Chapter 1

Introduction

In order to develop an effective virtual coaching system for a healthy lifestyle, the person’s mind is an important factor: it is needed to understand his/her mental states and processes. In this context, making sense of mental processes is one important part of the story, but there are two additional dimensions which need to be explored and exploited to take optimal advantage of such systems, especially when the aim is to stimulate physical activity. One of them is understanding a person’s physical environment in which he/she performs his/her routine activities; this will help to understand the context of a person better, so that opportunities can be found to help the person to achieve a healthy lifestyle. Modern technology such as smartphone and wearables provides an opportunity to continuously monitor and capture the context of a person meaningfully and use this information in providing help and support. Another important dimension concerns the social context. Over the years it has been realized that persons with a strong social network are more successful in developing and maintaining a healthy lifestyle (Wing & Jeffery, 1999). An individual’s social environment also contributes to the development of a healthy lifestyle and behavioral choices affecting health. It has been found that a human unintentionally affects the emotions and intentions of other humans, hence a positive emotion or behavior of a person can be strengthened by identifying other people who are already positive towards a certain behavior, and displaying them to the person, for example, via social media.

In this thesis, we investigate computational models of various mental process related to healthy lifestyle in the second part. In Part III, we focus on the modelling of social aspects. Based on this, the fourth part presents a prototype of the system that employs a computational model to predict the physical activity behavior. The work presented in this thesis is applied in two domains: one is in stimulating physical activity behavior and the other is mental health. Specifically, we investigate how the combination of computational models and other artificial intelligence techniques can contribute to mental support systems.

The remainder of this first Chapter is organized as follows. Section 1.1 provides the context, relevance and the elements on which the work in thesis is built. Section 1.2 describes the main research question and the various subquestions. The methodology used in thesis is elucidated in Section 1.3. A detailed outline of the thesis is given in Section 1.4 and overview of different parts of thesis are provided in Section 1.5.
1.1 Motivation

Healthy lifestyle is a goal of many people these days; for example, the lack of physical activity can lead to many kinds of mental and physical health issues. Avoiding stress or consequences of stress is another example, this can also be considered as part of maintaining a healthy lifestyle. Such risks can be reduced, for example, if an adult fulfills the requirement (according to recommendations of the WHO and other public health organizations) of at least 150 minutes of moderate or 75 minutes of vigorous intensity physical activity per week, or a combination of both (Garber et al., 2011; “WHO | Global recommendations on physical activity for health,” 2010). One specific aspect of healthy well-being is avoiding depression. Daily life stress, for example work-related or related to family issues could lead to different kinds of depression. This is often ignored and can have serious consequences as it is famously quoted that “Depression is a silent killer!”. It can lead to various kinds of psychological and social issues. According to one of the latest WHO’s fact sheet (“WHO | Depression,” 2017), around 300 million people are affected by depression and in several cases people may even commit suicide. One of the cost effective ways to prevent depression is to indulge in physical activity behavior. It is suggested that regular exercise can be an option to improve mood and cognitive function and can be considered for the treatment of anxiety and depression (Fox, 1999). Research shows that the baseline physical activity can help prevent mild depression (Mammen & Faulkner, 2013) but on the other hand stress can also have a negative effect on physical activity behavior (Stults-Kolehmainen & Sinha, 2014). Another element could be to seek help in a person’s social network in order to reduce the negative effects of stressful situations. To strengthen such supportive processes, innovative solutions based on modern technology can play an important role.

A solution based on state of the art technology can be a cost-efficient way to address the problems as described, for instance as compared to traditional ways (Bass, 2011; Bosse, Gerritsen, & de Man, 2015). In today’s technological arena, for providing support, a deeper understanding of the mind and the cognitive, affective and social processes it addresses is required. For example, cognitive processes such as self-efficacy, goals, and outcome expectations play an important role in shaping one’s behavior toward a healthy lifestyle. Affective and social processes are also a crucial part of our mental activities and can play an important role in how we function mentally and how we behave.

In this thesis, we develop an understating of mental processes by means of computational models that could provide support and used to influence behavior in order to achieve healthy lifestyle endeavors.
In the following sections, we discuss the background of several aspects that play a role in developing technological solutions for a healthy lifestyle. We start with a discussion of the role of mental processes, than we discuss the social aspects, and finally we describe trends related to wearable technology and self-monitoring.

1.1.1 Mental process

Emotions play an important role in an individual’s mental health, problems in emotion regulation are related with many kinds of clinical conditions (Berking & Wupperman, 2012; Sheppes, Suri, & Gross, 2015). Difficulties in emotion regulation strategies are associated with many kinds of mental health problems, such as depression (Joormann, Siemer, & Gotlib, 2007), anxiety disorder (Cisler, Olatunji, Feldner, & Forsyth, 2010), substance related disorders (Kober & Bolling, 2014). For example, it has been found that recurring events triggering stressful emotions have a bad influence over time on mood and can easily lead to depression when subjects are vulnerable to that (Kessler, 1997; Monroe & Harkness, 2005). Proper handling of negative emotions, for example relating to stress and anxiety help us to perform our daily life activities in an efficient manner, and take care of not becoming vulnerable to stress-related disorders such as depression or PTSD (Brewin, Andrews, & Valentine, 2000). Besides that, emotions also have a social function (Gross, 1998) and play an important role in decision making processes (Loewenstein & Lerner, 2003). It has been found that social phenomena such as social support and perception of it can help people in a social network to overcome stress (Cohen & Wills, 1985) and depression (Frasure-Smith et al., 2000). Because emotions are an important building blocks of a computational model that could capture the understanding of human functioning, two of the emotion phenomena, i.e. emotion regulation and emotion contagion are explored and studied in this thesis in detail. However, also other mental aspects such as self-efficacy are considered very important for a healthy lifestyle such as physical activity behavior.

1.1.2 The Role of Social Networks and Social Media

Social processes play a key role in health behavior. Several aspects of it are relevant for achieving a healthy lifestyle. It has been shown that people become more successful in maintaining a healthy lifestyle when they are integrated to their social context (Wing & Jeffery, 1999; Zimmerman & Connor, 1989). Moreover, the number and strengths of social ties can have positive effects on mental and physical health of a person (Umberson & Karas Montez, 2010). Social networks can be utilized in a number of ways to influence the behavior of individuals e.g. social support, comparison, social control (Thoits, 2011; Umberson & Karas Montez, 2010). As observed in (Kendall, Hartzler, Klasnja, & Pratt, 2011) people have already adopted social media to share health related information; this shows that social net-
works possess a potential in providing support and help in achieving and maintaining a healthy lifestyle; see also (McNeill, Kreuter, & Subramanian, 2006). Furthermore, interventions can be designed to target specific persons in the network. In addition, the social environment enables people to compare their physical activity achievements with their peers or to seek social support from them. Within online social networks based on social media, this is commonly implemented via leader boards with achievements, building on the theory of social comparison (Suls & Wills, 1991).

1.1.2.1 Social phenomena

One of the important aspects of a social network is that it forms a basis for diffusion or contagion processes, for example, for diseases, information, innovations, opinions, emotions, behavior and lifestyle (Coviello et al., 2014). As discussed earlier, a person’s social context plays an essential role in helping the person to develop and maintain a healthy lifestyle. Adopting a healthy lifestyle, for example, includes achieving a fitness level, to have a better mood, avoid social isolation (e.g., among elderly people) or for general well-being. The diffusion of these phenomena does not only occur in a face to face contact but it is also possible in case of an online social network based on social media (Coviello et al., 2014; Kramer, Guillory, & Hancock, 2014). There are a number of mechanisms by which a social network helps to achieve the goal of a healthy lifestyle. Understanding these mechanisms could provide an opportunity to exploit the power of social media and achieve the desired goal of a healthy lifestyle.

One of the ways in which a goal can be achieved is by social comparison. In today’s world of ubiquitous social media it is common for people to compare their abilities, opinions (or other traits) with their friends, colleagues and relatives. Social comparison is an important tool that people often use to perform self-evaluation. For example, in the context of achieving a desired fitness level social comparison provides a sense of competition which some people like to have.

Social support which is also sometimes addressed as peer support is not a new phenomenon, it has been studied extensively how social support can help people in stress and depression (Cobb, 1976). Social media such as Facebook, also are explored to see whether they could be helpful as support systems and whether perceived social support can be related with decreased stress; it turns out that social media indeed help in this regard (Frison & Eggermont, 2015; Nabi, Prestin, & So, 2013).
1.1.2.2 Social Network Interventions

There are many properties of real world social networks that can be exploited to design the interventions that targets the structure of the social network of a person rather than directly influencing the person for behavior change. Valente describes network intervention as “the process of using social network data to accelerate behavior change or improve organizational performance” (Valente, 2012). He describes four categories of network interventions. Individuals are identified in a network to act as leaders of change, based on a voting system or some algorithm (e.g., using centrality); those nodes are identified which can promote behavior change. Segmentation focuses on a group of people to deliver the intervention rather than focusing on an individual. Induction is another type of intervention in which the focus is peer-to-peer interaction: the initial set of people who are identified as being influential are called seeds and then these individuals ask their family and friends to adopt the new behavior. The last category is referred to as alteration; unlike the other three strategies this strategy exploits the network dynamics by utilizing different techniques for example updating vertices and edges of a network or modifying the strengths of connections in a network. Moreover, in (Valente & Pumpuang, 2007) various kinds of strategies are suggested to find the nodes in a network that are important to achieve a behavior change in the group. These strategies focus on persons in the network with larger numbers of connections, as they may affect many others. These kinds of people are usually famous in their respective fields, such as celebrities, opinion leaders or experts in a certain field. In another work (Borgatti, 2006), the network structure is used to find the important players that can help in propagating an innovation throughout the network. In (Valente, 2010, 2012) more can be found about network interventions.

1.1.3 Self-monitoring

Self-monitoring is not a new phenomenon, it is a very important concept in the field of behavioral psychology and is considered a positive determinant of health behavior. People can monitor their health behavior, for example, blood pressure, blood glucose, weight, or sleep patterns by keeping a diary. These days such aspects are often monitored digitally and referred to in the literature as self-tracking. Wearable devices have become an integral part of health intervention programs. The current paradigm for digital health interventions encompasses using one or more wearable sensors, a smart phone, and a solid theoretical foundation which can make sense of the data collected through sensors; based on the data personalized feedback is provided to the person.
1.1.3.1 **Wearables**

The history of pedometers may be traced back to Leonardo da Vinci who put forward the vision of a pedometer for military purposes (Bassett, Mahar, Rowe, & Morrow, 2008). However, the first pedometer that gained popularity dates back to 1965 when the *Manpo-kei* was created, and a daily amount of 10,000 steps was recommended. The name “Manpo-kei” of that pedometer translates into 10,000 steps meter (Hatano, 1993). Since then the sensor technology has evolved much more and these days we have very modern sensors available which record a number of physiological aspects. Nowadays a variety of wearable devices is available, which results in tremendous amount of data. Perhaps, this surging of devices, wearables and smart home appliances, would touch a figure between 19 billion and 40 billion by 2019 (Castillo & Thierer, 2015). As a result new applications, paradigms and techniques are becoming possible which show a great potential for personalized health. For the huge amounts of data generated by these devices, big data analytics can be used to detect early signs of diseases and therefore prove to be an important step towards preventive and personal health systems. This strengthens the idea to empower individuals and to understand their health by reflecting on systems which measure almost every physiological aspect one can think of. It is considered that wearables will play a crucial role, especially in the context of preventive medicine (Swan, 2009).

Initially trackers were simple for one dedicated activity like step count but with growing advancements in the sensor technology more and more sensors are interwoven into a single tracker and hence a single tracker can track a number of body measurements; this trend could still grow with the advent of smart watches and smart glasses. Perhaps smart watches and glasses provides opportunity to develop less obtrusive apps as compared to the apps on smartphones. One of the visions of ambient intelligent systems is to make objects in a person’s environment responsive. Furthermore, the Internet of Things provides a paradigm offering the opportunity to extend the ambient intelligence vision in the sense that these objects in the environment can also communicate through Internet and share information and knowledge (Dohr, Modre-Opsrian, Drobics, Hayn, & Schreier, 2010; Jara, Zamora, & Skarmeta, 2011).

1.1.3.2 **The practice of self-tracking**

These sensors are changing our sense of self which leads to new ideas and terms such as quantified-self, self-tracking, personal effects, personal informatics which are becoming increasingly popular lately. The quantified-self is essentially a practice of tracking one’s own data regarding different aspects of one’s physiological and psychological states. People who are engaged in a quantified-self are interested
to know their diseases or abnormalities better by continuously tracking themselves, others may be interested to self-manage and organize their daily life, monitoring some chronic condition, or exploring new tools or natural curiosity (Swan, 2012). The vision of quantified-self is extended to collect both qualitative and quantitative measures such as data about moods, emotions and other psychological states (Swan, 2012, 2013). The quantified self does not only help to accomplish a certain goal such as physically be more active or being in a good mood, but it also empowers an individual to be more self-aware and conscious about oneself and to know oneself better. Different kinds of hardware (wearables) and software (apps) tools can be employed in the self-tracking process (Choe, Lee, Lee, Pratt, & Kientz, 2014). Furthermore, the self-experimentation is not very sound in terms of scientific methods (Choe et al., 2014).

As described above, people that indulge are interested in self-recording of their personal information encounter many kinds of problems and with the passage of time, if these problems are not addressed the self-motivation could decrease and as a result people stop using the system or device. In order to address some of the problems and to design better personal informatics systems a model was proposed which consists of five stages (Li, Dey, & Forlizzi, 2010). Furthermore, in their next article they emphasize the importance of ubiquitous technology in the self-discovery and whether an individual is required to get motivation in terms of timely feedback by providing them alerts so that he/she can reach their desired goal (Li, Dey, & Forlizzi, 2011).

Generally these systems and ideas may help people to become more aware about their health and lifestyle but the real question arises to what extent they would help people to achieve their goals (if there is a one!), adapt a more healthy lifestyle. As pointed out, some of the drawbacks of these kinds systems include, lack of evidence based scientific theories and required feedback. Maintaining a healthy lifestyle is a difficult task, even in this technological era in which we are surrounded by many types of gadgets that aim at supporting this. If used in innovative ways, phenomena such as the quantified-self hold great potential to steer an objective (concerning healthy lifestyle) in the right direction and let a greater number of people benefit from it. However, this requires the right choices about a way in which technology is embedded in these programs. For example, simply using a wearable device alone will not suffice to achieve behavior change (Patel, Asch, & Volpp, 2015). Sustaining a new behavior for a longer period of time, other important elements are required e.g. evidence-based techniques such as goal setting and timely feedback, a supportive social environment and/or enabling people in a social network to compare their goals/objectives. Therefore, in this thesis we investigate these elements; based on these ingredients the presented system prototype was built.
1.2 Research Questions

In this section the research questions addressed in this thesis are discussed. In order to understand the relationship among the different research questions, and in particular how the main research question relates to other, more refined questions, they are organized in an hierarchical form. This structure also helps the reader who wants to focus on some specific parts of thesis. The following table gives the overview of different research questions addressed by various Chapters and Parts of the thesis.

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The research reported in this thesis addresses how knowing more about processes in the mind and modern ICT-technology together can be exploited to achieve a healthy lifestyle; it can be formulated as the following general research question:

1.2.1 Main Research Question

*How can knowledge and theories from the fields of cognitive, affective, social and neuro sciences, and state of the art technology based on smartphones, social media and wearables technology be combined to support a healthy lifestyle?*

Here a healthy lifestyle can concern both physical and mental health. This general research question poses a global challenge which has many facets. The first part of the question concerns investigation of knowledge and theories from the fields of Cognitive, Affective and Social Sciences, and Cognitive, Affective and Social Neurosciences. In this respect theories related to emotion regulation, generation, contagion and other theories that can be related to health are studied. Based on these theories computational models are developed and evaluated by simulation and/or verification (by mathematical analysis). The evaluation process helps to recognize the vulnerabilities and potential bugs which can lead to erroneous model behavior. These models are developed by keeping in mind the healthy lifestyle domain. However, they are not strictly domain specific and could be applicable to other domains.
as well. The first part of the question is also answered by further exploration of theories of social contagion and validation of those models in the empirical sense. The second part of this research question addresses the more technical aspect which include the implementation of a virtual coaching system. The implementation part addresses how such kind of system can be developed based on modern technologies such as wearable sensors, social sensors, and smartphones, and combining those technical aspects with evidence-based research.

The main research question was broken down into the following more specific questions that will be discussed one by one.

**Research Question 1**

*What domain knowledge and domain theories describe processes that can contribute to adopting a healthy lifestyle and can be used in a computational context?*

Healthy lifestyle is a broad term which involves choices about a more active lifestyle, healthy eating habits, better sleep quality, or overcoming stress and stress-related behavior. These involve various mental and cognitive processes. To understand their role, conceptual and computational models are developed. Different theories are addressed computationally: theories about emotion generation, emotion regulation and mood dynamics are addressed in Research Questions 1.1 and 1.2, and the social cognitive theory and the theory of self-regulation in Research Question 1.3.

**Research Question 1.1**

*How can we computationally model emotion regulation and its interaction with depression? For example, how can emotion regulation help an unstable person to avoid depression and help postpone it for a very unstable person?*

This question is addressed in Part II. In Chapter 2 the presented computational model integrates and captures three affective phenomena: mood dynamics, emotion generation and emotion regulation dynamics. A brief account is provided here discussing how a computational model can be developed that models these processes. Emotion regulation is a process based on a set of regulatory strategies used by persons to down-regulate their negative emotions or to up-regulate their positive emotions (Gross, 1998, 2001). The focus in Chapter 2 is on a cognitive reappraisal (re-interpretation) strategy, that involves changing the way one interprets a stimulus or situation by altering the semantic representation of an emotional stimulus in order to reduce the influence of such a stimulus.

Usually more than one regulation strategy can be applied. For a given situation, the selection of specific regulation strategies may partly depend on personal characteristics but also on the particular situation. Chapter 3 and 4 explore in more detail how selection of different emotion regulation strategies is dependent not only on a
Chapter 1

particular situation but also on other aspects of a personality, such as specific personality characteristics and the sensitivity of the emotion and feeling generation for a certain negative event. It is further analyzed how a process of emotion regulation can help persons maintain a healthy mood in case of the occurrence of stressful events that recur from time to time or even continuously. The model incorporates an earlier model of mood dynamics and a model for the dynamics of emotion generation and regulation incorporating different regulation strategies. Example model simulations are described that illustrate how adequate emotion regulation skills can avoid or delay development of a depression. The presented computational analysis shows how regulation of stressful emotions helps unstable persons to avoid a depression, and to postpone it in very unstable persons.

Research Question 1.2

How can emotion regulation strategies be combined and what is the role of decision making in the context of the choice for specific emotion regulation strategies?

Usually more regulation strategies can be applied. For a given situation, the selection of specific regulation strategies may partly depend on personal characteristics but also on the particular situation. Chapter 3 and 4 explore in more detail how the selection of different emotion regulation strategies is dependent not only on a particular situation but also on other aspects of a personality, such as specific personality characteristics and the sensitivity of the emotion and feeling generation for a certain negative event. Given a stressful situation, humans often apply multiple emotion regulation strategies. One of the motivations behind proposing this type of model is that some of the empirical work, such as (Heiy & Cheavens, 2014), suggests that implementing one strategy may not be enough to get the negative emotion experience lower. For example, in the occurrence of a high intensity emotion a strategy like reappraisal may not immediately help a person to decrease emotion intensity, but a strategy based on situation modification or attentional deployment would help on the spur of the moment, and later on a strategy based on reappraisal could be used to further lower the intensity. An important but often neglected part of the emotion regulation process is a decision making process determining under which circumstances different strategies are selected (Gross, 2015). In chapter 4 we explore the possibility that which strategy is applied depends on a number of factors, such as a person’s context, an internal monitoring and assessment concerning the person’s feeling intensity, and the individual characteristics or preferences. The role of monitoring and assessment, and control mechanisms to recognize a type of negative emotion and to choose for one or more strategies have been explored computationally.
Research Question 1.3
What domain knowledge and domain theories related to behavior change can be used in a computational context?

Humans often live according to habitual behavior. Changing an existing behavior or adapting to a new healthy behavior is not an easy task. There are number of things which are important when considering adapting physical activity behavior, for example. A behavior is affected by various cognitive processes, for example involving beliefs, intentions, goals, impediments. In Chapter 5 health behavior interventions are discussed that may be used in a coaching system. The model and the health behavior interventions are adopted here from previous work (Middelweerd A et al., 2017; Mollee & van der Wal, 2013).

Research Question 2
How to design, develop, and implement a health support system or coaching system that combines strong evidence based on modern technology and theories and findings from social science and social neuroscience? Can social processes help in steering a physical activity program? If so, how can a social network component be part of such a kind of support system?

The above research question is further detailed into the following sub-questions.

Research Question 2.1
What is the role of emotion regulation and contagion in socially affected decision making?

A computational model was developed which integrates emotion-related valuing, in order to analyze the role of emotions in socially affected decision making. The question addresses how decisions can be affected by regulating the emotions involved, and how these emotions are affected by emotion regulation and contagion. The research question is addressed in Chapter 6.

Research Question 2.2
To which extent do different nodes in a network influence an individual in a simulated social network depending on the paths from one node to the other? Is it possible to identify and change specific connections in such a social network in such a manner that it has a positive effect on a targeted individual?

This question is addressed in Chapter 6. An individual’s friends or family network can play an essential role in helping that person to support and maintain a healthy lifestyle. This question addresses how network interventions can be designed based on the knowledge of the social network structure and by embedding this knowledge in an application exploiting this knowledge and recommend people
in a network to have stronger or weaker connections with certain individuals. In this paper, a method for finding effective network interventions to influence specific individuals is proposed. The effect of these interventions was analyzed by simulating the diffusion of emotional values about intentions and goals in a social network. Experiments showed that changing connections closer to the target have a stronger influence than changing connections further from the target node. A comparison of the effect of the proposed network interventions with all possible network interventions under consideration showed that they are among the most optimal possible interventions. Finally, it was shown that nodes with fewer connections are easier to influence. The proposed interventions could form the basis for a support system that focuses on affecting the social interaction between people in an online social network.

Research Question 2.3

*Can a social network contribute to a behavior change towards a healthy lifestyle, and if so what kind of social phenomena play a role?*

This question was addressed in two steps: first by analyzing a large data set collected in a health behavior intervention program. A detailed analysis of a data set of participants in an online physical activity promotion program was conducted. It is important to understand which elements of these physical activity programs are effective or could potentially accelerate the impact of these programs. Research has already revealed that being part of an online social network in a health promotion program is correlated with a higher level of physical activity (Groenewegen, Stoyanov, Deichmann, & Halteren, 2012). The first part of the work tests the hypothesis that whether participants in the community have higher levels of physical activity as compared to not being part of a community. The second part focuses on what kind of social phenomena could have caused it for example it could be social comparison, social support and social contagion. Social processes play a key role in health behavior. Several aspects of it are relevant for achieving a healthy lifestyle. It has been shown that people become more successful in maintaining a healthy lifestyle when they function within their social context (Wing & Jeffery, 1999; Zimmerman & Connor, 1989). For example, if a person is vulnerable to adapt a certain kind of negative behavior, more positive people in that person's friendship network could be shown more prominently. Here we focus on social contagion and try to answer this question whether the increase in physical activity can be explained by social contagion. Social contagion can play a large role in shaping a certain kind of behavior in a social network (Christakis & Fowler, 2013). Our main hypothesis is that higher activity levels for the community can be partially explained by social contagion and partially by the effect of the health promotion program.
Research Question 2.4

*How to design, develop, and implement a support system with the aim to encourage young adults to adapt a healthy behavior towards physical activity?*

- *How can we monitor travel behavior?*
- *What kind of functionality is required in such a system?*
- *What is the role of a computational model in such a system?*

This question and its sub-questions are addressed in Chapter 10 and Chapter 11. Choosing for active transport, such as cycling and walking, can contribute to an increase in activity. Fostering a change in behavior that prefers active transport could start with self-monitoring of travel choices. In chapter 10 it is discussed how we can derive from GPS data the actual travel behavior, as actual behavior is essential to give appropriate feedback (for example to use an active transport mode). Moreover, it is also discussed how to locate people's important places. The biggest challenge is to determine transition periods because of missing or inaccurate GPS readings that occur in real life settings. Virtual coaching is not a new phenomenon. It is referred by different names such as virtual training or smart coaching in the literature. Last two sub-question (b and c) are answered in Chapter 11. In Chapter 11, the lessons learnt during the design, implementation and evaluation of the system are discussed, as well as recommendations for further development and improvement. Monitoring travelling behavior could be one ingredient of such a system. Furthermore, it is also discussed how a computational model can be used in an intelligent coaching system. We believe that these insights will prove helpful to designers and developers of healthy lifestyle interventions, in order to produce effective and appealing coaching systems.

### 1.3 Research Methods

The methodology used includes mainly three methods. First, exploring the relevant literature regarding different domain theories about various mental and social processes which can help to provide support in the context of a healthy lifestyle. The second method involves designing computational models based on these theories which can be simulated and predict relevant behavior. Thirdly, experimental work was done to validate the approaches.

With respect to the second method, modeling mental processes has been done using a Network-Oriented Modeling approach based on networks of temporal-causal relations (Treur, 2016). This network-oriented modeling approach has been successfully applied in a wide variety of problem domains.

This approach was used to address computational modeling of cognitive, affective and social phenomena. This is essentially a two-step process: first a conceptual representation is obtained for which the relevant states and the relationship among
them are identified depending on the problem domain, and next this is transformed into a numerical representation. For example, modeling an emotion generation process would require to identify the concepts such as world state, sensor state, sensory representation state, emotional response preparation state and feeling state. This is called conceptual modeling, the resulting conceptual representation is usually displayed in a graphical form of a temporal-causal network where each state is represented as a vertex and the relationship between two states is formed by an edge. To this basic structure three types of labels are added, resulting in a labeled graph:

- for each connection from state $X$ to state $Y$ a weight $\omega_{X,Y}$ (a number between -1 and 1), for the strength of the impact through this connection; a negative weight is used for suppression
- For each state $Y$ a speed factor $\eta_Y$ (a positive value) and
- For each state $Y$ (a reference to) a combination function $c_Y(\ldots)$ used to aggregate multiple impacts from different states on one state $Y$

A graphical conceptual representation can be converted into a matrix form, as shown in (Treur, 2016, Chapter 2).

The conceptual representation is the basis for a numerical representation of the model. For a numerical representation of the model the states $Y$ get activation values indicated by $Y(t)$: real numbers between 0 and 1 over time points $t$, where the time variable $t$ ranges over the real numbers. More specifically, the conceptual representation of the model can be transformed in a systematic or even automated manner into a numerical representation as follows [20]:

- At each time point $t$ each state $X$ connected to state $Y$ has an impact on $Y$ defined as $\text{impact}_{X,Y}(t) = \omega_{X,Y} X(t)$ where $\omega_{X,Y}$ is the weight of the connection from $X$ to $Y$
- The aggregated impact of multiple states $X_i$ on $Y$ at $t$ is determined using a combination function $c_Y(\ldots)$:

$$\text{aggimpact}_Y(t) = c_Y(\text{impact}_{X_1,Y}(t), \ldots, \text{impact}_{X_k,Y}(t))$$

$$= c_Y(\omega_{X_1,Y} X_1(t), \ldots, \omega_{X_k,Y} X_k(t))$$

where $X_i$ are the states with connections to state $Y$

- The effect of $\text{aggimpact}_Y(t)$ on $Y$ is exerted over time gradually, depending on speed factor $\eta_Y$:

$$Y(t + \Delta t) = Y(t) + \eta_Y [\text{aggimpact}_Y(t) - Y(t)] \Delta t$$

or

$$dY(t)/dt = \eta_Y [\text{aggimpact}_Y(t) - Y(t)]$$

- Thus the following difference and differential equation for $Y$ are obtained:

$$Y(t + \Delta t) = Y(t) + \eta_Y [c_Y(\omega_{X_1,Y} X_1(t), \ldots, \omega_{X_k,Y} X_k(t)) - Y(t)] \Delta t$$

(3)
or \[ \frac{dY(t)}{dt} = \eta_Y \left[ c_Y(\omega_{Y,i}, X_i(t), \ldots, \omega_{Y,k}, X_k(t)) - Y(t) \right] \]

Often for all states for the combination function either the \textit{identity function} \( \text{id}(..) \) or the \textit{advanced logistic sum combination function} \( \text{alogistic}_{\sigma, \tau}(..) \) is used [20]:

\[
c_Y(V) = \text{id}(V) = V
\]

\[
c_Y(V_1, \ldots, V_k) = \text{alogistic}_{\sigma, \tau}(V_1, \ldots, V_k) = \left( \frac{1}{1 + e^{-\sigma(V_1 + \cdots + V_k - \tau) + \tau}} - \frac{1}{1 + e^{-\tau}} \right) \left( 1 + e^{-\tau} \right)
\]

Here \( \sigma \) is a steepness parameter and \( \tau \) a threshold parameter. The advanced logistic sum combination function has the property that activation levels 0 are mapped to 0 and it keeps values below 1. The identity function \( \text{id}(..) \) is often used for the states with a single impact. For all other states the advanced logistic sum combination function is often used.

Simulations are performed by applying a computational simulation method to this numerical model representation, in a dedicated software environment. All the simulations were performed within the MATLAB™ environment.

1.4 Thesis outline

The thesis consists of a combination of journal and conference papers. The following two subsections provide the list of different journal and conference papers. Most of the chapters in this thesis are directly derived from these papers, with the exception of Chapter 6 about exploring various theories regarding behavior change, which hasn’t been published before. For Chapters 2, 3, and 4 the extended journal versions are used.

1.4.1 Journal papers

Following is the list of journal articles listed from most recent to oldest:


* For papers marked with an ‘*’ the following holds: all authors are in alphabetical order and all are regarded as having made an equal contribution to the work.


### 1.4.2 Conference papers


Chapter 1


1.4.3 Personal contribution to each chapter

The table below provides information about the personal contribution of the author for each of the chapters. This first column mentions chapter number and the second column provides a small description regarding the contribution of the author to each chapter.

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Contributions</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>This work is an extension of a conference paper. The extension resulted in a journal paper. It includes a large number of simulations compared to the conference submission. I was involved in the modelling and simulation experiments. Besides, I also performed structuring the paper and take part in the writing. Although I was not the first author I contributed substantially; to present the whole picture I have included it in the thesis.</td>
</tr>
<tr>
<td>3</td>
<td>This chapter is also an extension of a conference paper. My contribution for this paper includes the design of the model and</td>
</tr>
</tbody>
</table>

* For papers marked with an ‘*’ the following holds: all authors are in alphabetical order and all are regarded as having made an equal contribution to the work
executed a number of simulations in order to obtain the parameters values for different example scenarios. I also wrote most parts of this chapter.

<table>
<thead>
<tr>
<th></th>
<th>I did most of the work for this chapter which includes modeling and simulation. I also wrote a substantial part of the chapter.</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>I contributed most of the work in this Chapter.</td>
</tr>
<tr>
<td>6</td>
<td>This is published as a Journal paper, it is an extension of a conference paper. For this paper I was involved in the modelling process. I implemented the model and obtained the parameter values for various scenarios, performed the literature review. In order to explore the different dynamics of the model the extended version of the paper includes more scenarios.</td>
</tr>
<tr>
<td>7</td>
<td>My contribution to this chapter includes implementation of the computational model and performing simulations. I was involved in reviewing the literature for the paper, structuring the paper and wrote different parts of the paper.</td>
</tr>
<tr>
<td>8</td>
<td>I am the main contributor in this conference paper. I carried out most of the experimental work which included data cleaning, filtering and analysis. Besides, I was also involved in the design of the experimental work. I wrote most part of the paper.</td>
</tr>
<tr>
<td>9</td>
<td>This chapter is published as a conference paper, my contribution includes writing different parts and structuring the paper. Although I did not contribute as the first author, to present the whole picture I have included it. Also it complements Chapter 7.</td>
</tr>
<tr>
<td>10</td>
<td>I performed most of the experimentation work which involve cleaning data, applying algorithms and generating and processing of results. I also wrote most of the chapter.</td>
</tr>
<tr>
<td>11</td>
<td>I was mainly involed in the designing and implementing the technical infrastucture of the system. My contribution also includes substantial writing efforts for various parts of the chapter.</td>
</tr>
</tbody>
</table>

1.5 Thesis Overview (different parts of thesis)

The work in this thesis is presented in five parts. The second part includes the study of cognitive and emotion processes. In this part we try to develop a better understanding of the empirical theories about emotion regulation and generation processes by means of computational modelling and simulation. Various computa-
tional models designed and developed that help to study different aspects of emotion regulation process e.g. integration of emotion regulation strategies, the role of decision making in deciding about emotion regulation strategies. The third part consists of studying the role of contagion process and emotion regulation in a social context. The fourth part presents the prototype of the system. Part I consists the introduction chapter and Part V addresses the discussion.

The content of the three main parts is described below in more detail.

**Part II: Modeling Different Aspects of Affective and Cognitive Processes for a Healthy Lifestyle**

In this part various models are designed to study different aspects of emotion regulation, for example how emotion regulation strategies can be combined. It is known from various empirical studies that people often use multiple emotion regulation strategies when downregulating a certain negative feeling. This could help in designing of virtual training systems that could train people to use multiple emotion regulation strategies e.g. to downregulate a high intensity emotion through two or more regulation strategies such as situation modification and reappraisal. In addition, this part also explores how recurring negative events could lead to a negative mood and how can emotion regulation strategies be used to lower the negative effect of those feelings on mood. Other important traits of emotion regulation are monitoring, assessment and decision making. With the help of simulation experiments the role of the monitoring, assessment and decision making are demonstrated, which is used as a basis to select one or more of the three available regulation strategies. One of the important aspect of healthy lifestyle changes includes adapting a healthy behavior or changing an unhealthy behavior. In this respect various theories are studied to observe what kind of cognitive determinants are essential in order to approach a behavior change.

**Part III: Social Contagion and its Role in Health Behavior**

The third part of the thesis deals with the study and exploration of social processes which can contribute in shaping a certain kind of behavior in a social context. Chapter 6 proposes a computational social agent model for the integration of emotion regulation, emotion contagion and decision making in a social context. The model integrates emotion-related valuing, in order to analyze the role of emotions in socially affected decision making. This kind of model could be beneficial in designing ambient applications which involve some kind of support based on an individual’s social network. The second chapter in this part discusses the role of network interventions in achieving a positive behavior with the help of positive people around a person. This is a simulation study which observes the role of contagion (spread of a certain behavior) of nodes in a network. The next two chapters in this
part presents a proof of concept. It is first shown that people in a social network are more inclined towards a positive behavior and second that the positive behavior can be explained by social contagion. An analysis was carried out based on a large data set of participants in an online physical activity promotion program to see whether some social aspect play a role in improving the physical activity level of people who opted to join a network. Different hypothesis were suggested that could have led to increase in physical activity of people who are part of a community. The final chapter in this part is a follow-up work in which we test the hypothesis that higher activity levels for people that participate in an online community can be partially explained by social contagion and partially by the effect of the health promotion program.

Part IV: A Prototype Integrating Modern Technology with Evidence-Based Research.

In the last part of the thesis a prototype of a personalized mHealth Intervention system is presented (Active2Gether) to encourage young adults to increase their physical activity levels. The design and architecture of this paper is presented in detail.

One of the characteristics of such type of systems is to provide personalized and context specific feedback e.g. to use active travelling options. Therefore, a study was conducted to see what are the necessary ingredients to provide this kind of feedback. For example, it is shown how it can be deduced whether people travelled actively or inactively based on individual’s location data (which can be captured through a smartphone) and/or an activity tracker. Hence, this information can be used to record individual’s history and provide necessary feedback.

The prototype of the system has been evaluated in a 12-week study to see the effect of using it in real life. The participants of the study were randomized into three different conditions, namely the A2G-Full condition (tailored coaching messages, self-monitoring, social comparison), A2G-Light condition (self-monitoring, social comparison) and the Fitbit condition (control, self-monitoring). All participants received a Fitbit One activity tracker - that synchronized with all three intervention apps - to monitor their behavior. The result of this evaluation will be reported in a separate paper (Middelweerd A et al., 2017), but is out of the scope of this thesis.

References


