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With a little help from my friends: A computational model for the role of social support in mood regulation

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Abstract

The growing interest in the role of social support in mental and physical health has led to the development of several intelligent systems that aim to use social mechanisms to simulate healthy behaviour. In this paper a computational model of a human agent is presented which describes the effect of social support on mood. According to the literature, social support can either refer to the social resources that individuals perceive to be available or to the support that is actually provided in problematic situations. The proposed model distinguishes between both roles of social support. The role of social network characteristics has been taken into account, as an individual can perceive or receive social support through his/her social network. In addition, the number of connections (friends), strength of ties (relationships), social isolation and social integration have been studied. Simulation experiments have been done to analyze the effect of the different types of support in different scenarios and also to analyze the role of various social network characteristics on the mood level. It is shown that support can help to reduce the induced stress and thus can contribute to healthy mood regulation and prevention of depression. The presented model provides a basis for an intelligent support system for people with mood regulation problems that take the social network of people into account.

Keywords: Social support; Stress buffering; Human ambient agent; Perceived support; Social network characteristics

1. Introduction

In the life of people, now and then stressful events take place. For some people, these events ultimately lead to mental problems. Support of others can alleviate the effect of stress on an individual's psychological situation (Aneshensel & Frerichs, 1982). Social support plays a beneficial role in the mental wellbeing of humans through its impact on emotions, cognitions and behaviours (Cohen, 1988), and through this it even contributes to good physical health. Effective social support can be provided through adequate social networks. A person who is well integrated in social networks is less vulnerable to stress or depression.

Social support is often used in a broad sense, referring to any process through which social relationships might promote health and wellbeing. It is still a scientific question by which mechanism the social support actually influences people's mental health. The psychological literature on social support and health includes multiple points of view, pathways and effects. Some literature (Grav, Hellzèn, Romild, & Stordal, 2012) describes that the subjective perception that support would be available if needed may reduce and prevent depression and unnecessary suffering. In other theories (Cohen & Wills, 1985; House & Kahn, 1985), structural and functional support measures are distinguished. Structural supports refer to measures

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describing the existence and types of relationships (e.g. marital status, number of relationships). Functional support assesses whether interpersonal relationships serve particular functions (e.g. provide affection, feeling of belongings). According to Glanz, Lewis, and Rimer (2002), social support is one of the important functions of the web of social relationship around an individual. Moreover, people may provide social support either in the form of emotional or tangible support. In (House, 1981), it is explained that social support is associated with how networking helps people to cope with stressful events and how it can enhance psychological wellbeing. Social isolation and low level of social support have been shown to be associated with medical illness (e.g. depression).

In this paper, we first use an existing model for mood regulation (Both, Hoogendoor, Klein, & Treur, 2008) to describe the different types of effect of social support on mood, which is also described in Abro, Klein, and Tabatabaei (2015). This paper extends (Abro et al., 2015) by transforming the individual model into a multi-agent model. We perform a number of simulation experiments in the context of small social network. The model involves different cognitive states of a human being that are considered as important for mood and appraisal of the situations. The model is first used to investigate the difference in effect of perceived (expected) and received (actual) support Cohen and Wills (1985) and House (1981) from the social environment during a period of stress on an individual person. Second, a multi-agent simulation is performed to analyze the effect of support in a group of persons. In this analysis, the characteristics of the social network are taken into account, such as the number of connections, the amount of strong and weak tie connections, and the level of social integration.

This paper is structured as follows. Section 2 contains a more detailed discussion on the literature about social support and its effect on mental health and wellbeing, and the effect of a social network. In Section 3, the conceptual model of mood dynamics and its extension with social support concepts are discussed. Next, in Section 4, a number of expected properties of the behavior of the model related to the effect of different types of support on an individual are formulated, which are then investigated by simulation experiments with the model for a single agent. Section 5 describes expectations about the effect of how people are part of a social network on their mood, which are analyzed via a multi-agent simulation of a small social network. Finally, Section 6 concludes the paper with a discussion and an outlook to future work.

2. Background

There is an increasing interest of researchers in the concept of social support and its role in psychological and physical health. Literature over the last decades demonstrated relevant research in the field of social support and its effects on health and wellbeing. Many studies have shown that stress is generated when an individual appraises a situation as stressful or threatening and does not have proper coping response (Cohen & Syme, 1985a; Lazarus, 1966). Moreover, if an individual appraises a stressful situation with a feeling of helplessness or hopelessness (e.g., without the perception or reception of support), the situation become more stressful to deal with (Lazarus & Launier, 1978) .

Social support can be seen as a coping resource to handle stressful events. The protective mechanism of social support in the face of psychosocial stress is called a buffering mechanism. Social support may play a role at different points in the process of relating the occurrence of stressful events to illness (Cohen & Wills, 1985; Garber & Seligman, 1980; House, 1981). Support may intervene between stressful events (or expectation of it) and a stress response by attenuating or preventing a stressful appraisal. The perception of support by others through a network will provide necessary resources and may redefine the potential for harm posed by a stressful situation and strengthen one's capability to cope with imposed stressful demands. Actual support may alleviate stress appraisal by providing a solution to the problem, or by reducing the perceived importance of the problem. Thus social support prevents a particular situation from being appraised as highly stressful. Moreover, sufficient support may intervene between experience of stress and the beginning of the pathological outcome of illness by reducing the stress reaction or by directly influencing accompanying psychological and physiological processes; so people are less reactive to perceived stress or by facilitating healthful behaviours (Garber & Seligman, 1980).

According to literature (Cohen & Wills, 1985; House, 1981; Turner, 1983) there are two hypothesis about the nature of the relationships between social support and health. First, the *main effect hypothesis* describes that social relationships have a beneficial effect regardless of whether individuals are under stress, as large social networks provide individuals regular positive experiences and socially rewarded roles in the community. This kind of support (i.e., a sense of identity, of purpose, of meaning, belonging, and self-esteem) could be related to overall wellbeing because it provides positive effects during stressful events on self-esteem, so integration in a social network may also help one to avoid negative experiences of life; otherwise that would increase the probability of psychological or physical disorder. Second, the *stress buffering hypothesis* describes that the social relationships are related to wellbeing only for individuals under stress. The buffering process takes into account both the variety of coping requirements that may be required by a stressful event and the range of resources that may (or may not) be provided by social relationships. Buffering effects occur when an individual perceives the availability of resources that will help him to respond to stressful events. Whereas it has been suggested that structural aspects of relationships might operate through the main effect model, functional aspects of

relationships might operate through the stress buffering mechanism, and perceived availability of functional support is thought to buffer the effects of stress by enhancing individuals coping capabilities. The model proposed later in this paper simulates the stress buffering model as described in Cohen and Syme (1985b).

As social support is always perceived or received in social networks, the structural characteristics of social networks have prominent role in the exchange of social support among members of the social network. Scientific literature shows that many structural characteristics of social network can be used as the basis for analyzing and predicting the level of integration (how well people are integrated within their social networks), the level of perceived support (perception that other will provide support), the level of actual support (actual help or support received from others) from social circles during stressful situations and how mood varies over time considering various personality characteristics. According to Berkman, Glass, Brissette, and Seeman (2000), social network characteristics includes elements such as number of relationships/friends, density, strength of relationships (in terms of strong and weak relations), and also the frequency of contact between friends. These characteristics are the frequently used to describe the impact of social relationships on health and wellbeing in general and mental health in particular.

Both the quality and the quantity of social relationships have effect on the mental and on the physical health (Umberson & Montez, 2010), and social relationships shape health outcomes throughout the life course and have a cumulative impact on health over time. Also other researches describe how the social environment functions on health through psychosocial mechanisms, either by means of structural (being integrated within social network) support, or by means of functional (emotional, instrumental, etc.) means. For example, (Berkman et al., 2000) describes how social influence can lead to the adoption of positive and negative health-related behaviours.

Researchers from social science studied several other aspects of social relationships in terms of their effect on health. Social *connectedness* represents the overall degree of connectivity within a network, which is also called social integration. It refers to the overall level of involvement or engagement in social relationships. In contrast, social isolation refers the lack of social relationships within social networks. Both can affect the health (Smith & Christakis, 2008). Socially isolated people have generally social withdrawal type behavior (Cacioppo, Fowler, & Christakis, 2009), but they still may use coping strategies such as support seeking within their social circle. Social isolation and low social support has been consistently related to health damaging effects (Berkman, 1995; House, Landis, & Umberson, 1988). Lack of social relationships and perceived isolation was negatively associated with mental and physical health (Cornwell & Waite, 2009; Martire & Franks, 2014). More isolated people have less chance to receive support than the socially well connected people who have more strong relationships that lead to a better perception of support. On the other hand, socially well integrated people experience better health. Those who have more social relations (number of connections) have reduced mortality and morbidity (Berkman & Syme, 1979; Holt-Lunstad & Smith, 2012) .

As discussed above, the social relationships can be categorized in various ways, so in this extension of multiagent model, we use the strength of social ties between individuals in a social network . Strength of ties is also called closeness of a friendship and it varies from strong ties with close friends to weak ties with more distant friends . Recent findings provides more evidence about the importance of social ties: for individuals it seems to be more beneficial to have ties within a group, because they can identify themselves with a social group and it forms the basis for social support (Haslam, Cruwys, Milne, Kan, & Haslam, 2016). Individuals who are well integrated and have strong social ties within a social networks may perceive and receive more social support than the isolated ones who only have weak social ties.

3. Model of a human agent

The human agent model (see Fig. 1) describes how the stress buffering affects different cognitive states and helps a person to deal with a bad event, and how this can increase his/her coping skills. The model adopts an existing model for the dynamics of mood (Both et al., 2008), and extends it by concepts of social support. In this section, the model of mood dynamics is described first, and then the extension parts are explained.

3.1. The model of mood dynamics

The model of mood dynamics is depicted in the lower part of Fig. 1 (illustrated in the dashed box). The main concepts include the *mood level*, *appraisal* and *coping* skills of a person, and how the levels for these states affect the external behavior in the form of selection of situations over time (objective emotional value of situation). The model is based upon a number of psychological theories; see (Both et al., 2008) for a mapping between the literature and the model itself. A short definition of each state and its role is explained in Table 1.

In the model a number of states are defined, whereby to each state at each point in time a number from the interval [0, 1] is assigned. First, the state objective emotional value of situation (*oevs*) represents the value of the situation a human is in (without any influence of the current state of mind of the human). The state *appraisal* represents the current judgment of the situation given the current state of mind (e.g., when you are feeling down, a pleasant situation might no longer be considered pleasant). The *mood* level represents the current mood of the person, whereas *thoughts* indicates the current level of thoughts (i.e., the positivism of the thoughts). The *long term prospected mood*

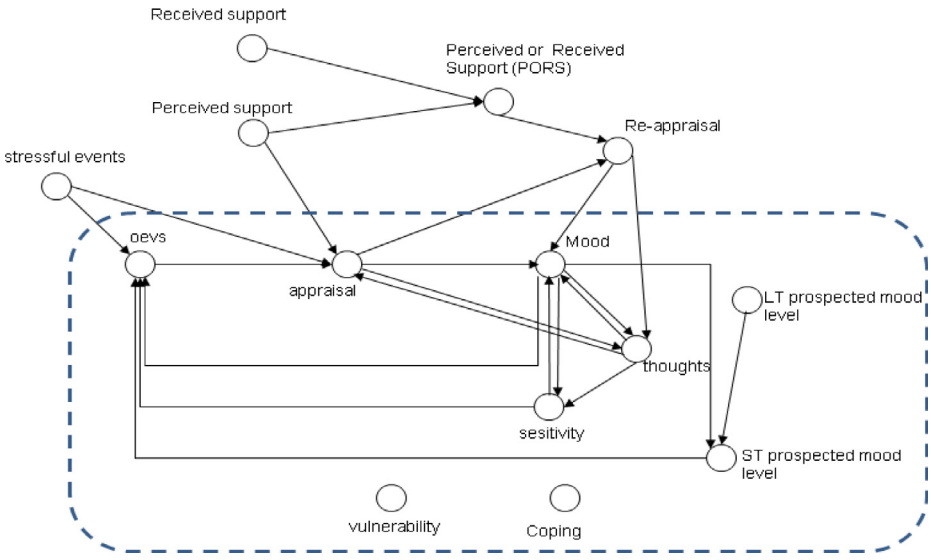

Fig. 1. Conceptual agent model of mood dynamics and social support.

Table 1
Definition of states of conceptual model.

Short name	Definition
Stressful event	Circumstances in the world that affect the situation in a stressful manner (e.g. losing his job)
OEVS	The objective emotional value of situation (OEVS) represents how an average person would perceive the situation
Appraisal	The current judgment of the situation given the current state of mind (e.g., when you are feeling down, a pleasant situation might no longer be considered pleasant).
Mood	The complex notion of mood is represented by the simplified concept *mood level*, ranging from low corresponding to a bad mood to high corresponding to a good mood
Thoughts	The mood level influences and is influenced by *thoughts*. Positive thinking has a positive effect on the mood and vice versa
Sensitivity	This node represents the ability to change or choose situations in order to bring mood level closer to prospected mood level. A high sensitivity means that someone's behavior is very much affected by thoughts and mood, while a low sensitivity means that someone is very unresponsive.
St-prospected mood level	The mood level someone strives for, whether conscious or unconscious is represented by *prospected mood level*. This
Lt-prospected mood level	notion is split into a *long term (LT) prospected mood level*, an evolutionary drive to be in a good mood, and a *short term (ST) prospected mood level*, representing a temporary prospect when mood level is far from the prospected mood level.
Vulnerability	Having a predisposition for developing a disorder
Coping	*Coping* is used in the model presented in this deliverable by means of continuously trying to adapt the situation in such a way that an improvement is achieved.
Received support	The actual support which person received from his social network
Perceived support	The perception that others will provide appropriate aid if it is needed. The belief that others will provide necessary resources may bolster one's perceived ability to cope with demands, thus changing the appraisal of the situation and lowering its effective stress (Cohen and Syme (1985a))
Perceived or received support	Whole amount of social support (both received and perceived received)
Re-appraisal	Reappraisal process occurs when a person, reappraises the stress experience in the presence of actual support as well as perceived support

indicates what mood level the human is striving for in the long term, whereas the *short term prospected mood level* represents the goal for mood on the shorter term (in case you are feeling very bad, your short term goal will not be to feel excellent immediately, but to feel somewhat better). The *sensitivity* indicates the ability to select situations in order to bring the mood level closer to the short term prospected mood level. *Coping* expresses the ability of a human to deal with negative moods and situations, whereas *vulnerability* expresses how vulnerable the human is for negative events and how much impact that structurally has on the mood level. Both coping and vulnerability have an influence on all internal states except the prospected mood levels; but in Fig. 1 those arrows are left out for clarity reasons. Finally, the stressful world events state indicates an external situation which is imposed on the human (e.g. losing your job). Please see (Both et al., 2008) for more details about this model.

3.2. Extending the model with social support concepts

Social factors can promote health through two generic mechanisms: stress-buffering and main effects (Cohen, 1988; Cohen & Wills, 1985; Garber & Seligman, 1980).

As mentioned, in this paper the focus is on stress buffering; this mechanism is often considered by psychologists, especially by those interested in intervention. This model asserts that health benefits from social connections by providing psychological and material resources needed to cope with stress. In the literature, an important difference is made between actual and perceived support; they are included as two separate states in the agent model introduced here.

Actual support: This state presents the value of actual support which person received from his social network (e.g., your friend provides some money when you temporary loss your job)

Perceived support: According to the psychological literature, the critical factor in social support operating as a stress buffer is the perception that others (even one reliable source) will provide appropriate aid (Cohen, 1988; Cohen, Underwood, & Gottlieb, 2000; Cohen & Wills, 1985). A belief that (s)he can ask a friend for help changes the person's opinion about the situation. According to Wethington and Kessler (1986), the perceived availability of social support in the face of a stressful event may lead to a more benign appraisal of the situation, thereby preventing a cascade of ensuing negative emotional and behavioural responses. As a result, the value of this state has effect on *appraisal* in the proposed model.

In addition to these two kinds of support states, some additional states are added to the previous mood model.

Perceived or Received support: The value of this state shows the whole amount of social support (both perceived and actually received). According to the psychological literature, the belief that others will provide necessary resources may bolster one's perceived ability to cope with demands (Cohen & Wills, 1985; Thoits, 1986; Uchino, Cacioppo, & Kiecolt-Glaser, 1996). For instance, the perceived availability of functional support is thought to buffer the effects of stress by enhancing an individual's coping abilities (Wethington & Kessler, 1986). So, this state has effect on the coping skills of person. Please note that the value of this state has influence on the state *coping*; however this is not shown as an arrow in Fig. 1.

Re-appraisal: The *reappraisal* state uses the concept of the perception of the support in addition to the appraisal state. More specifically, the reappraisal state uses the concept perception as well as actual reception of the support; a reappraisal process occurs when a person reappraises the stress experience (generated by the appraisal) in the presence of actual support as well as perceived support. Reappraisal intervenes between the actual and perceived support and stress and the pathological illness.

3.3. Numerical details of the agent model

As mentioned, for the model of mood dynamics (the lower part of Fig. 1, illustrated in the dashed box) an existing model was adopted. To obtain the initial values of the states and the values for the model parameters, we performed a number of initial simulations to find suitable values that resulted in stable behaviour of the model (i.e. without a tendency of the states to develop towards the extremes). In addition, verified whether the model exhibits the patterns that can be expected on the basis of the literature. In the simulations in this paper, we adopted these settings from the initial version of the paper. We refer to the original article (Both et al., 2008) for the numerical details of this part of model.

In the simulations weights of arrows which connect the new states to each other or to old states have been set at the following values: $w_{perceived,appraisal}$ 0.2, $w_{perceived,PORS}$ 1, $w_{received,PORS}$ 1. The weights of all arrows to the *reappraisal* are the same as arrows to/from *appraisal*, except $w_{PORS,\ Reappraisal}$ which is 0.2. Moreover, in this new model the *mood* states thoughts and *sensitivity* are affected by an average value of *appraisal* and *reappraisal* instead of only *appraisal*. Furthermore, the initial for the simulation, are as follows: *coping* 0.1, *vulnerability* 0.9, *LT_prospected* 0.6, *ST_prospected* 0.6, *oevs* 0.6, *appraisal* 0.8, and *sensitivity* 0.6.

In each iteration, the value of each state (except *coping*), V_{new}, is defined according the weighted sum of its inputs from other, connected states and its old value (V_{old}):

$$V_{new} = V_{old} + af * (w_1 V_1 + W_2 V_2 + \ldots)$$

The adaptation factor *af* for all states in the mood model is 0.1. The new value of coping is calculated by this formula ($af_{coping} = 0.0005$):

$$\text{Coping}_{new} = \text{coping}_{old} + af_{coping} * \text{coping}_{old} * (0.55 - \text{coping}_{old}) * \text{PORS}$$

4. Verification of the single agent model

The human agent model presented above is used to make a comparison between what the model predicts for the human agent, and what actually holds in the real world (according to the literature). The aim of this section is to verify whether the single agent model is in line with the literature and can be used as basis for the multiagent simulation.

4.1. Properties

The objective of this paper is proposing a cognitive model that is consistent with related theories about social support. A number of expected behaviors of the model can be formulated as expected properties:

P1. Social support (both perceived and actual) leads to less negative mood.
P2. A person who has a suitable social support will be more robust against bad events.
P3. Perception that others will provide appropriate aids during bad events (perceived support) is more helpful than the actual support itself.

P4. Social support can help people to learn how to cope with bad events. It means that at the very first times which a bad event happen, (s)he needs social support to cope with. But, after some successful experiences to handle the problem, (s)he will be more robust to cope with events with almost same demands.

4.2. Assumptions behind the example simulations

To do the simulation experiments, some simplifying assumptions about the availability of *actual* and *perceived supports* and their affect on the *coping* have been made:

- Perception about the availability of support starts meanwhile the stressful event and fades out gradually after the event.
- In cases that actual support occurs, it starts meanwhile the event, and fades out gradually (10 times faster than perceived support) after the event.
- Both kinds of social support have a positive effect on coping.

4.3. Simulations

In the **first experiment**, a scenario is simulated which one bad event (stressful_event with value 0.2) occurs for the person and lasts for three days. Fig. 2 shows the changes in mood and appraisal for four different conditions:

(a) No perceived support, no actual support.
(b) No perceived support, just actual support.
(c) Just perceived support, no actual support.
(d) Both perceived and received support.

As it can be seen, the value of mood and appraisal decrease much when there is not any kind of support (a). In contrast, only a minimal decrease in the value of mood happens when both perceived and received are available (d). Moreover, comparison between situations in which just one kind of support is available shows that the perception of support has a more positive effect on mood than actual support.

In the **second experiment**, we consider three different scenarios. In the first scenario the person experiences a very stressful event (value 0.6). In the next scenarios, two and four events happen, but the events are less negative (value of 0.3 and 0.1 respectively). In all scenarios, the time is discretized with the time steps of 0.1 (h), and the bad event lasts for 2.5 days.

The scenarios are simulated for three types of persons with different personalities. For each of the persons, we consider 5 different combinations of perceived and actual support: no support, a (little) perceived support, a (little) actual support. Together this results in $3 \times 3 \times 5$ is 45 simulations.

The following types of persons are used. First, an emotionally **stable person**, defined by having good coping skills that balance out any vulnerability, and by having the desire to have a good mood: coping value is 0.5, vulnerability 0.5 and LT prospected mood level 0.8. An emotionally **moderate person** is defined by having some vulnerability and bad coping skills and the desire to have a medium mood: settings 0.9, 0.1 and 0.6 respectively. The third type, an emotionally **very unstable person**, is characterized by settings 0.01, 0.99 and 0.6. For type 1 the OEVS is 0.8, for type 2 it is 0.94 and for type 3 the stable OEVS is 0.999.[1] The results of the 45 simulations are presented in Table 2 and Fig. 3, The figure depicts the maximum value of mood during simulation given different increasing values for support. The idea behind this is that the maximum value of the mood is an indicator for the recovery of a person from a depression.

According to the literature, depression is defined as low mood level during at least two weeks (336 h). We use a threshold of 0.5. Table 2 shows the length of period that the mood is bellow two particular thresholds (0.5 and 0.25), the cases that the length is higher than 336 h are highlighted, and the average of value of mood in the first two weeks of depression is mentioned in the second line of cell. Lower values of mood refer to a stronger depression, which is shown by darker colours. The table illustrates that social support in some cases prevents the depression; and in some other cases it decrease the depth.

Fig. 3 shows the average of mood in the last two weeks of experiment 2. This figure is just for cases that only one type of support is available, and shows the results for different amount of actual and perceived support.

As in can be seen in Fig. 3, the social support is beneficial mostly for a person number 2, but not for a stable or very unstable person. A stable person seems not to need to social support; on the contrary, social support cannot help a very unstable person. The exception is for a very unstable person: when some moderate events happen for this person, a high value of perceived social support can help to recovery after the event.

On the other hand, by focusing on the graphs related to person 2, we can see that the graph of perceived social support has a higher gradient. This suggests that the same amount of perceived social support is more effective than actual support.

In **the third experiment**, the long-term effect of social support is studied. Handling a bad event by help of social support may lead to bolster one's perceived ability to cope with demands, and the person will be more ready to deal with next events (with almost the same kinds of demands). In this simulation, several bad events occur with interval of one month. Each bad event lasts for 2.5 days; during each event, the value of stressful_event is 0.2. It is assumed that

[1] The start value for OEVS needs to be calculated for each type so that when no events occur, the person stays balanced with all variables equal to LT prospected mood level.

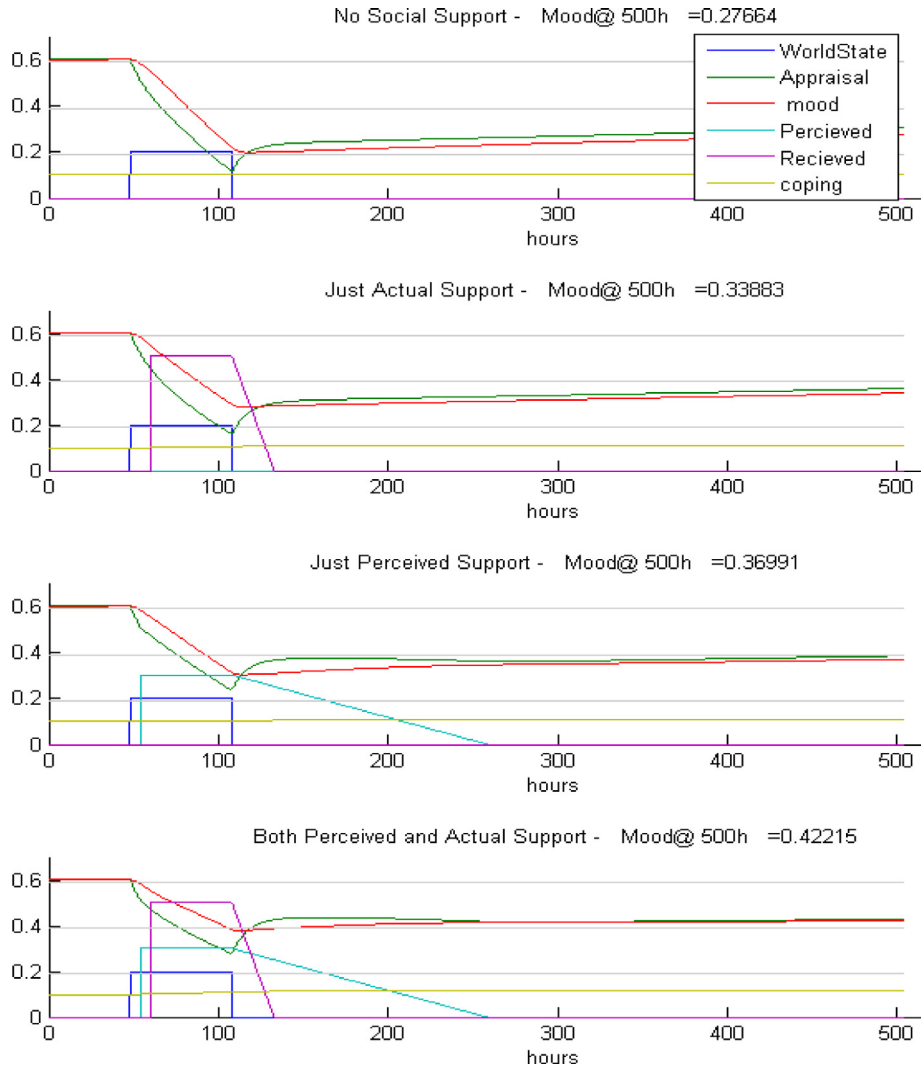

Fig. 2. Simulation results of the first experiment. Studying the influence of perceived and actual support on handling a bad event. Value of mood after 500 h is mentioned above each graph. The value of each state is a value between [0, 1].

both perceived and received social supports are available during all events.

Fig. 4 shows the result of this simulation experiment. As it can be seen, the value of coping skills is increasing during each event. As a result, the last events have less effect on mood and appraisal, in comparison to the first ones. In fact, during the first event, the value of mood is decreased by 0.235; while it is decreased only by 0.164 during the last event.

4.4. Discussion

The results of the experiments described previous section are used to validate the properties of our model with respect to the relation between support and mood. Based on the literature, four different properties have been defined.

P1. The first property states that social support (both perceived and actual) leads to less negative mood. The simulations in Fig. 2 show that mood goes down when a stressful event occurs. However, when a person has a perception of adequate social support he appraises the situation less negative and the lowest value of the mood is less negative. Actual support doesn't have much effect on the appraisal, but still reduces the effect of the stressful event. Thus, both types of supports leads to less depression in our model and P1 is validated.

P2. The second property states that a person who has a suitable social support, will be more robust against bad events. Fig. 3 shows that this only holds for a moderate person (there we see that the mood value increases with additional support), but not for stable or very unstable persons (except for scenario 3). A similar patterns is visible in Table 2. The property partly holds.

Table 2
Length and depth of period which mood is less than threshold (in hours). First number: the length of period when mood is bellow threshold; second number: average mood value during this period. Situations in which length > 336 h are highlighted.

Personality	Perceived or Actual Support	Threshold = 0.5			Threshold = 0.25		
		Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Stable Person	P=0,A=0	119 0.322	93 0.407	0 -	37 0.196	0 -	0 -
	P=0.25,A=0	103 0.331	57 0.445	0 -	29 0.205	0 -	0 -
	P=0.5,A=0	86 0.341	17 0.484	0 -	19 0.220	0 -	0 -
	P=0,A=0.25	117 0.327	83 0.422	0 -	34 0.2	0 -	0 -
	P=0,A=0.5	113 0.334	69 0.439	0 -	30 0.206	0 -	0 -
Moderate Person	P=0,A=0	1286 0.075	1281 0.065	1261 0.233	1273 0.064	1257 0.043	1139 0.116
	P=0.25,A=0	1286 0.091	1280 0.090	1241 0.363	1273 0.081	1252 0.066	50 0.241
	P=0.5,A=0	1286 0.126	1279 0.14	1056 0.456	1013 0.117	849 0.118	0 -
	P=0,A=0.25	1286 0.078	1281 0.072	1256 0.287	1273 0.067	1255 0.049	675 0.167
	P=0,A=0.5	1286 0.083	1281 0.085	1245 0.342	1273 0.072	1253 0.060	174 0.234
Very Unstable Person	P=0,A=0	1287 0.035	1282 0.039	1265 0.131	1275 0.022	1261 0.015	1172 0.032
	P=0.25,A=0	1287 0.041	1281 0.048	1249 0.246	1274 0.028	1257 0.021	1077 0.064
	P=0.5,A=0	1287 0.047	1280 0.063	1147 0.346	1274 0.033	1251 0.032	756 0.136
	P=0,A=0.25	1287 0.038	1282 0.042	1261 0.162	1275 0.025	1260 0.017	1158 0.046
	P=0,A=0.5	1287 0.039	1282 0.046	1254 0.212	1275 0.026	1258 0.02	1132 0.075

P3. The third property says that perceived support is more helpful than actual support. Fig. 3 indeed shows that – when there is a positive effect – the perceived support is more helpful than the actual support (in the figure the blue[2] line is above the green line). Thus, this property holds.

P4. The fourth property states that social support can help people to learn how to cope with bad events. Indeed Fig. 4 clearly shows that the coping skills increase after negative events. As a result, the last events have less effect on mood and appraisal, in comparison to the first ones.

In summary, social support has a positive effect on mood and can prevent the subject from low mood, social support also has positive impact on coping skills and it enable a person to learn how to cope during stressful events, but this mainly holds for moderately stable persons.

[2] For interpretation of color in Fig. 4, the reader is referred to the web version of this article.

5. Simulation experiments – multiple agents

In this section, simulation experiments in a multi-agent setting are described. These experiments are meant to analyze the effect of differences in how people are embedded in a social network. In this type of modelling approach we generally make various assumptions based on literature, so not every aspect is incorporated in the model.

To investigate the effect the social embedding on support, we first formulate some behaviours of the model that are expected on the basis of the literature as properties, Then, we explain the network that has been selected for these experiments, as well as assumptions for simulations. After that, the simulation scenarios and the results are presented. Finally, the consequences of the simulations for the properties are discussed.

5.1. Expected properties

The idea behind the inclusion of social network characteristics is to analyze the effect of the structure of a social network on social support, and to predict the mood level

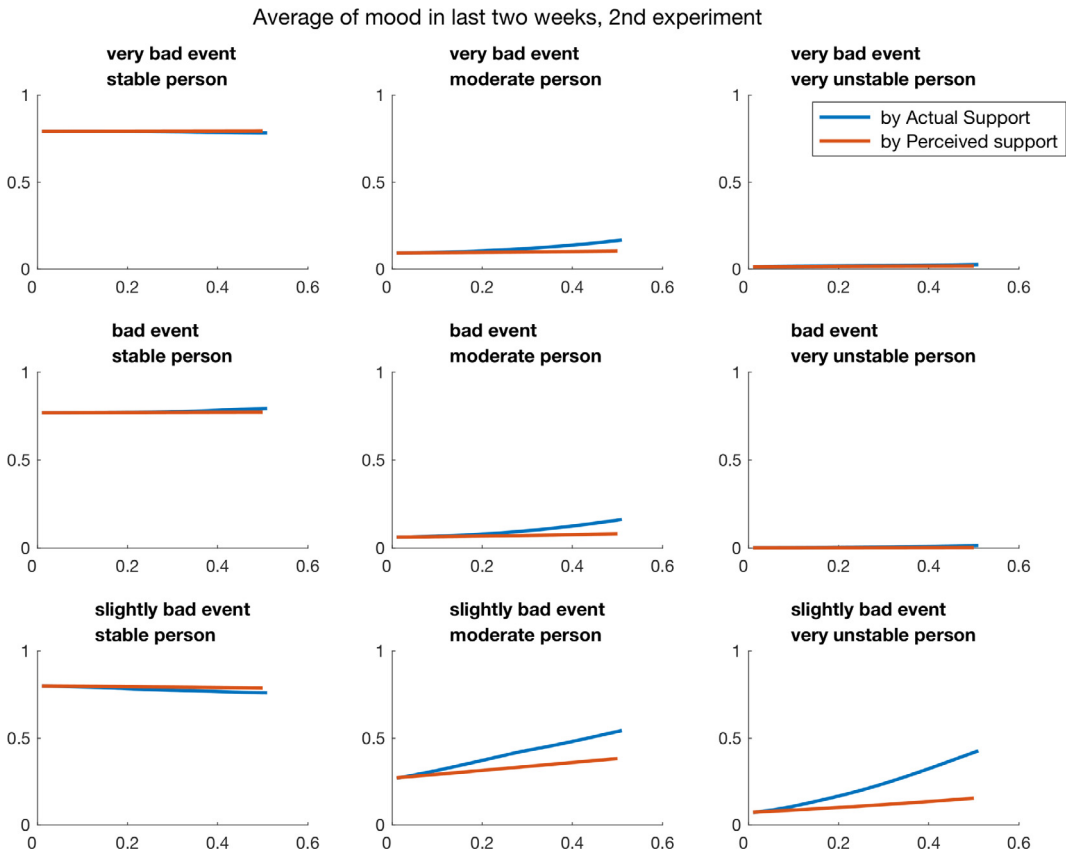

Fig. 3. The average of mood in last two weeks for different amount of social support (perceived and actual).

of individuals within that social network. The following expected properties are formulated.

P5. Mood of less integrated people will develop on average more negatively than the mood of better integrated people.
P6. The social environment has a more positive effect on the mood of moderate people, than on stable or very unstable people.
P7. Individuals that have friends with a high level of the mood in their social circle, receive more social support than people that have friends with a lower level of mood.
P8. A central person within a network with a stable personality provides more support to the network members than a very unstable central person.

5.2. Network model of agents

To perform multi-agent simulation experiences, we have selected Zachary's network (Zachary, 1977) which is based on a real small network that shows the network of friendship between members of a Karate club. This network is originally undirected and unweighted. We adapted it to make it a weighted network, where the weights represent the strength of friendship. The weights of ties are assigned randomly from a uniform distribution. The resulting network is shown in Fig. 5. For our experiment, we have added three isolated nodes to the original graph, which are used to study the effect of isolation on three different types of personality (the same as mentioned in the second scenario in Section 4.3).

5.3. Simulations assumptions

For the multi agent simulations, the same settings are used as single agent simulations. However, with regard to the new aspects the following assumptions are taken into account:

A **Negative Event** may happen for an agent at the beginning of a day with the probability of 0.2.
Perception of support for each agent is based on its degree in the network (sum of the weight of its connections). More precisely, the perceived support of an agent (agent number i) is calculated according to this formula:

$$\text{Perception of support} = \text{Sigmoid\_Function}(1,\ 0,\ \text{Degree of Agent}_{\,i})$$

The reason for using the sigmoid function[3] instead of the degree of the agent directly is that the model requires

[3] $Sigmoid\text{function}(\sigma, \tau, x) = \frac{1}{1-e^{-\sigma(x-\tau)}} - \frac{1}{1+e^{\sigma\tau}}$

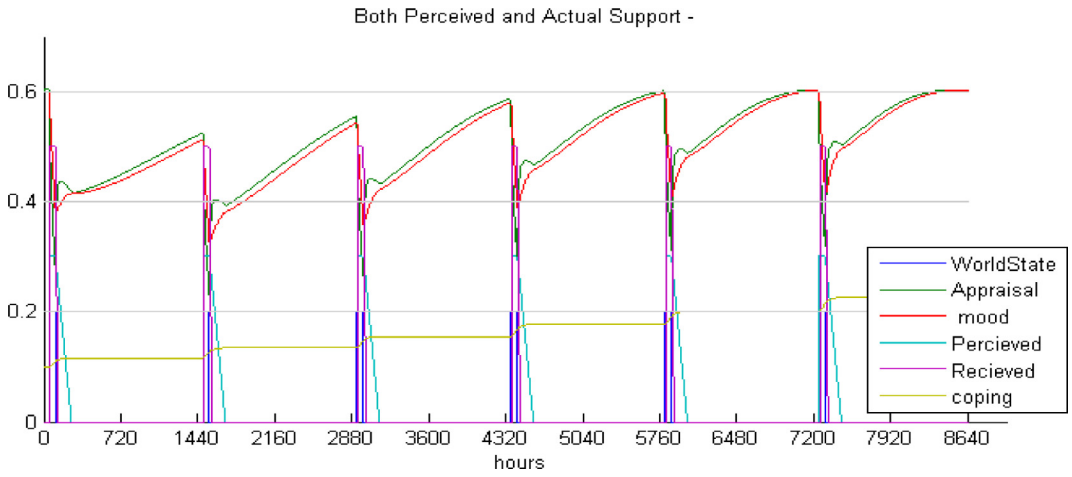

Fig. 4. Increasing the coping skills after during each bad event. The value of each state has a value between [0, 1].

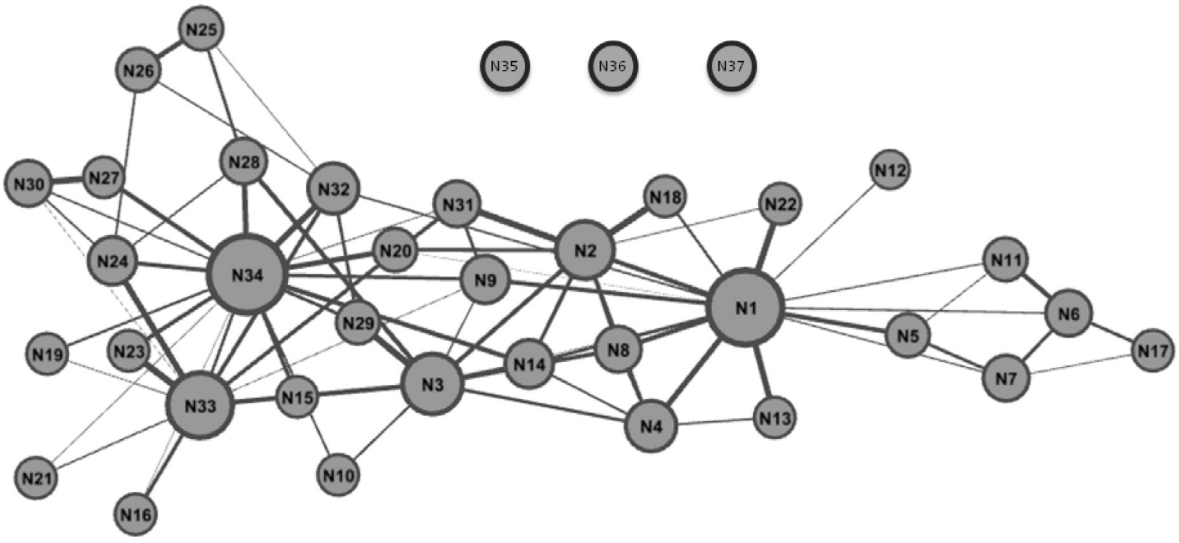

Fig. 5. A model of a network of human agents (every node represents an agent model of mood dynamics and social support see Fig. 1).

that the value of perceived support is kept within the range of (0, 1).

When an event has happened for an agent, each of its friends could provide actual support. The probability that an agent provides actual support to a friend is calculated with this formula:

$$= Sigmoid\_Function(10,\ 0.25,\ weight\ of\ friendship * mood\ of\ supporter)$$

This means that the probability of providing support is dependent on the *weight of friendship* and the *mood of supporter*. When the product is lower than 0.25, the chances are almost zero. The value of the actual support is fixed to an arbitrary 0.5 for these simulations.

5.4. Simulations

In the **fourth experiment**, all agents have stable personalities and events are happening for agents as explained in the assumptions. An agent that experiences a bad event recently, will have a chance to profit from actual support. Each run is a simulation of 90 days, and the average of mood of each agent is reported. This simulation is repeated 100 times and the average of mood values over all runs are reported. The results of this experiment are shown in Fig. 6. One can see that there is a positive correlation between the degree (i.e. the sum of all weights of the edges for a specific node) of a person and its average mood value after 90 days over 100 runs. Similarly, people with more friends have on average higher mood values.

Fig. 6 shows the relation between the average and standard deviation of mood of agents and their integration level.

Table 3 shows the result of Pearson and Spearman's correlation tests on the results of experiment 4. The first one is for linear dependency, and the later one is a measure of rank correlation. It is clear that there is a significant correlation.

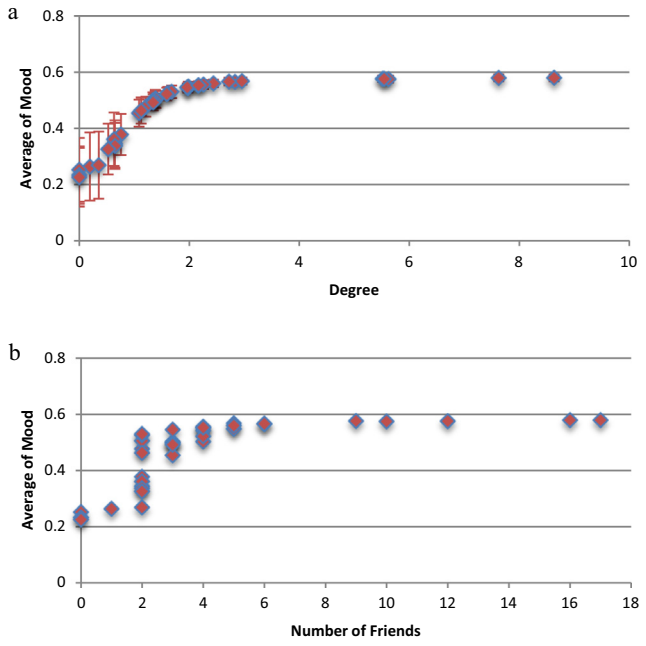

Fig. 6. Results of 4th experiment. Average and standard deviation of mood value of agents related to their (a) degree and (b) number of friends; in a simulation with all stable personalities.

The **fifth experiment** is similar to the previous one. In this experiment, we look at the effect of personality on isolated agents. To do so, we have added three isolated agents and we gave each of them one specific type of personality. Each one behaves the same, as there is no influence on them from the network. The personality type of all other agents are randomly assigned. The simulations are again performed 100 times and the average of mood of each agent is reported. Fig. 7 shows the results of this simulation, in which different colours and shapes represent the different types of persons. It is clear that stable personality has on average the highest mood values, while very unstable personality has the lowest resulting mood values. It is also visible that moderate personality has the strongest correlation between degree and mood level.

Table 4 shows the value of the average of mood level for best integrated and an isolated node of each personality.

The goal of **sixth experiment** is to study the effect of *the mood level of friends of a person* on his own mood. To do so, the personality of the agent under investigation is set as a moderate person. We measure the effect of having friends with a different personality (either stable or very unstable) on the average mood.

We have performed a paired *t*-test on the resulting mood levels to investigate the significance of the effect of having friends with a different mood level. The test reveals that the average of the mood levels of all agents under investigation is 0.474 when all friends are stable and 0.467 when all friends have an unstable personality. This difference is significant with a p-value of 0.0268.

Fig. 8 shows the results in a visual form. In these graphs, vertical axes show the difference in the average of mood level of the agent when all friends have a stable personality and when all friends have very unstable personality. The graphs also show that there is a slightly positive effect on the mood of having stable friends. In addition, it suggests that this mainly holds for people with a degree between 0.75 and 3.

In the **seventh experiment**, the effect of the mood level of an agent on others is studied. In this experiment, the personality of all agents is set to moderate. However, the personality of one agent is first set to very unstable and after that to stable. In this way, were are able to compare the effect on others of the personality of one specific agent. Fig. 9 shows the results of this experiment. In these figures, the vertical axis shows the average change in the mood level of *all agents*, except the agent for which the personality is changed. It can be seen that the trend is that improving the state of a more central person has a more positive effect on the whole network. However, by noticing on the range of y-axis, we find that these changes are too small. The reason is that improving the state of one person cannot change the state of the whole network too much ("One swallow does not make summer").

Table 5 lists the results of a Pearson test (assuming linear relation) and a Spearman's test (assuming a monotonic relationship) to show the correlation between the integration level of an agent and the effect of changing his personality on the mood of other agents. It can be seen that there is some correlation, although only for degree it is significant if we assume a linear relationship.

5.5. Discussion

Based on the simulation described in Section 5.4, we are now able to discuss whether the properties stated in Section 5.1 can be confirmed.

Table 3
The results of correlation tests between integration level (degree and number of friends) and the average of mood in experiment four.

	Pearson correlation		Spearman's correlation	
	Degree	#Friends	Degree	# Friends
Average (mood)	rho = 0.668	rho = 0.621	rho = 0.9965	rho = 0.919
	p = 6.26e−06	p = 4.08e−05	p = 2.05e−39	p = 9.23e−16
Std (mood)	rho = 0.617	rho = −0.563	rho = −0973	rho = −0.90
	p = 4.68e−05	p = 2.85e−04	p = 4.07e−34	p = 1.30e−14

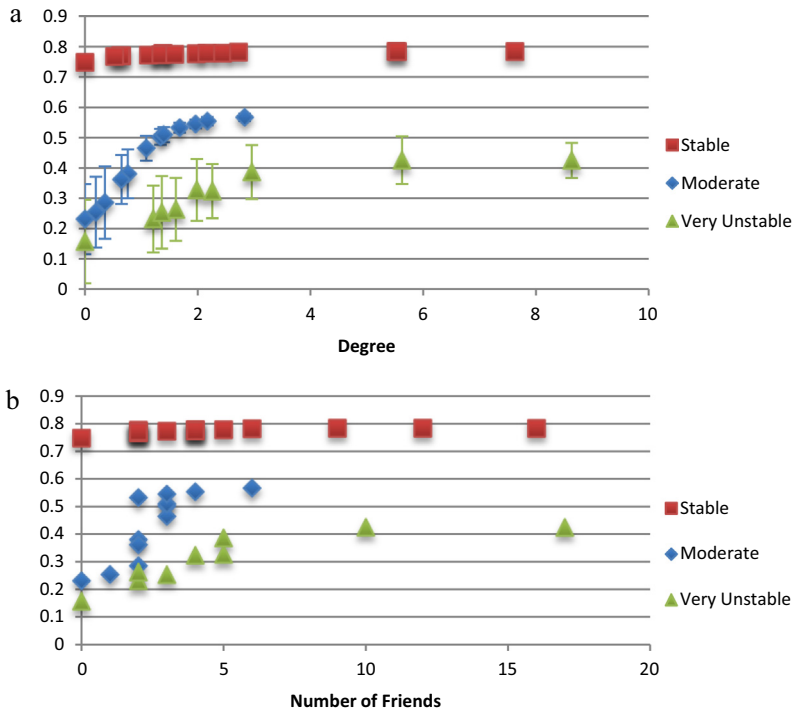

Fig. 7. Results of 5th experiment. Average mood value of agents related to their degree (a) and number of friends (b) in a simulation with randomly assigned personalities.

Table 4
The average of mood for the most and least integrated persons with different personalities in 5th experiment.

	Personality 1 stable person	Personality 2 moderate person	Personality 3 very unstable person
Isolated node	0.748	0.2309	0.1573
Best integrated node	0.7832	0.5668	0.4245
Difference	*0.0352*	*0.3359*	*0.2672*

Table 5
The results of correlation tests between integration level (degree and number of friends) and the effect of changing the personality of an agent on the mood of other agents (in experiment seven).

	Pearson correlation		Spearman's correlation	
	Degree	#Friends	Degree	# Friends
Changed in mood Level of other agents	rho = 0.338 p = 0.0405	rho = 0.3095 p = 0.0623	rho = 0.268 p = 0.109	rho = 0.1883 p = 0.2645

P5. The first property of the multi-agent setup stated that the mood of less integrated people will develop on average more negatively than the mood of better integrated people. The fourth experiment, of which the results are shown in Fig. 6, indeed revealed a positive correlation between the mood level of and both the degree and the number of friends. Thus, it can be concluded that when support is with some probability provided by friends, it is beneficial to have more friends. However, as also can be seen in the graph, the added value for the mood of more than 5 friends is limited.

P6. The next property reads: the social environment has a more positive effect on the mood of moderate people than on stable or very unstable people. This is something that can be clearly seen in Fig. 7: people with a stable personality (the red squares) all have a high mood, independent of their degree. Similarly, people with a very unstable personality and a low degree have a low mood on average and the mood of very unstable personality with a higher degree is only slightly higher. The moderate people instead (green triangles) show a large correlation between degree and mood. This is

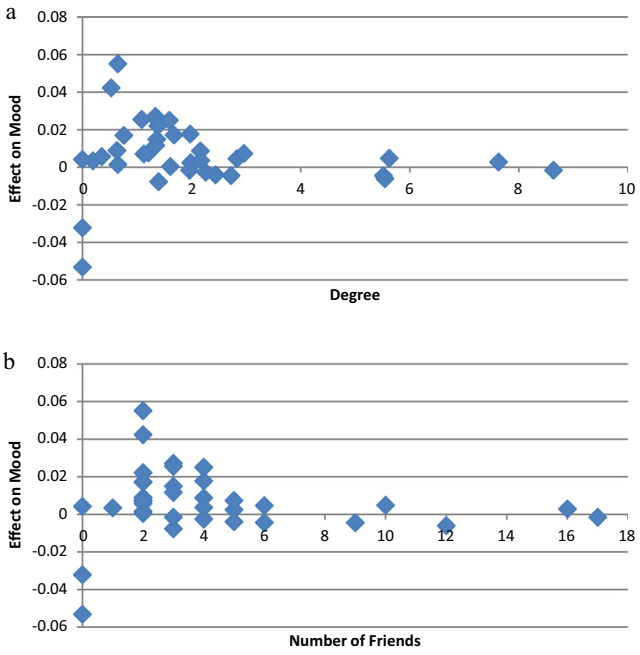

Fig. 8. Results of 6th experiment. The difference in average mood level of agents between having stable friends and having very unstable friends, related to their degree (a) and number of friends (b).

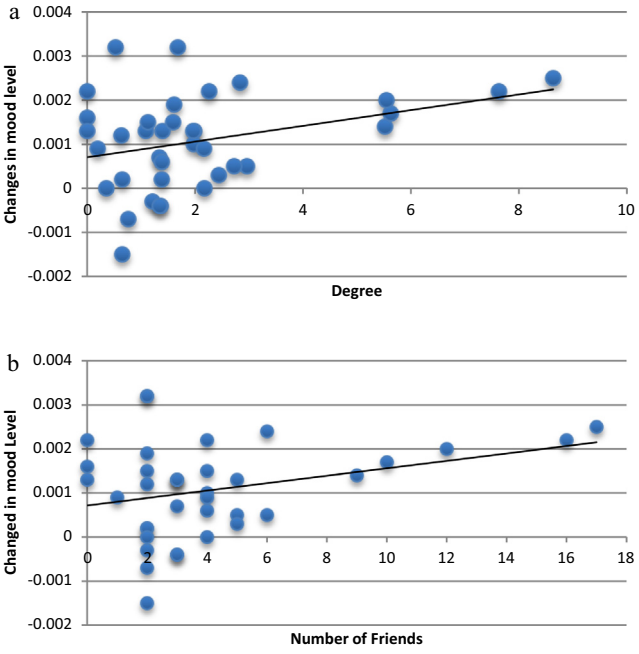

Fig. 9. Results of 7th experiment. The change in the average mood level of all agents caused by changing the personality of one person from "very unstable to stable". The x-axis shows the (a) degree and (b) number of friends of the agent which its personality is changed from very unstable, to stable personality.

further illustrated by Table 3, which shows that the difference between the mood values of the best integrated node and the isolated node is (very) small for personality 1 and 3, but large for personality type 2. Thus, this property can be confirmed.

P7. The seventh property says that individuals that have friends with a high level of mood in their social circle receive more social support than people that have friends with a lower level of mood. For this property, we consider Fig. 8. It is visible that on average, all points in the graph are above 0. This means that the mood of people with stable friends is better than the mood of people with very unstable friends. Interestingly, it can be seen that this effect is the strongest when people only have a small number of friends. This is because when you have a large number of friends, there is almost always somebody that provides support.

P8. The final property stated that a central person within a network with stable personality provides more support to the network members than an unstable central person. Fig. 9 illustrates that the effect of having a stable person in the center compared to a very unstable person is indeed larger than zero on average. It is also visible that the effect is stronger when the degree of the nodes is higher.

6. Conclusion and future work

The computational model presented in this paper is the part of ongoing work on modelling social support and its effects on health and psychological wellbeing, particularly on stress and depression. In this paper an extension of a human agent model of mood dynamics is presented that takes social support and social network characteristics into account. It distinguishes between actual support and perceived support. The simulation experiments show that the effect of different types of support are in line with the literature.

This model can form the basis of a support system that provides advices for persons based on a prediction of the effect of situations on a person's mood. For such a system, it is important to be able to estimate whether a person has social support and how large that is. For this, it might be possible to use data from social media. In the current decade, many electronic social environments have been developed in the form of social media or social network sites (e.g., Facebook, Twitter, Myspace). These social media provide a social environment where people can communicate with each other through forming their own social networks or groups, and thus integrating with these social networks. Such social media environments can be used for data collection (e.g., network size, frequency of the contacts, locations, etc.) to develop, analyze, and validate predictive models.

In future work, it is planned to investigate whether the measureable aspects of social environment (e.g. size and structure of social networks and a person's interaction with it) can be used as input for the current model and can be used to correctly predict the dynamics in the mood of a person. For this, user studies will be performed that investigate the correlation between these measureable aspect

and people's perception of support and loneliness. Ultimately, this could lead to a support system that is able to exploit social network data for predicting the mood of a person.

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