follow expected patterns when applying these therapies. These models form building block for intelligent therapy support systems.

Introduction

Living organisms aim at being in some kind of balance (or homeostasis) with their environment; e.g., (Cannon, 1926, 1932). For human beings part of this challenge takes the form of keeping their mood within certain boundaries. Especially avoiding negative moods may be a nontrivial challenge faced by a human organism from time to time encountering

* Corresponding author.
E-mail addresses: mhoogen@cs.vu.nl (M. Hoogendoorn), mcaklein@cs.vu.nl (M.C.A. Klein), treur@cs.vu.nl (J. Treur).
URLs: http://www.few.vu.nl/~mhoogen (M. Hoogendoorn), http://www.few.vu.nl/~mcaklein (M.C.A. Klein), http://www.few.vu.nl/~treur (J. Treur).

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negative kinds of events. In the richer countries the number of persons struggling with longer periods of negative moods, like in a depression, is relatively high, and is expected to increase further. Major depression is currently the fourth disorder worldwide in terms of disease burden, and is expected to be the disorder with the highest disease burden in high-income countries by the year 2030; e.g., (Mathers & Loncar, 2006). To avoid or to recover from a negative mood requires mechanisms for mood regulation. In recent neurological literature many contributions can be found about relations between mood regulation or depression and brain functioning; e.g., (Anand et al., 2005; Beauregard, Paquette, & Levesque, 2006; Davidson, Lewis, Alloy, Amaral, et al., 2002; Disner, Beevers, Haigh, & Beck, 2011; Drevets, 2003, 2007; Harrison, 2002; Konarski et al., 2008; Levesque et al., 2003; Mayberg, 2003). Much neurological support has been found for the processes of emotion and mood regulation, and in particular for modulation (down-regulation) of a negative mood in order to avoid or recover from a depression; e.g., (Anand et al., 2005; Beauregard et al., 2006; Davidson et al., 2002; Levesque et al., 2003).

Effective interventions for treating depressions are of utmost importance for both the patients suffering from a depression as well as for society in general. A supporting software environment can be very helpful in effectively treating a depression by providing knowledgeable advices, for example, on which therapy to choose for a given situation and type of patient. In order for such a software environment to function effectively, detailed computational model on the relevant human states and their interrelationship regarding regulation of mood and depression can be very useful. Such a model can not only help to understand and analyze the basics behind a depression better, but also be used to evaluate different therapeutic options by simulation experiments with virtual patients. This work is one of the first steps in the development of a software agent to support patients in a personal manner.

In this paper a computational model of mood regulation and depression based on literature on emotion and mood regulation is presented and evaluated. A point of departure for this computational model was the somewhat simpler model presented in Both, Hoogendoorn, Klein, and Treur (2008) (which will be discussed as a point of departure in the section 'The basic model for mood regulation'). In the current paper the model gets an extended form and its usefulness is discussed in some more depth. More specifically, it is explored in how far the model can be used as a generic cognitive framework or architecture which is suitable to incorporate different interventions or therapies and their effects. The interventions addressed are activity scheduling (Lewinsohn, Youngren, & Grosscup, 1979), cognitive restructure-ing (Beck, 1972), exercise therapy (Cooney et al., 2013; Cotman & Berchtold, 2002), and a general intervention aimed at enhancing *coping* skills. To support patients during a major depression, knowledge about the functioning of these therapies is important to give effective support, and hence, detailed models about the functioning of the therapy can be of great added value certainly when thinking of automated therapies. The process of down-regulation of negative moods, as is described in neurological literature, has been a basic point of departure for the presented extensions of the mood regulation model. More specifically, the model presented in this paper addresses how this down-regulation process can be stimulated and improved by therapeutical interventions.

In order to create the models for each of the therapies, the main principles of the interventions from psychological literature have been incorporated, and these additional concepts have been incorporated in the generic model for mood regulation and depression. The models were then used to conduct simulation experiments with various (virtual) patient types and the correctness was analyzed using a method for formal verification of a number of expected behaviors. The obtained models are suitable to be integrated within a software environment in order to provide adequate advices concerning effective support for a specific type of patient.

In the paper, first in the section 'A generic model for mood regulation and depression' the generic model for mood regulation is described. Next in four subsequent sections extensions of this model to incorporate four different types of therapy (varying from activity scheduling to exercise therapy) are described. In the section 'Simulation' it is discussed how simulation experiments have been performed studying how the model simulates different types of therapy and patients. In the section 'Computational analysis of therapeutic models' analysis of the models is discussed. Section 'Discussion' concludes the paper.

A generic model for mood regulation and depression

The generic model for mood regulation and depression describes the relationship between the most prominent states of a human with respect to mood and depression. Hereby, a state refers to a relevant concept in the model that is operationalized by means of a numerical value. In order to be able to use this model of the virtual patient to make predictions of the future states of the patient following a certain therapy, this model is extended with general therapeutic concepts in this section. Hereby, some equations underlying the general model have been modified to allow for this extension. To obtain a step by step explanation of the model, first the original model from Both et al. (2008) is summarized. Next the extended model will be explained.

The basic model for mood regulation

In the model basic concepts form the theories summarized above will be used. From the behavioral theory of Lewinsohn et al. (1979) the idea is adopted that a lack of reinforcement from the environment (i.e., *situation*) influences the choice of a new situation via the mood. According to Beck (1972) the perception of the situation will be negatively influenced by negative thinking patterns (*thoughts*), so also a *subjective emotional value of the situation* is used. This is also in line with the ideas of stress by