Advertisement and Expectation in Lifestyle Changes: A Computational Model

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Abstract. Inspired by elements from neuroscience and psychological literature, a computational model of forming and changing of behaviours is presented which can be used as the basis of a human-aware assistance system. The presented computational model simulates the dynamics of mental states of a human during formation and change of behaviour. The application domain focuses on sustainable behavior.

Keywords: Computational modeling · Temporal-casual network · Cognitive states · Behaviour change · Decision making

1 Introduction

Human-aware assisting computing systems have been proposed as a promising tool to support behaviour and habit changes toward a more healthy [1], or a more sustainable [2] lifestyle. Such a system is supposed to collect many different types of data from the environment and user about a specific context. It can use the ubiquitous power of mobile systems in combination with cloud computing to collect data all the time, make computational processes on them and deliver interventions at proper time. Doing this, it is possible to equip such a system with understanding of behavioural and mental processes of users. In this way, psychological theories (like [3]) are translated into formal and dynamic models implemented in the system, which can be used for understanding, prediction and anticipation of mental processes and behaviour [4].

There is a growing interest in understanding different ways to change the behaviour of people in different contexts (e.g. [5–7]). Performing a specific action or behaviour in general is due to a series of attitudes and related goals. So it can be argued that changing attitudes and goals can change the behaviours. In addition, behaviour change can sometimes be affected through regulation, or economic instruments [8]. This strategy is applied in the energy market of many countries. In these countries, a dynamic price is offered for the electricity consumers by defining time-based prices for electricity.

Some works also drawn attention to the importance of cultural elements, norms, routines, habits, social networks, fashion and advertising. It should be noticed that strongest degree of behaviour change occurs when different strategies are combined [9]. In this work, the focus is mostly on the combination of two

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strategies: the economical motivations in combination with the advertisements that promise people benefits of these motivations.

The expectancy theory of motivation, introduced by Victor H. Vroom, says that a person will behave in a specific way because he intends to select that behaviour over others due to what he expects the result of that selected behaviour will be [10]. In the other words, the intention or motivation of the behaviour selection is determined by the desirability of the expected outcomes. According to [11], Vroom asserts that "intensity of work effort depends on the perception that an individual's effort will result in a desired outcome".

Expectation confirmation theory [3] is a cognitive theory which seeks to explain post-adaptation satisfaction as a function of expectation and disconfirmation of beliefs. Although this theory originally appeared in psychology and marketing literature, it has been adopted in several other fields. This theory involves four primary constructs: expectations, perceived performance, disconfirmation of beliefs, and satisfaction. In our model, we took inspiration from such theories. However, there are also some small differences. For example, our model also contains expectation but the pre-consumption expectation is replaced by post-consumption expectations (the same is done in [12]).

In this work, a computational model is proposed for understanding the role of economical motivations and advertisements on changing behaviours toward a more sustainable lifestyle. The model is at the cognitive level, which abstracts from too specific neurological details, but still reflects the underlying neurological concepts.

The rest of this paper is organized as follows: the next section is a review on the main concepts of temporal-causal modeling approach. In Sect. 3, the proposed model is explained. In Sect. 4, the results of some experimental simulations are depicted and discussed. Section 5 is a mathematical analysis on the results of the simulations, which validate their accuracy. Finally, the conclusion will come.

2 Temporal-Causal Modeling

The proposed model in this work was designed as a temporal-causal network model based on the Network-Oriented Modeling approach described in [13]. The dynamic perspective takes the form of an added continuous time dimension. This time dimension enables causal relations, where timing and combination of causal effects can be modeled in detail.

This approach is used in many different domains, for example: habit learning [14], contagion and network change in social networks [15], emotion regulation [16] and the role of social support on mood [17]. For more information about this Network-Oriented Modeling approach, see [18].

Based on this approach, a model can be designed at the conceptual level. Figure 1 shows the graphical representation of a part of model. In a graphical conceptual representation, states are represented by nodes, and their connections are represented by arrows which connect the nodes.

A complete model has some labels in addition to its nodes and arrows, representing some more detailed information:

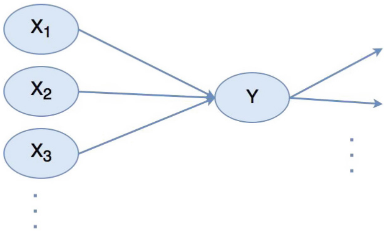

Fig. 1. The graphical representation of a part of a model

- The weight of a connection from a state X to a state Y, in the range of [−1, 1], denoted by $\omega_{X,Y}$
- A speed factor ηY for each state, in the range of [0, 1]
- The type of combination function cY(...) for each state Y shows how to aggregate the multiple causal impacts on that state.

The following rules show how such a model works from a numerical perspective:

- The variable t indicates the time and varies over the non-negative real numbers
- At any time point, any state of the model has a real value, X(t), in the range of [0, 1]. (0 means that state is deactivated and 1 means it is fully activated)
- If there is a connection from state X to state y, the impact of X to Y at time t is equal to: $impact_{X,Y} = \omega_{X,Y}$ X(t)
- The aggregated impact of multiple states (X1, X2, X3,..) connected to state Y at time t is calculated using the combination function of node Y:

$$\begin{aligned} \mathbf{aggimpact}_Y(\mathbf{t}) &= \mathbf{c}_Y(\mathbf{impact}_{X1,Y}, \mathbf{impact}_{X2,Y}, \mathbf{impact}_{X3,Y},) \\ &= \mathbf{c}_Y(\omega_{X1,Y} X_1(t), \omega_{X2,Y} X_2(t), \omega_{X3,Y} X_3(t),) \end{aligned} \tag{1}$$

- The effect of aggimpactY(t) on state Y is exerted on this state gradually; its speed of change is dependent on the speed factor η_Y of Y:

$$Y(t + \Delta t) = Y(t) + \eta_Y[\mathbf{aggimpact}_Y(t)Y(t)]t \tag{2}$$

For each state the speed factor represents how fast its value is changing in response to the casual impacts. States with fleeting behaviour (like emotional states) have a high value for speed factor. Thus the following equations show the difference equation for state Y:

$$Y(t+\Delta t) = Y(t) + \eta_Y[\mathbf{c}_Y(\omega_{X1,Y} X1(t), \omega_{X2,Y} X2(t), \omega_{X3,Y} X3(t),)Y(t)]\Delta t \tag{3}$$

The above numerical representations can be used for mathematical and computational analysis and simulations.

3 The Computational Model

The proposed computational model is based on the literature and the concepts introduced in Introduction. This model was designed at the conceptual cognitive level, which is based on the neurological theories but abstracts from low level details. It uses temporal relations between different cognitive states to describe the mechanisms for action selection and behaviour changes.

3.1 Graphical Representation of the Model

Figure 2 shows the conceptual representation of the causal model of cognitive states related to two long-term goals. For the sake of presentation, it is assumed that there are just one short-term goal and one behaviour paired to each long-term goal. In this figure, the states related to one long-term goal are in the same color. As depicted, long-term goals lead to short term goals. In general, there is a many-to-many relation between long-term goals and short-term goals.

In the next step, a short-term goal affects the intention for a specific behaviour, which in turn leads to that behaviour. In this work, it is assumed that there is a competition between (assumed at least partly mutually excluding) behaviours: the intentions of different behaviours have negative relations to each other. Thus, activation of one behaviour has a negative effect on the others, which models a winner-takes-it-all principle. The other state which affects the intention is the expectation about the results of a behaviour. If the person expects good results from performing a behaviour, then he or she has a stronger intention to do it. On the other hand, if he or she is dissatisfied about that behavior, the intention will become down.

The expectation about the results of a behaviour is affected both by the advertisements about that behaviour and by the observation of real results. In the proposed model, in the cases that a person does not have any experience in performing a behaviour, this expectation is mostly based on the advertisements. By performing the behaviour for a while and increasing the confidence about the observed real results, the expectations would be mostly based on these observations. It should be noticed that unrealistic expectations (a big difference between promised results in the advertisements and real observed results) leads to dissatisfaction. A short definition of each state and its role is explained in Table 1.

In this paper, some assumptions are made for the sake of simplicity in presentation. These are some assumption that applied here but do not limit the model and the model can work beyond them:

Assumption 1: There are just two long-term goals available, which are not fully antithetical. For instance, one goal can be living environmental friendly; and another one living with more comfort.

Assumption 2: There are just two short-term goals, which are aligned with long-term goals. Instances for short term goals can be: saving money by not

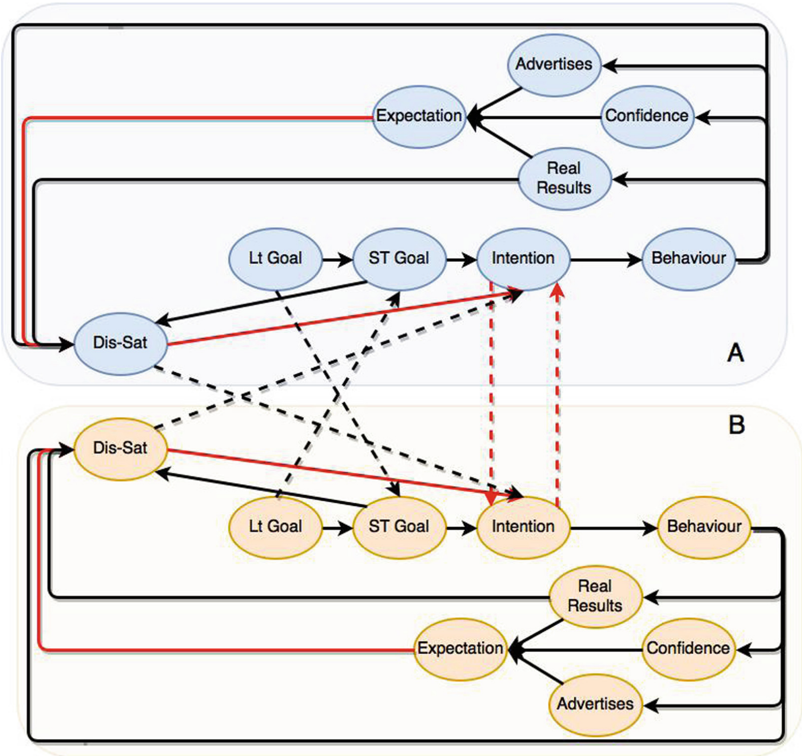

Fig. 2. The graphical conceptual representation of proposed model. This representation contains just two goal-behaviour pairs and their relevant states. In this figure, ovals represent the nodes and arrows show the connections. The blue arrows have positive weight and red ones a negative one. Dashed arrows are the connections between the states of two goals. For a brief description about each node, please look at Table 1. (Color figure online)

using high power electrical devices during peak hours, and being completely comfortable by using devices when they are needed.

Assumption 3: There are just two behaviours, behaviour 1 and 2 that are respectively more related long-term goal 1 and 2. As instances for possible behaviours: using high power electrical devices during of peak hours, and using electrical devices when they are needed.

As it can be seen, goals and behaviours are not fully antithetical, while there are obvious differences. These conditions aim at simplifying the presentation of the model and the corresponding simulation results. And as explained, the model is not limited to these conditions.

Table 1. Definition of states of conceptual model

State name	Definition
Lt Goal	This stated indicates a long-term goal of the person, which can be related to a few short-term goals. Examples: living environmentally friendly; living comfortable
St Goal	A short-term goal of the person which can be aligned with a few long term goals and can lead to a few behaviours in different contexts. Examples: saving money through using high power devices during off-peak hours
Intention	This state shows the intention of performing a specific behaviour
Behaviour	This state indicates a behaviour in a specific context. It is assumed that in each time point, just one behaviour can be activated. Examples: Do not using high power devices during peak hours
Real Result	The observed real results of a behaviour after doing it. Example: the amount of money saving on the electricity bill due to the using high power devices during off-peak hours
Confidence	The confidence of the person about his expectation. If he or she performs a behaviour for a longer time, he or she would be more confident about his/her expectation
Advertisement	The promised results for doing a behaviour via advertisements
Expectation	The expectations about the results of performing a behaviour in a specific context. This expectation can be form due to the personal observations of the real results, or due to the advertisements
Dissatisfaction	Dissatisfaction in performing an action can happen due to a big difference between the observed result and expectations

3.2 Numerical Representations and Parameters

As explained in Sect. 3.1, to be able to use a temporal-causal network model in simulations, some elements need to be known: the weight of connections, speed factors and the type of combination function for each state, and the parameters (if any) of these combination functions. However, reading this subsection is not necessary for understanding the model and simulation results.

Connection Weights. The following table shows the connection weights for the connections of one goal and its related states.

It should be noticed that the connection weights between the states for the other goal are the same. The only exceptions are the weights of the connections from st-goal to intention, and from behaviour to real result which both are 0.2 in the second pair of goal-behaviour.

Table 2. Weight of connections in the proposed model. The graphical representation of model is presented in Fig. 2

	Behaviour	Intention	St goal	Dissat	Real result	Confidence	Expectation
Behaviour				1	0.5	1	
Intention	1						
St goal		0.35		0.05			
Lt goal			0.45				
Dissat		−1					
Real result				−0.5			1
Confidence						0.9	1
Ads							1
Expectation		0.3		0.4			

In addition to the weights shown in Table 2, there are some connections which connect the states of two parts of the model (from one goal-behaviour pair to the other one). The weights of these connections are these: $\omega_{ltGoal,st-goal} = 0.05, \omega_{intention,intention} = -0.35, \omega_{Dissatisfaction,intention} = 0.05$

Combination Functions and Parameters. In this work, states which are not affected by other states, are external states (advertisement and long term goal). So, the value of these states are not dependent on the model and are used to define different scenarios (Sect. 4.2). As explained, before performing a behaviour, the expectation of the person about the results is mostly based on the advertisements, and by performing the behaviour, the expectation would gradually become based on the real observations. To have such dynamics, for the expectation, the following combination function is used, expressing that the aggregated impact is a weighted average of the impacts by advertising and real result, where the weights are Conf and 1-Conf:

$$CF(Ads, Real-result, Conf) = Conf * Real-result + (1 - Conf) * Ads \quad (4)$$

For the Real result state, an identity combination function id(.) is used. The output of this function is equal to its input. For the other states of the model, a simple logistic function is used:

$$\mathbf{alogistic}_{\sigma,\tau}(V1, V2, V3 \cdots) = 1/(1 + exp(-\sigma(V1 + V2 + V3 \cdots - \tau))) \quad (5)$$

As it is clear, this function has two parameters (steepness σ, and threshold τ) which can be defined for each states. The following Table 3 shows the values of σ and τ for the states with logistic function, in addition to the speed factor of all states.

4 Simulation Experiments

The human-aware network model presented above was used to make a comparison between what the model predicts and what actually holds in the real world (based on the literature [3,10]). In the first subsection, some of hypotheses are explained. In Subsect. 4.2 three different scenarios and their corresponding results are discussed. Finally, the defined hypotheses are analysed using the results of simulations.

4.1 Hypotheses

Some of the expected behaviours of the model can be formulated as follows:

- **Hypothesis 1.** Due to conflicts between the different behaviours, at any time point, just one behaviour can be activated.
- **Hypothesis 2.** In the case that a behaviour is activated and the person is not dissatisfied with its result and there is no external motivation to stop it, its activation should continue.
- **Hypothesis 3.** External motivations (like advertisements via television or social networks) can motivate a person to change the behaviour via increasing the expectation about its corresponding results.
- **Hypothesis 4.** After performing an action (due to advertisements) for a while, if the observed results are much lower than the promises, the person will become dissatisfied about it, and stop that behaviour.

4.2 Scenarios and Results

To have more realistic scenarios, "domestic energy usage" was selected as the application domain of simulated scenarios. By the growth of electricity generation by non-schedulable sources, matching supply and demand becomes a more important challenge in this context. An often used way to encourage the costumers to shift their loads to off-peak hours is time-based pricing. In this strategy, the price of electricity during the peak hours (when demand is high and supply is low) is higher than off-peak hours. In addition to such an economical motivations, it is important to inform the costumers about these economical advantages. In the defined scenarios, the role of advertisements about these commercial advantages is analysed.

To study the matching of simulation results and hypothesis, the model was used with two long-term goals:

- Long term goal 1: living environmentally friendly
- Long term goal 2: living with comfort

Table 3. Parameters of the model. Speed factors and parameters of logistic functions

<table>
<tr><th></th><th>Behave 1</th><th>Behave 2</th><th>Intention 1& 2</th><th>St-goal 1& 2</th><th>Dissat 1</th><th>Dissat 2</th><th>Real result 1 & 2</th><th>Confidence 1& 2</th><th>Expect 1& 2</th></tr>
<tr><td>Speed factor</td><td>0.5</td><td>0.5</td><td>0.3</td><td>0.2</td><td>0.5</td><td>0.5</td><td>0.5</td><td>0.025</td><td>0.2</td></tr>
<tr><td>Steepness σ</td><td>50</td><td>50</td><td>50</td><td>30</td><td>50</td><td>50</td><td colspan="3" rowspan="2">The combination function of these states is not Logistic</td></tr>
<tr><td>Threshold τ</td><td>0.4</td><td>0.6</td><td>0.1</td><td>0.3</td><td>1.05</td><td>1.15</td></tr>
</table>

Each of them has one short-term goal:

- Short term goal 1: saving money by using the high power electrical devices in off peak hours (when the price is lower)
- Short term goal 2: having comfort by using the devices whenever they are needed

And each short time goal leads to a different behaviour:

- Behaviour 1: using the high power electrical devices in off peak hours
- Behaviour 2: using the electrical devices whenever they are needed

In the defined scenarios both goals are available in parallel. Only the availability of advertisements and the promising results in the advertisements affect change in the scenarios. Moreover, the result of first behaviour is higher (0.5) than the second one (0.2). In all scenarios, it is assumed that the person in the past just always lived based on behaviour2 (using the electrical devices whenever they are needed) and there was no dissatisfaction.

In the **first scenario**, a very low advertisement (0.1) is assumed for living environmentally friendly. Figure 2 shows the results:

As it can be seen in Fig. 3, in the first scenario the person will continue doing behaviour 2. And due to the lack of external motivations, the person will not switch to the behaviour1.

In the **second scenario**, some advertisements inform the person about the advantages of behaviour1. However, the promised result about the behaviour 2 is much higher than actual result (1.0 vs. 0.5) of this behaviour. Figure 4 shows the results; the changed behaviour does not persist:

In the **third scenario**, some advertisements inform the person about the advantages of behaviour1, and the promised results are not too different the real

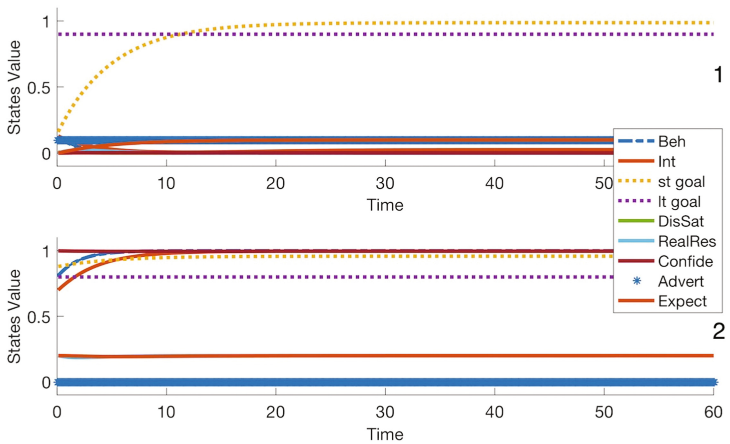

Fig. 3. The results of the 1st scenario. Upper graph is related to the Behaviour 1. Lower graph is related to Behaviour 2.

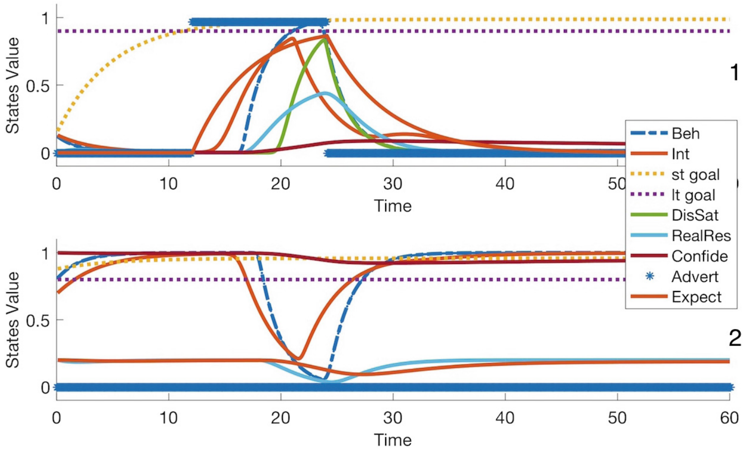

Fig. 4. Results of the 2nd scenario. Upper graph is related to the Behaviour 1. Lower graph is related to Behaviour 2.

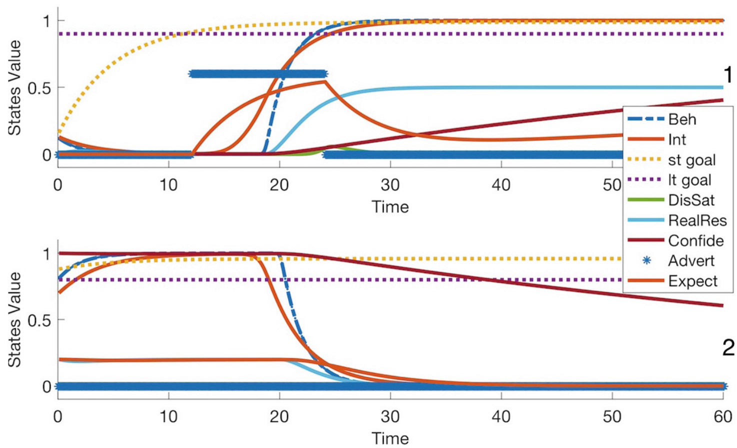

Fig. 5. Results of the 2nd scenario. Upper graph is related to the Behaviour 1. Lower graph is related to Behaviour 2.

results (0.6 vs. 0.5). Figure 5 shows the results of this simulation; the changed behavior persists.

4.3 Explanation

In Sect. 4.1, four hypothesis are defined based on the literature. In this subsection, these hypotheses are analyzed based on the results of the scenarios in Sect. 4.2:

- **Hypothesis 1.** By looking at the Figs. 3, 4 and 5, it can be seen that never two behaviours are activated together. By activation of a behaviour, the other one become deactivated simultaneously.
- **Hypothesis 2.** This hypothesis says that without any stimulant, no changes will happen in the behaviours. This hypothesis can be analysed in the first scenario, which there is no external motivation. As it can be seen in Fig. 2, in this case the person will not change behaviour in this specific context.
- **Hypothesis 3.** The third hypothesis talks about the necessity of motivations in changing the behaviours. This hypothesis can be analysed in scenarios 2 and 3, where there is an external motivation.
  In both cases, the agent switch from behavior 2 to behaviour 1 after advertisements.
- **Hypothesis 4.** The last hypothesis states that a big difference between expectations about the results and the real results of a behaviour leads to dissatisfaction. This hypothesis can be analysed in scenario 3, where the person changes behaviour due to the very high expectation about the results of behaviour1. This high expectation is built due to the unrealistic advertisements. As it can be seen in Fig. 4, after performing behaviour 1 for a while, observing its real results and comparing it with expectations creates dissatisfaction, which stops this behaviour.

5 Conclusion

In this paper, a computational model was proposed to simulate the dynamics of cognitive states of a person during a behaviour change. The presented model can be used as the basis of a human-aware smart support system. Such a system can be used for better understanding the cognitive dynamics of a person while he or she is changing (or persisting on) his or her behaviour.

In the experimental simulations, it was studied how economical motivations in combination with advertisements can tempt a person to change behaviour. However, it is shown that unrealistic advertisements can make dissatisfaction. Subsequently, the person may change his mind again, and return to his old behaviour.

The results of the simulations match to the expectations. The model was verified via a mathematical analysis which had a positive outcome.

As mentioned, the probability of behaviour change toward a better lifestyle is higher, when different strategies are combined together. Therefore, in future work, the role of other elements (like social networks) will also be considered in the model.

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