# Agent-based support for behavior change

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# A Computational Model for Therapy Adherence and Behavior Change

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**Abstract** Mobile applications have proven to be a promising tool to support people in adhering to their health goals. Although coaching and reminder apps abound, few of them are based on established theories of behavior change. In the present work, a behavior change support system is presented that uses a computational model based on multiple psychological theories of behavior change. The system determines the user's reason for non-adherence using a mobile phone app and an online lifestyle diary. The user automatically receives generated messages with persuasive, tailored content. The system was designed to support chronic patients with type 2 diabetes, HIV, and cardiovascular disease, but can be applied to many health and lifestyle domains. The main focus of this work is the development of the model and how it can simulate behavior change.

## 2.1 Introduction

According to the World Health Organization, in 2015 there will be 1.5 billion overweight adults worldwide, and about one third of them will be obese.[2] Obesity significantly increases the risks for developing chronic diseases such as cardiovascular disease, diabetes, and various types of cancer.[3] These chronic diseases are the leading causes of disability and death. Accordingly, in today's society, adhering to a healthy lifestyle is considered of the utmost importance.

Research has shown that a healthy lifestyle can contribute to (i) the prevention of the development of chronic illness, (ii) the prevention of serious complications that follow from this development, and (iii) the improvement of the quality of life of people who have developed a chronic illness. It is therefore that therapy for chronic patients often consists of healthy lifestyle regulations, including a healthy diet and a regular exercise regime, aside from medication intake. For many people, however, adhering to a healthy lifestyle requires behavioral changes.

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[2]`http://www.who.int/chp/chronic_disease_report/part2_ch1/en/index16.html`, last visited on June 21, 2013.

[3]`http://www.who.int/mediacentre/factsheets/fs311/en/index.html`, last visited on June 21, 2013.

Even whilst knowing the benefits of a healthy lifestyle, people find it hard to find (and keep) the optimal balance between work, social life and a healthy diet or medicine schedule. Physical discomforts and side effects of medicine intake are additional barriers for committing to healthy behavior. In short, people have many reasons why they don't do what's good for them. As a consequence, the number of people that are obese or have a chronic disease has increased considerably over the past years, and the prevalence and costs of interventions addressing the chronic disease burden is expected to rise.

It has been shown that patient engagement and empowerment can improve patient therapy adherence and consequently the patient's health condition (Maes and Karoly, 2005). This engagement and empowerment is often referred to as *self-management*: the individual's ability to monitor one's condition (symptoms, treatment) and to affect the cognitive, behavioral and emotional responses necessary to maintain a satisfactory quality of life (for a more comprehensive definition, see Barlow, Wright, Sheasby, Turner, and Hainsworth (2002)).[1] But how can people increase and optimize their self-management? As self-management consists of many challenging components, this question is not easily answered. For example, good self-management involves coping with the psychosocial problems generated by chronic disease, having sufficient knowledge of the condition and its treatment, and applying the necessary skills to maintain adequate psychosocial functioning (Clark, Becker, Janz, Lorig, Rakowski, and Anderson, 1991). Additionally, therapy adherence is strongly intertwined with self-management, as it implements the expert's advice on how to keep the illness and its effects under control. This means that the patient has to change the way he or she would normally behave, using *self-control* to maximize long-term best interests by inhibiting immediate desires or competing behaviors (Barkley, 1997; Kanfer and Karoly, 1972; Muraven and Baumeister, 2000).

In short, effective self-management is challenging and involves many aspects of human personality and behavior. The use of computers to support people has proven to be an effective approach to increase self-management (Kreuter, Farrell, Olevitch, and Brennan, 2000; de Vries and Brug, 1999). Systems that support self-management are able to provide personalized (*tailored*) interventions at low costs (Eysenbach, 2001), constantly, and at home (Rogers and Mynatt, 2003). Furthermore, interventions that are closely tailored to the individual's convictions and motivations have shown to be more likely to be observed and remembered (Skinner, Campbell, and et al, 1999).

Although intelligent support systems have become increasingly popular for the use of behavior interventions in recent years, those systems are rarely based on models of behavior change (Riley, Rivera, Atienza, Nilsen, Allison, and Mermelstein, 2011). In order to design an effective support system, it is necessary to understand the underlying mechanisms of behavior change and how these mechanisms can be influenced to establish the desired behavior. As Michie, Johnston, Francis, Hardeman, and Eccles state in their 2008 article: "Ideally, researchers designing interventions would choose a small number of the theoretical frameworks based on empirical evidence of their predictive and intervention value, i.e., there should be evidence that the theory can predict the behavior and that interventions which change these determinants achieve change in behavior"(Michie et al., 2008). When targeting sustainable behavior change, it is not enough to target behavioral outcomes alone. Underlying motivations, attitudes and opinions need to be changed in order to make the changes last. In the literature however, little work exists that provides a model based on theoretical frameworks (one notable exception is the iChange model (de Vries and Mudde, 1998), which describes the factors that influence behavior change, but fails to explicate how these factors interact).

[1]The benefits of self-management can also apply to healthy people trying to reduce the risks for chronic disease by adhering to a healthy lifestyle.

The aim of this work is to bridge that gap with a computational model based on theoretical frameworks of behavior change. The model was first presented in (Klein, Mogles, and van Wissen, 2011). In this work we will elaborate on the design of the model, which was developed by integrating several established psychologocial theories on behavior change. Also, the implementation and evaluation of the model in an e-coaching system are discussed. This intelligent support system for self-management attempts to detect the cause of unhealthy behavior, and provides tailored coaching. What makes this approach particularly challenging, is that the system is designed to target three domains: food intake, physical activity and medication intake. The system observes behavior directly and indirectly: observations of medication intake are obtained with an electronic pillbox and subjective observations on food intake and physical activity are based on information provided by the user via a mobile application and a website. Based on this information, the system supports users with tailored information and persuasive motivational messages on how to improve their behavior. In order to create a system with the capacity to target three different domains of behavior change, it was designed as a general framework that can include specific modules (containing domain-specific information). This allows the system to be applicable to a broad range of domains of behavior change.

The paper is structured as follows. First, an overview of approaches for intelligent support systems is provided in Section 2.2. This Section also outlines how the current work differs from previous work in this area. In Section 2.3 a model is presented that formalizes the interaction between the different determinants of behavior change. The theoretical framework that provides the foundation of the model is also discussed. The validation of the model, as well as details of the reasoning system and implementation, are described in Chapter 8.

## 2.2 Approaches for Intelligent Coaching and Mobile Persuasion

As noted in Lehto (2012), many terms have emerged over the past years to describe technology-based interventions for mental and physical health purposes. There is no consensus about the terms yet, but one that closely fits our aims is *Behavior Change Support Systems* (BCSSs), a term introduced by Oinas-Kukkonen. A behavior change support system is defined as “an information system that is designed to form, alter or reinforce attitudes, behaviors or an act of complying without using deception, coercion or inducements” (Oinas-Kukkonen, 2010). Although many studies demonstrate the promise of such support systems, it seems that more scrutinized evaluations of computerized interventions are necessary to fully determine their potential as tools for facilitating health behavior change (Norman, Zabinski, Adams, Rosenberg, Yaroch, and Atienza, 2007). This is because building a successful behavior change support system is challenging. It needs to address aspects such as accessibility, adaptability and interactiveness. Many contemporary approaches use mobile phones to interact with the user, as phones have several distinct characteristics that make them useful for support systems: they are easily available to the users, they are at the users’ fingertips, and they support both user and system initiated interactions. Also, information provided by the mobile phone can easily be personalised and designed to persuade or manipulate (Fogg and Eckles, 2007). Because of these capabilities, the mobile phone is an ideal platform for using persuasive techniques to induce behavior change.

For an extensive overview and comparison of recent work in health interventions using a mobile approach, see Klasjna and Pratt (2012). Addressing all relevant work in this area would be beyond the scope of this paper. Instead, we focus on different levels of complexity and automation of e-coaching systems.

Based on relevant literature in mobile interventions, a distinction can be made between different types of mobile health interventions. The simplest form is using the mobile phone for sending reminders and keeping track of progress, e.g., reminding patients to take their medication or logging their nutritional intake. These interventions do not depend on any model of health behavior and are the same for all users. For example, CARDS — Computerized Automated Reminder Diabetes System (Hanauer, Wentzell, Laffel, and Laffel, 2009) — is a system that sends diabetic patients text messages and e-mails with reminders about blood monitoring, without further medical advice. In this category many mobile phone and web-based applications exists that help patients keep track of data such as calorie intake, blood monitoring and exercise by means of an online mobile dairy[1].

However, because tailored messaging interventions are proven to be more effective than those that use generic messages (Fjeldsoe, Marshall, and Miller, 2009), more complex approaches have been developed that include tailored feedback based on user data gathered by sensors (such as an accelerometer or GPS) or user input (such as survey questions or a diary). Many of these systems include human coaches to directly create and coordinate the interventions. For example, a health care professional is asked to write the feedback messages or a human care giver tracks the progress and effects of the messages (e.g., Moskowitz, Melton, and Owczarzak (2009); Philips (2011)).

Persuasive systems that do not involve human coaching at runtime (ideally, health care professionals are always part of the design process), are increasing in popularity. These systems can be especially useful for illness self-management, as the monitoring and support that comes with the regulation of chronic illness involve large costs. The fact that a human coach or caregiver is not directly involved can also lower the threshold for users to sign up for support. These support systems can help patients to manage their disease, for example by improving their therapy adherence, in the comfort of their own home and without the involvement of expensive health care professionals. For example, in Bauer, Niet, Timman, and Kordy (2010) a predefined algorithm selects a feedback message from a large pool of pre-formulated texts which is tailored to the user's individual pattern of change or treatment.

Systems that use automated mechanisms to create and send (tailored) text messages can directly or indirectly influence user behavior determinants central to many behavioral theories (e.g., cues to action, self-efficacy, social support). Moreover, data suggests that intervention programs can achieve stronger impacts when the content of these messages is theory-based (Cole-Lewis and Kershaw, 2010). It is therefore important to design these messages such that (i) the tone of the message is in line with persuasive theories, and (ii) the message incorporates knowledge from behavioral theories. However, as referred to in the introduction, many works on mobile interventions for adherence and disease management do not use or do not specify any health behavior theories underlying their interventions (Riley et al., 2011).

Our approach differs from above mentioned approaches in several respects. First, it does not only target the user's behavior, but also the underlying mechanisms causing that behavior. The core of the proposed behavior change support system is a computational model based on multiple psychological theories describing determinants for behavior change. The system does not rely on a human coach, but instead automatically provides tailored feedback that is not just focused on the user's behavior, but also on the underlying individual cause of non-adherence. Patients will be monitored and will receive feedback on their progress. Automatically generated messages targeting their personal barriers (i.e., their causes for non-adherence) attempt to induce behavior change, using validated persuasion techniques such as the use of authority, repetition

[1] see for example apps such as Lose It! (`http://www.loseit.com/`) and GlucoseBuddy (`http://www.glucosebuddy.com/`).

and consistency measures (Kaptein, Markopoulos, de Ruyter, and Aarts, 2010). Secondly, in addition to being a tool for patient self-management, it is also a tool for researchers to test their model of behavior change and the effectiveness of the design of their persuasive intervention. The system is part of a framework that is designed in such a way that the messages and the model can be adjusted to different domains of behavior change research. It can be applied to patients with different diseases and therapies. Thirdly, the system integrates many technical components, such as a telephone message service, an online diary, questionnaires, a smart pillbox and an information portal to provide support on three lifestyle domains: medicine, diet and exercise. This innovative and interdisciplinary approach captures many of the challenges of designing behavior change support systems.

## 2.3 Modeling Behavior Change

As put forward in Section 2, for health interventions to be effective they need to incorporate existing theories of behavior change and persuasive design. The model of behavior change COMBI designed in this work is based on several theories from psychological literature that describe determinants for behavior change. A conceptual representation of the model can be found in Figure 2.1. Subsection 2.3.1 will describe the theories that the model incorporates and will elaborate on their key constructs. The cursive constructs are the ones that can be found in the proposed model. In Subsection 2.3.2 the structure of the model will be explored in more detail. The formalization of the model and how it can be used to simulate behavior change will be addressed in Subsection 2.3.3.

### 2.3.1 Theories of behavior change

There are many theories that describe different mechanisms of behavior change in psychological and medical literature. This subsection will give an overview of the most influential theories in this area. The theories described below have substantial empirical support and are most frequently used in behavior change interventions (Armitage and Conner, 2000; Glanz, Rimer, and Viswanath, 2008), and as such are considered to be valid to be applied in behavior change interventions. A more comprehensive description of the model's constructs and the related theories can be found in Klein et al. (2011).

Riley, Rivera, Atienza, Nilsen, Allison, and Mermelstein argue that it is unclear whether traditional health behavior models are capable of guiding the dynamic process of iterative and adaptive interventions for behavior change, given their predominately linear and static nature (Riley et al. (2011, p. 54)). As the name implies, behavior change concerns a process of development from executing one type of behavior to adopting another. The **Transtheoretical Model (TM)** (Prochaska and DiClemente, 1984) focuses on behavior change as a dynamic process rather than an event. This characteristic makes TM very suitable to use it in interventions of behavior change, and it is why it was chosen as the basis for the COMBI model. The TM was successfully applied in many programs aiming at the elimination of addictive behavior, and the improvement of mental health, exercise frequency, and dietary change (Armitage and Conner, 2000; Prochaska and Norcross, 2001). It assumes that behavior change is a five-stage process with the stages of *precontemplation*, *contemplation*, *preparation*, *action*, and *maintenance*. This theory implies that the kinds of interventions needed to move from one stage to another differ per stage, as each stage represents specific stages of readiness for change. Depending on the *awareness, motivation* and *commitment* of an individual, he or she progresses through the stages. In the *precontemplation* stage individuals have no intention to change their behavior and will likely be unaware of their problems. In the *contemplation* stage individuals are aware that a problem exists and are seriously thinking of changing their behavior in the next six months, but do not have any concrete plans of change. Individuals are in a *preparation* stage when they intend to take action in the next month and have a concrete action plan. During the *action* stage individuals overcome their obstacles and actively change their behavior. The *action* stage may last from one day to six months after having made the first overt change. Those who have engaged in a new behavior for more than six months are classified as being in the *maintenance* stage. Although a person advances through the stages in a sequential order, relapse to a previous stage is possible.

Bandura's **Social Cognitive Theory (SCT)** (Bandura, 1977) has been frequently used to predict different health behaviors and behavioral intentions (Armitage and Conner, 2000). According to this theory, behavior is executed if one perceives (i) control over the outcome, (ii) few external barriers and (iii) confidence in one's own ability. Bandura introduces a new construct that relates to the expectancies concerning the outcome: *self-efficacy*, defined as confidence in one's own ability to carry out a particular behavior. The construct of *self-efficacy* has shown to be a good predictor of behavior, related to coping with stress and recovery from illness (Armitage and Conner, 2000).

**The Theory of Planned Behavior (TPB)** (Ajzen and Madden, 1986) has been widely applied in many behavior interventions (Glanz et al., 2008). This theory is a revised version of the **Theory of Reasoned Action (TRA)** that was proposed by Fishbein and Ajzen (1975). The Theory of Reasoned Action is based on the assumption that *intention* is an immediate determinant of behavior, and that it in turn is predicted by *attitude* — which is a function of the *beliefs* held about the specific behavior, as well as the evaluation of the likely outcomes — and (subjective) *social normative* factors. This approach is thus based on expectancy-value interactions. In the Theory of Planned Behavior, which is a more recent version of the theory, one more component was added: *perceived behavioral control*, which has a motivational effect on intentions. There is substantial overlap between the construct of *self-efficacy* in Bandura's Social Cognitive Theory and the construct of behavioral control in the theory of Fishbein and Ajzen.

The TRA does not include social norms as a factor that influences attitude formation directly. According to the TRA, social norms are defined as a factor that influences intention along with already formed *attitude*. The **Attitude Formation (AF)** theory (Smith and Mackie, 2000) also defines *attitude* as an important aspect of behavior, influenced by the *beliefs* about an object (in this case, behavior), emotional connotations associated with the object, and social norms concerning this object in this case.

**Self-Regulation Theories (SRT)** regard individuals as active problem solvers whose behavior reflects an attempt to close the gap between their current status and their goals, or a standard which serves as a reference value for one's behavior. In his later work Bandura positioned the construct of *self-efficacy* in the **Self-Regulation Theory** framework as well (Bandura, 1991). Levental's self-regulation model of illness identifies three stages of variables regulating the adaptive behavior: cognitive representation, action plan, *coping* and appraisal stage (Leventhal, Nerenz, and Steele, 1984). Important aspect of this approach is the possible influence of *emotions* and *mood* on behavior.

In the **Relapse Prevention Model (RPM)** (Marlatt and Gordon, 1980) *coping* also plays an important role. It describes the influence of environmental factors along with the cognitive determinants, such as *self-efficacy* and *coping*, and emphasizes *high risk situations* (such as a switch of work schedule, being on holiday or living near a snack bar) and the ability of *coping* with them. The theory provides an explanation of relapse from the acquired behavior stage to the stage of the previously performed behavior in the terms of the **Transtheoretical Model** of Prochaska.

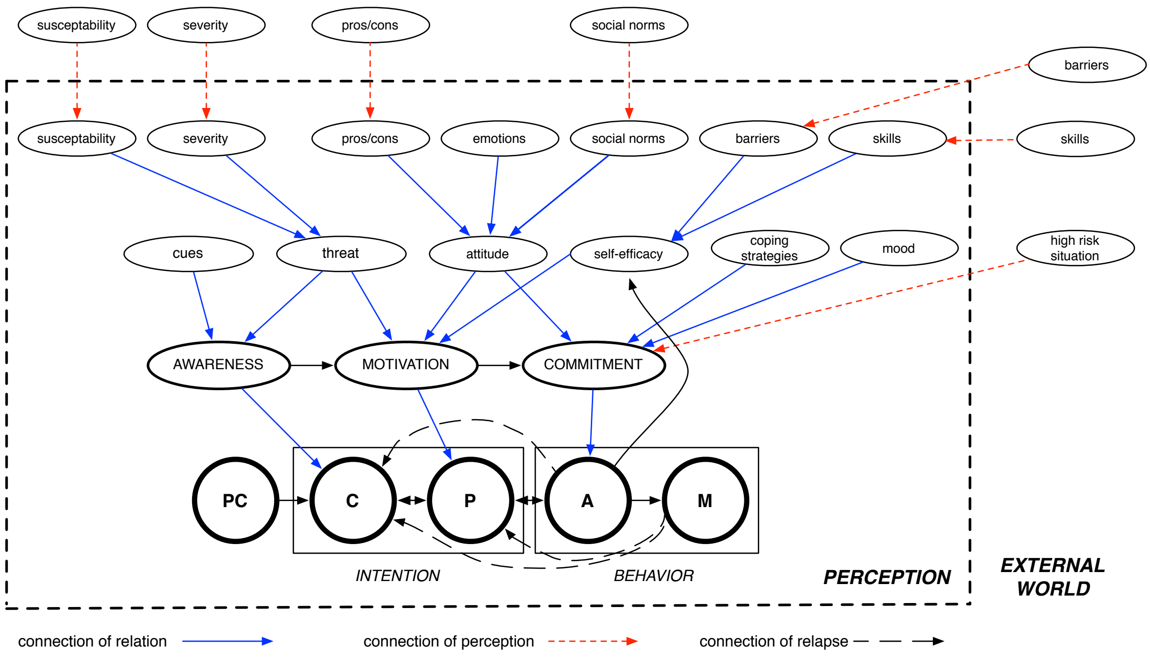


**Figure 2.1:** The integrated model of behavior change COMBI

**The Health Belief Model (HBM)** (Janz and Becker, 1984) includes six determinants of behavior related to perception: *susceptibility*, *severity*, *benefits*, *barriers*, *motivation* and *cues* for action. According to this theory, a combination of perceived susceptibility and perceived severity determine perceived *threat*, and the combination of perceived benefits with perceived *barriers* lead to an evaluation of the course of action taken.

## 2.3.2 Integrated Model: COMBI

It is evident that there is a lot of overlap between the existing theories of behavior change described in the previous subsection, and many of the theories use similar constructs with sometimes different names. The COMBI model —which stands for Computerized Behavior Intervention— is an attempt to integrate these theories into a formal representation that will comprise multiple mechanisms of behavior change and their interaction. Combining models needs to be handled with care because of interaction effects. However, there have been some promising attempts in this direction (Armitage and Conner, 2000; Glanz et al., 2008; Schwarzer, 2008). Model integration allows for more complete and comprehensive explanation of complex human behavior. We integrate model that complement each other with respect to their focus on behavior determinants, taking the overlapping elements as the core of the model. For instance, if one theory explains the attitude formation and the other describes the impact of attitudes on motivation and behavior, then an integration of these two theories will not misrepresent the general picture because these theories are complementary in the sense that one theory refines a concept used in the other.

This integration of the most influential theories of behavior change described in Section 2.3.1 resulted in one complex, but fairly complete model. The model is depicted in Figure 2.1. As can be seen from Figure 2.1, the model differentiates between the internal and external determinants of behavior. External factors (*susceptibility*, *severity, pros/cons, social norms, barriers, skills* and *high risk situation*) are depicted beyond the dotted line. The internal constructs of an individual consist of *cues, threat, attitude, self-efficacy, coping strategies* and *mood*.

**Table 2.1:** The constructs of the model and the related theories

| construct | description | related theory |
|---|---|---|
| susceptibility | likeliness of being affected by the consequences of behavior | HBM |
| severity | severity of the consequences of the behavior | HBM |
| pros/cons | beliefs about the importance of behavior change | TPB,AF,HBM |
| emotions | feelings and cognitive appraisal related to the behavior change | SRT,AF |
| social norms | the influence of culture and environment of a person | TPB,AF |
| barriers | practical obstacles that prevent behavior change | HBM |
| skills | experience and capabilities to overcome barriers | TPB,SCT |
| cues | environmental or physical stimuli | HBM |
| threat | perceived risk of continuing to perform behavior | HBM |
| attitude | mental state involving beliefs, emotions and dispositions | TPB,AF |
| self-efficacy | perceived behavioral control | SCT,TPB,RPM |
| coping strategies | the ability to deal with tempting situations and cues | SRT,RPM |
| mood | temporary state of mind defined by feelings and dispositions | SRT |
| high-risk situations | contexts/environments that influence a person's behavior | RPM |
| awareness | conscious knowledge of one's condition, the threat and the influence of current behavior | TM |
| motivation | incentives to perform goal-directed actions | HBM,TM |
| commitment | (intellectual or emotional) binding to a course of action | TM |

The stages of change from the TM are represented as five circles with the initial letters of the names of the stages at the bottom of Figure 2.1. The *contemplation* and *preparation* stages ('C' and 'P', respectively) are embedded in the 'intention' block and *action* and *maintenance* stages ('A' and 'M', respectively) are embedded in the 'behavior' block. The internal factors that determine the stage of change of an individual consist of 3 layers, showing the causal hierarchy between them. The action stage has also a feedback loop to self-efficacy, in accordance with the SRT.

The bottom layer consists of three constructs, *awareness, motivation* and *commitment*, which directly influence the stage of change of an individual. The constructs in the intermediate layer influence the stage of change indirectly, through connections with the other constructs, just like how the constructs of the top layer influence the constructs of the intermediate layer. The intermediate layer consists of six internal constructs and one external (high risk situation). The determinants in the model have a causal hierarchy between them and the layers are constructed based on their relations with other constructs. An overview of all behavior determinants and the related theories can be found in Table 2.1.

### 2.3.3 Formalization and Simulations

The COMBI model can be used to analyze how the behavioral determinants influence each other and how they can be manipulated to influence behavior. In order to implement the model and reason with it, it is necessary to formalize it. A computational representation of the model can be used to perform simulations in order to check whether the model is able to reproduce known patient behavior. Furthermore, such a model can be used to make hypotheses about the cause of non-adherent behavior. Another advantage of formal models is that they can be used to predict future behavior of the patients. Once the probable causes are identified, predictions about the effects of certain interventions can be made.

The COMBI model has been implemented in the numerical simulation environment Matlab. Figure 2.1 can be viewed as a graph, which can be used to find hypotheses for non-adherent behavior via bottom-up reasoning. The arrows in Figure 2.1 denote causal dependencies found in the theoretical frameworks that form the basis of the model. The exception to this are the arrows between the stages of change: they represent transitions from one stage to another. In the formalization this change of stage occurs when the value of a stage exceeds a certain threshold. For example, if the value of awareness, motivation or commitment is greater than 0.5, a transition to the next relevant stage occurs; if the value drops to a value lower than 0.5, the person relapses to the previous stage. An elaboration on how these thresholds can be determined can be found in Section 8.2. Dependencies between the constructs are expressed by weighted sums, where the weights are determined by the connection strengths of the causal relations between the constructs. For example:

```
Rule 1: Calculation attitude value

If  pros/cons have value V1
and emotions have value V2
and social norms have value V3
and connection strength between pros/cons and attitude has value w1
and connection strength between emotions and attitude has value w2
and connection strength between social norms and attitude has value w3
Then attitude will have value w1 * V1 + w2 * V2 + w3 * V3
```

All values in the model are calculated similarly. In the initial analysis it is assumed that all determinants contribute equally to the construct in the graph that they influence, i.e., to the construct on the receiving end of the arrow. Thus connection weight $\omega$ from construct a to b is initially given as $\omega_{a,b} = \frac{1}{\#incoming\_connections b}$. The formal model can be personalized by adjusting the connection strengths. For example, the behavior of some people is much more affected by mood or the lack of social support than that of others. Furthermore, there is no one-to-one mapping between what takes place in a real world and what one perceives. By increasing or decreasing the connection strengths between the constructs, these personal variations can be accounted for. The relevant connections can be updated when a discrepancy is discovered between observed patient behavior and the predicted behavior from the model.

Figure 2.2 shows a simulation of the behavioral determinants of a person — let's call him Alan — whose process of behavior change changes from stage P to A, i.e., from merely planning to really executing the desired behavior. The constructs mentioned in the titles of the figures are the ones that are derived from the values of the other constructs. The values of the other constructs are used as input. For example, it is assumed that the system can obtain information about the values of susceptibility and severity of the patient. These values serve as input, in this case a value of 4 for susceptibility and 6 for severity (on a scale of 0 to 10). The value of threat is determined similarly to rule 1. Also, an assumption has been made that at t=30, due to an intervention, Alan's perception of his susceptibility to the consequences of his chronic disease increases. The top right figure shows how the change in perceived threat (Alan's realization that he can be negatively affected by the consequences of his old behavior) influences the awareness in turn. It is assumed that the cues change over time. The increased threat causes a heightened state of motivation for Alan, yet it is the increase in his mood that pushes his commitment to a value higher than 0.5, which caused the change of stage from P to A.

## 2.4 Discussion and Conclusion

This work introduces a computational model of behavior change that integrates several theories. It is shown how the model can be used to examine and simulate behavior change. The computational model will be used as the basis for a reasoning mechanism that determines a patient's

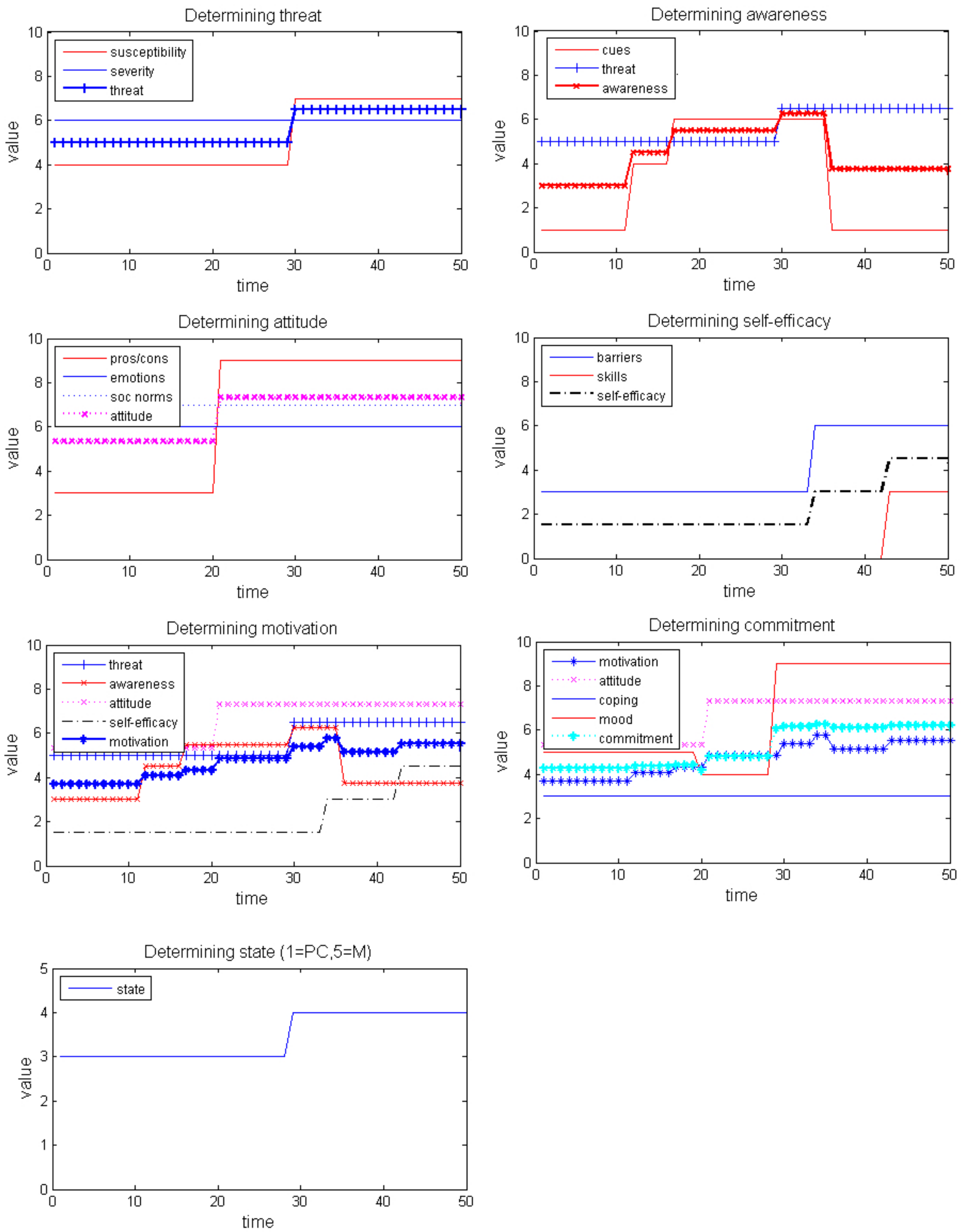


**Figure 2.2:** Modeling behavior change in Matlab

main causes of non-adherence. The details of the reasoning mechanism and of the support system that incorporates the COMBI model are discussed in Chapter 8. Section 8.1 discusses a pilot validation study of the model. Section 8.2 describes in more detail how the model and the simulations can be used to reason about effective types of interventions. Chapter 8 also contains a more elaborate discussion of the implications of this work.

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