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Modeling multi-level mechanisms of environmental attitudes and behaviours: The example of carsharing in Berlin

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ABSTRACT

Psychological research practices are often prone to individualistic biases, emphasizing individual-level mechanisms of attitudes, behaviour, and persuasion, while neglecting the dynamics of communication in social networks. We illustrate with our InnoMind simulation model how agent-based modeling as a research method can account for the multi-level interactions between information processing in individual brains and flows of information in societies. InnoMind is based on theories of emotional cognition from cognitive science, theories of attitudes and persuasion from social psychology, and theories of social networks from sociology. In a case study, we show how the model can be used to address practical research questions in environmental psychology: We describe computer simulations with InnoMind that can serve as ex-ante evaluations of suitable campaign strategies for the promotion of carsharing as an innovative means of sustainable urban transportation. We discuss how empirical/experimental versus computational/theoretical research strategies in environmental psychology can and should be regarded as mutually informative.

An important topic of environmental psychology is the role of human decision-making and behaviour in sustainable development. Often, the goal of environmental psychologists is to come up with scientifically based strategies to change people's attitudes and behaviours in desirable ways – for example, to persuade commuters to use public transport instead of cars. A major limitation to this endeavour stems from the individualistic bias of psychology as a discipline: Psychological theories and research practices tend to neglect the fact that individual perceptions, decisions, and actions are always embedded in a larger social system (Oishi, Kesbir, & Snyder, 2009; Scholl, 2007). This individualistic bias sometimes leads to underestimating the complexity involved in changing people's attitudes and behaviours, as information processing in individual brains interacts with social dynamics and flows of information at the level of society (e.g., Homer-Dixon, Leader Maynard, Mildenberger, Milkoreit, Mock, Quilley et al., 2013). Of course, many sociologists – and, more recently, physicists and computer scientists – have studied the social dynamics of changing attitudes and behaviours (e.g., Friedkin & Johnson, 1999; Pentland, 2014; Rogers, 2003), but they in turn tend to neglect the individual cognitive and emotional mechanisms underlying such changes. For developing effective strategies for attitude and behaviour change in support of a more sustainable society, environmental psychologists need tools that integrate knowledge about the relevant mechanisms across individual and social levels of explanation and across the scientific disciplines.

In this paper, we use our agent-based model *InnoMind* (for Innovation Diffusion by Changing Minds) (Wolf, Schröder, Neumann, & de Haan, 2015) as an example to demonstrate the suitability of social simulation as a method to analyze the multi-level mechanisms underlying environmental behaviour. The idea behind social simulation is to model artificial societies with computer programs that represent individual actors and their decision rationales as well as the communications among those actors (for review, see Helbing & Balietti, 2012; Squazzoni, Jager, & Edmonds, 2014; Epstein & Axtell, 1996). The InnoMind model was developed as a decision-support tool for policy-makers and other stakeholders in the context of the dissemination of electric cars (Wolf et al., 2015); however, we will show in the present paper that it is a generic multi-level model of attitudinal dynamics in a society that can be easily adapted to other research questions besides electric cars. InnoMind is rigorously based on psychological and

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sociological theory and informed by empirical data gained from classical social science research such as experiments and surveys. In the next section, we will describe how it works. Then, we provide the design of a media campaign purported to promote carsharing in cities as an example case study that illustrates the kinds of research questions that can be answered with theoretically plausible and empirically grounded simulation models.

1. The InnoMind model

Here, we provide a summary description of the agent-based model *InnoMind*, whose development as well as a previous application simulating dissemination strategies for electric cars are described elsewhere (Wolf et al., 2015). We proceed here by levels of explanation. First, we illustrate how individual agents' attitudes are represented as constraint-satisfaction networks (Thagard, 2000; 2006). Second, we explain how attitude change as a result of agent-to-agent communication is modeled as a change in the topological structure of those networks. Third, we describe how InnoMind models flows of communication in society as an artificial social network implementing the principle of homophily established in sociology (McPherson, Smith-Lovin, & Cook, 2001). In each of these three subsections, we first describe the relevant theoretical background (i.e., attitudes, persuasion, social networks), then the computational implementation of the theory in InnoMind, and finally empirical strategies for connecting InnoMind simulations to psychological and sociological reality (cf. Sobkowicz, 2009). We keep the present description verbal to convey the basic ideas as simply as possible, but readers interested in the more technical details will find information on equations and parameters in the Appendix and in Wolf et al. (2015).[1]

1.1. *The individual level: modeling agents' attitudes*

InnoMind can be used to simulate attitude changes that result from the complex interactions of multiple agents. At the core of InnoMind is thus a model of individual agents' attitudes, which is based on relevant psychological theory and can be grounded in empirical data.

1.1.1. *Theoretical background*

From the perspective of psychology, attitudes are evaluative dispositions of individuals towards certain mentally represented objects, issues, or people (Fishbein & Ajzen, 2010; Petty & Briñol, 2015). Attitudes have cognitive, affective and conative aspects (Ajzen, 1989); i.e., the beliefs, feelings, and action tendencies, respectively, associated with an object. Attitudes can vary along a spectrum from more implicit, associative, and automatic to more explicit, propositional, and reflective evaluations (Fazio & Towles-Schwenn, 1999; Gawronski & Bodenhausen, 2007). Similarly, attitudes influence people's behaviours through a variety of mechanisms from more automatic ones that operate outside people's awareness (Bargh & Chartrand, 1999) to more controlled ones that operate through people's deliberate intentions (Fishbein & Ajzen, 2010).

From the perspective of cognitive-affective neuroscience, the different aspects of attitudes (beliefs, affect, implicit vs. explicit evaluations etc.) should, however, not be understood as separate categories, but rather as dynamically interacting components (Cunningham & Zelazo, 2007; Duncan & Barrett, 2007; Schröder, Stewart, & Thagard, 2014). The attitude-behaviour relationship can be described as a parallel constraint-satisfaction process, where many different – more or less conscious – mental representations such as beliefs, emotions, and intentions compete with each other interactively in the brain for control over behaviour (Ehret, Monroe, & Read, 2015; Monroe & Read, 2008; Orr, Thrush, & Plaut, 2013; Schröder et al., 2014; Schröder & Thagard, 2014). Based on Thagard's (2006) computational HOTCO model of emotional cognition (for HOT COgnition), InnoMind uses artificial neural networks to model individual attitudes as parallel constraint satisfaction.

1.1.2. *Computational implementation*

The HOTCO networks representing InnoMind agents are localist neural networks, signifying that their nodes represent single concepts, while the links between the nodes represent relationships between the concepts. At any given point in time, the nodes exhibit varying degrees of activation, which roughly corresponds to the current cognitive salience of the concepts represented by the nodes. There are two possible types of relationship in a localist network. Concepts can be mutually compatible (e.g., environmental friendliness and bikes), which is modeled by the spread of activation from one node to a connected node. Concepts can also be incompatible (e.g, environmental friendliness and old diesel cars), which is modeled by inhibition of the activation of connected nodes. In a localist network, which may represent many different concepts as well as compatibility and incompatibility relationships between them, updating the activation of nodes as a function of all their connections in several iterations often yields a stable network pattern, where some nodes are activated and some are inhibited. This iterated network-stabilization process is an efficient solution to parallel-constraint-satisfaction problems and was shown empirically to predict many instances of human decision-making (Glöckner & Betsch, 2008; Glöckner, Hilbig, & Jekel, 2014; McClelland, Mirman, Bolger, & Khaitan, 2014; Thagard, 2000).

Localist networks like HOTCO are not biologically realistic, as in the brain concepts do not correspond to single neurons, but rather to patterns of activity in large populations of neurons. However, it could be shown that the kinds of networks used to model InnoMind agents translate readily into more realistic neurocomputational models; hence, they can be regarded as viable approximations to the computations of real brains (Schröder & Thagard, 2014; Thagard & Aubie, 2008). Most importantly, HOTCO networks appropriately model the cognition-emotion interactions that underlie attitudes, decisions, and behaviours (Simon, Stenstrom, & Read, 2015; Thagard, 2006).

Fig. 1(A) shows the generic architecture of an InnoMind agent. There are two layers of nodes that represent the agent's perceived needs[2] and action options. A special valence node that is connected to the first layer of nodes (i.e. needs) is used to model emotional influences on the agent's attitudes (cf. Petty & Briñol, 2015). For example, people might have a need to see themselves as environmentally friendly and attach positive emotions to this need. They might also have a need to avoid stress, to which they attach negative emotions. Cognitive beliefs are modeled in InnoMind agents by excitatory and inhibitory links between need and action nodes. For example, if a person thinks that using public transport would be conducive to their need of environmental friendliness, InnoMind models this belief as an excitatory link between a need node that represents environmental friendliness and action node that represents the use of public transport. “Excitatory link” means that there is a spread of activation between the nodes; i.e., activation of the node representing environmental friendliness will spread to the node representing the use of public transport (and vice versa). Relatedly, a person might think that driving a car would contradict their need of environmental friendliness. InnoMind would model this belief as an inhibitory link between the two respective nodes; i.e., activation of the environmental friendliness node would suppress the activation of the car-driving node.

Once all the needs and actions, along with their respective