Modelling Caregiving Interactions During Stress

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Abstract. Few studies describing caregiver stress and coping have focused on the effects of informal caregiving for depressed care recipients. The major purpose of this paper was to investigate the dynamics of the informal care support and receipt interactions among caregivers and care recipients using a computational modelling approach. Important concepts in coping skills, strong ties support networks and stress buffering studies were used as a basis for the model design and verification. Simulation experiments for several cases pointed out that the model is able to reproduce interaction among strong tie network members during stress. In addition, the possible equillibria of the model have been determined, and the model has been automatically verified against expected overall properties.

1. Introduction

Caring for a family member, spouse or friend (informal caregiving) who is diagnosed with a severe illness (e.g., a unipolar disorder) can be a stressful experience. While most caregivers adapt well to the situation of caring for a person with a unipolar depression, some do not. A number of studies investigate the negative consequences for the informal caregiver, such as the development of depression, burden, burnout, or (chronic) stress, when caring for elderly patients or patients with illnesses like dementia, or Parkinson's [5], [6], [7], [9], [10]. The current paper addresses the development of stress in informal caregivers of patients with unipolar depression and the effect of this stress on the interactions between the caregiver and care recipient. To understand the caregiver's adaptations to the cognitive disabilities of his/her close acquaintance, the complex nature of stress processes must be accounted for and the constructs and factors that play a function in the caregiving must be considered. For each individual a number of cognitive and physiological mechanisms regulate the impact of stress on health and well-being. Individuals typically occupy multiple roles in life; becoming a caregiver of a person with depression introduces an additional role, and therefore will require some rearrangement of priorities, and redirection of energy [10]. Not only is this likely to produce strain at a personal level, but it is also likely to spur reactions (potentially negative) from diverse people who are interconnected to a person through his or her roles outside the realm of caregiving.

Although much work has been dedicated to understand the caregiving mechanism, little attention has been paid to a computational modelling angle on how caregivers work together to support their close acquaintances under stress. The caregiving process is highly dynamic in nature, and it requires demanding resources to monitor such a process in the real world [6]. The aim of this paper is to present a computational model that can be used to simulate the dynamics in the caregiver and care recipient under influence of external events. The current work is an addition to our previous model of social support selection, where in the current model, individuals with a depressive state are receiving help from close acquaintances [1].

The paper is organized as follows; Section 2 describes several theoretical concepts of social support networks and their relation to stress. From this point of view, a formal model is designed (Section 3). Later in Section 4, a number of simulation traces are presented to illustrate how the proposed model satisfies the expected outcomes. In Section 5, a mathematical analysis is performed in order to identify possible equilibria in the model, followed by verification of the model against formally specified expected overall patterns, using an automated verification tool (Section 6). Finally, Section 7 concludes the paper.

2. Underlying Principles in Informal Caregiving Interactions

Researchers from several domains have become increasingly interested in social support, caregiving, and mental health. For instance, researchers in nursing and healthcare domain have contributed several theories to explain those relationships by presenting foundations on coping behaviours, mediating attributes, caregiving adaptation, and stress. One of the theories that has been used to explain these interactions is the Theory of Caregiver Stress and Coping which combines important principles in Lazarus Stress-Coping Theory, Interpersonal Framework of Stress-Coping, and Stress Process Theory of Pearlin [3], [4], [11].

Within the model introduced, three aspects play important roles to regulate support and maintain the caregiver's personal health: 1) externally generated stressors (negative events), 2) mediating conditions, and 3) caregiver outcomes [4], [6], [10]. For the first aspect, stressors are related to specific internal or external demands (*primary stressors*) that the caregiver has to manage. For example, several studies show that sufficient caregiver *personal resources* (e.g. financial incomes, social) reduces the perception of caregiving burden, while a loss of emotional resources (*long term emotional exhaustion*) amplifies the perceived burden [9]. The second aspect represents how the caregiver reacts (coping strategies) when facing the adversity in caregiving. In the proposed model, caregivers who face a primary stressful situation generally use a combination of *problem-focused coping* and *emotion-focused coping*. Problem-focused coping is associated with positive interpersonal efforts to get the problem solved [3]. In contrast to this, emotion-focused coping strategies (thinking rather than acting to change the person-environment relationship) entail efforts to regulate the emotional consequences (e.g. avoidance) of stressful or potentially stressful events [4]. This choice of coping is related to the *caregiver's personality*, for example, a caregiver with a positive personality (e.g., low in neuroticism) tends to choose problem-focused approach [5]. Another important concept that can derived from these coping strategies is *the relationship focused coping* (positive or negative). The combination of high caregiver's *empathy* (perceiving the inner feeling of care recipient) and problem-focused coping will lead to *positive relationship coping*, and vice versa [4], [7], [8]. The third aspect is related to the caregiver's outcome. Mainly, this component ranges on a continuum from *bonadaptation* (meeting the needs to support the care recipient) to *maladaptation* (continued negative situation and need for referral and assistance) [4], [11]. In addition to this, bonadaption is related to the high personal accomplishment (*expected personal gain*) and provided support (*social support*), while maladaptation is linked to the *emotional exhaustion* [9]. A high expected personal gain reduces the *short term* and *long term stress level* in caregivers, which will improve interaction during the caregiving process [7]. When the care recipients receive support, it will reduce their stress by the resource serves as an insulating factor, or *stress buffer*, so that people who have more social support resources are less affected by negative events [5], [6].

3. Modeling Approach

Based on the analysis of the dynamics in coping behaviours, mediating attributes, caregiving adaptation, and stress, as given in the previous section, it is possible to specify computational properties for the multi-agent model. The results from the interaction between these variables form several relationships, both in instantaneous and in temporal form. To represent these relationships in agent terms, each variable will be coupled with an agent's name (*A* or *B*) and a time variable *t*. When using the agent variable *A*, this refers to the caregiver agent and *B* to the care recipient agent. This convention will be used throughout the development of the model in this paper. The details of this model are shown in Fig. 1.

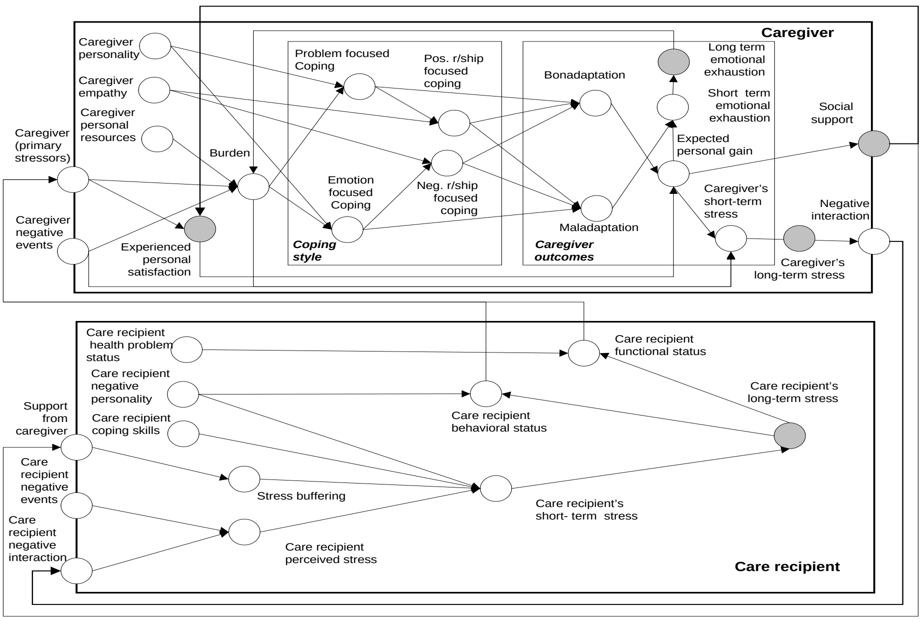

Figure 1. Global Relationships for Caregiving Interactions During Stress

3.1. The Caregiver Model

This component of the overall model aims to formalise important concepts within the caregiver. The instantaneous relationships are expressed as follows. The problem-focused coping *PfC* is calculated using the combination of the caregiver personality *GpP* and burden *Bd*. Note that a high burden level close to 1 will have the effect that the choice of using problem focused coping becomes smaller.

$$PfC_A(t) = GpP_A(t).(1-Bd_A(t)) \quad (1)$$

$$EfC_A(t) = (1-GpP_A(t)).Bd_A(t) \quad (2)$$

However in emotional-focused coping *EfC*, those factors provide a contrasting effect. Positive relationship focused coping (RfC^+) depends on the relation between problem focused coping and caregiver's empathy. A high empathy will increase this function, while reducing its counterpart (negative relationship focused coping (RfC^-)).

$$RfC_A^+ = PfC_A(t).GE_A(t)$$

$$RfC_A^- = EfC_A(t).(1-GE_A(t))$$

Burden (*Bd*) is determined by regulating proportional contribution β between caregiver primary stressors (*GpS*), long term emotional exhaustion (*ExH*), and caregiver resources (*GpR*). Expected personal gain *(PgN)* is measured using the proportional contribution (determined by α) of the bonadaption (*Bn*) and experienced personal satisfaction *EpN*. Short term emotional exhaustion *EsH* is measured by combining maladaption *Md* and negative relationship of expected personal gain.

$$Bd_A(t)=[\beta.GpS_A(t)+(1-\beta).ExH_A(t)].(1-GpR_A(t)) \quad (5)$$

$$PgN_A(t) = \sigma.Bn_A(t) + (1-\sigma).EpN_A(t) \quad (6)$$

$$EsH_A(t) = Md_A(t).(1-PgN_A(t)) \quad (7)$$

Caregiver short term stress *GsS* is related to the presence of caregiver negative events *GnE* and burden *Bd*. Note that a high expected personal gain will reduce the short term stress level. The maladaptation *Md* is calculated using the combination of negative (RfC^-), positive, relationship, and emotional-focused coping. In the case of bonadaptation, it is determined by measuring the level of positive, negative, relationship, and problem-focused coping. Parameters ϕ, Υ, and ρ provide a proportional contribution factor in respective relationships. In addition to the instantaneous relations, there are four temporal relationships involved, namely experienced personal satisfaction *EpN*, long term emotional exhaustion *ExH*, caregiver long term stress *GlS*, and social support *ScP*. The rate of change for all temporal relationships are determined by flexibility rates, γ, ϑ, φ, and ψ, respectively

$$GsS_A(t) = [\phi.GnE_A(t) + (1-\phi).Bd_A(t)].(1-PgN_A(t)) \quad (8)$$

$$Md_A(t) =[\Upsilon.RfC_A^-(t)+(1-\Upsilon).EfC_A(t)](1-RfC_A^+(t)) \quad (9)$$

$$Bn_A(t) =[\rho.RfC_A^+(t)+ (1-\rho).PfC_A(t)].(1-RfC_A^-(t)) \quad (10)$$

The current value for all of these temporal relations is related to the previous respective attribute. It should be noted that the change process is measured in a time interval between t and $t+\Delta t$. The operator Pos for the positive part is defined by Pos$(x) = (x + |x|)/2$, or, alternatively; Pos$(x) = x$ if $x \geq 0$ and 0 else.

$$ExH_A(t+\Delta t) = ExH_A(t)+\gamma.[(Pos(EsH_A(t)- ExH_A(t)).(1-ExH_A(t))) - Pos(-(EsH_A(t) - ExH_A(t)).ExH_A(t))]. \Delta t \quad (11)$$

$$EpN_A(t+\Delta t)=EpN_A(t)+ \vartheta.[(Pos ((Scp_A(t)- GpS_A(t))-EpN_A(t)).(1-EpN_A(t))) - Pos(- ((Scp_A(t)-GpS_A(t)) - EpN_A(t)).EpN_A(t))].\Delta t \quad (12)$$

$$GlS_A(t+\Delta t)= GlS_A(t) + \varphi.(GsS_A(t)-GlS_A(t)).(1- GlS_A(t)).GlS_A(t)].\Delta t \quad (13)$$

$$ScP_A(t+\Delta t)= ScP_A(t) + \psi.[(Pos(PgN_A(t) - ScP_A(t)).(1-ScP_A(t))) - Pos(-(PgN_A(t)- ScP_A(t)).ScP_A(t))].\Delta t \quad (14)$$

3.2. The Care Recipient Model

The care recipient model is another interacting components in the overall model. It has five instantaneous relations (care recipient perceived stress *RpS*, stress buffer *SbF*, care recipient short term stress *RsS*, care recipient functional *RfS*, and behavioural status *RbS*) and one temporal relation (care recipient long term stress *RlS*).

$$RpS_B(t) = \tau.RnI_B(t) + (1-\tau).RnE_B(t) \quad (15)$$

$$SbF_B(t) = \omega.RsG_B(t) \quad (16)$$

$$RsS_B(t) = [\lambda.Rp_B(t) + (1-\lambda).(1- RcS_B(t))].RpS_B(t).(1-Sbf_B(t)) \quad (17)$$

$$RfS_B(t) = RhS_B(t).RlS_B(t) \quad (18)$$

$$RbS_B(t) = Rp_B(t).RlS_B(t) \quad (19)$$

$$RlS_B(t+\Delta t)= RlS_B(t) + \eta.(RsS_B(t)-RlS_B(t)).(1-RlS_B(t)).RlS_B(t).\Delta t \quad (20)$$

Care recipient perceived stress is modelled by instantaneous relations (regulated by a proportional factor τ) between the care recipient negative interactions *RnI* and events *RnE*. Stress buffer is determined by ω times received support *RsG*. Care recipient short term stress depends on the relation between stress buffer *SbF*, and the proportion contribution λ of care recipient coping skills *RcS*, perceived stress *RpS*, and negative personality *RpS*. For the care recipient functional and behaviour status levels, both of these relations are calculated by multiplying the value of care recipient health problem status *RhS* and negative personality *Rp* with care recipient long term stress *RlS* respectively. In addition, the temporal relation of care recipient long term stress is contributed from the accumulation exposure towards care recipient short term stress with the flexibility rate η.

4. Simulation Results

In this section, a number of simulated scenarios with a variety of different conditions of individuals are discussed. Only three conditions are considered: prolonged, fluctuated stressor, and non-stressful events with a different personality profile. For clarity, cg and cr denotes caregiver and care recipient agent profiles respectively. The labels 'good' and 'bad' in Table 1 can also be read as 'effective' and 'ineffective' or 'bonadaptive' and 'maladaptive'.

Table 1: Individual Profiles

Caregiver		***GpR***	***GE***	***GpP***
cg1	('good' caregiver)	0.8	0.7	0.7
cg2	('bad' caregiver)	0.1	0.2	0.2
Care recipient		***RhS***	***Rp***	***RcS***
cr1	('good' coping skills)	0.9	0.9	0.8
cr2	('bad' coping skills)	0.9	0.9	0.1

Corresponding to these settings, the level of severity (or potential onset) is measured, defining that any individual that scored more than 0.5 in their long term stress level (within more than 336 time steps) then the caregiver or support receipt agent will be experiencing stress. There are several parameters that can be varied to simulate different characteristics. However, the current simulations used the following parameters settings: $t_{max}=1000$ (to represent a monitoring activity up to 42 days), Δt=0.3, (flexibility rate) $\varphi=\eta=\beta=\psi=\vartheta$=0.3, (regulatory rate) $\alpha=\beta=\Upsilon=\rho=\sigma=\phi=\tau=\lambda$=0.5, $\omega=\xi$=0.8. These settings were obtained from previous systematic experiments to determine the most suitable parameter values in the model.

Result # 1: Caregiver and receiver experience negative events. During this simulation, all agents have been exposed to an extreme case of stressor events. This kind of pattern is comparable to the prolonged stressors throughout a life time. For the first simulation trace (Fig. 2(a)), a good caregiver tends to provide a good social support provision towards its care recipient even facing persistent heighten stressors. This pattern is in line with the findings reported in [5]. One of the factors can be used to explain this condition is the increasing level of caregiver's personal gain. It proposes that caregivers do not unequivocally view caregiving as an overwhelmingly negative experience but can appraise the demands of caregiving as rewarding [4], [9]. Previous research works has also suggests that caregiving satisfaction is an important aspect of the caregiving experience and seem to share parallel relationships with other variables (e.g, personality and empathy) [4], [11]. Moreover, a good caregiver normally uses a problem focused coping to solve the perceived problem and later increases positive relationship focused coping. By the same token, research has consistently established a significant relationship between personal gains, problem focused coping, and positive social support. For example, several studies reported that caregivers who were satisfied with caregiving used more problem-focused coping [3]. Having this in motion, it provides a positive view of social support and later will be translated as a support received by the care recipient.

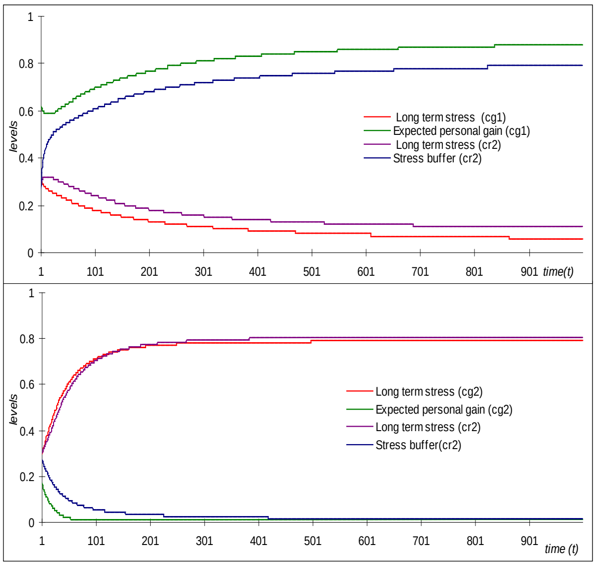

Figure 2: Simulations during prolonged stressors for (a, upper graph) a good caregiver and bad care recipient (b, lower graph) a bad caregiver and bad recipient

In the second simulation trace (as shown in Fig. 2(b)), both agents (caregiver and care recipient) are facing high long term stress levels in the long run. The precursors of having these conditions are perception of caregiving as a burden and the inability of the caregiver to provide positive coping during stressful events [11]. These factors lead to the decreasing level of caregiver's positive relationship focused coping and experienced personal gain, and later will reduce the ability to provide support. Additionally, in the real world, it can be perceived as feeling overwhelmed and out of control of the situation. This condition occurs almost within the majority of caregivers when they feel burdened by the demands of caregiving [6].

Result # 2: Caregiver and receiver experience different types of negative events. In this simulation, a new kind of stressor was introduced. This stressor comprises two parts: the first part is one with very high constant prolonged stressors, and is followed by the second one, with a very low stressor event. During simulation, the caregiver agents (cg*1* and cg*2*) were exposed towards these stressors, while the care recipient agents will only experience prolonged stressors. As it can be seen from Fig. 3(a), the graph indicates both agents (cg*1* and cr*2*) experience gradual drops in their long term stress. Comparison between Fig. 3(a) and Fig. 3(a), shows that the scenario's almost have a similar pattern, but 3(a) has a substantial decrease in a caregiver's long term stress level after the first half of the simulation. It is consistent with the findings that caregivers with a positive personality, empathic, and high personal resources tend to help more if they experienced less negative event [3], [8]. Meanwhile, Fig. 3(b) provides different scenarios. The simulation results show that caregivers with a negative personality, less empathic, and low personal resources is incapable to provide support during caregiving process. Note that despite the caregivers experience non-stressor events after the first half of the simulation, their care recipient is still experiencing a high long term stress level. Similar findings can be found in [5], [10].

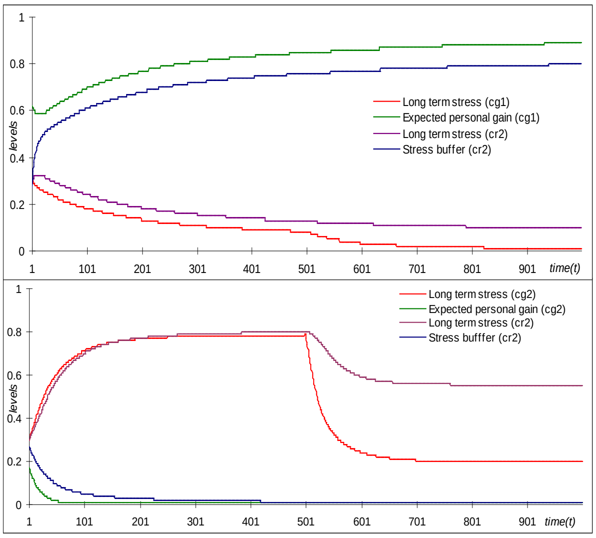

Figure 3: Simulation traces during different stressors for (a, upper graph) a good caregiver and bad care recipient (b, lower graph) a bad caregiver and bad recipient

Result # 3: Managing a good care recipient. In this part, simulation was carried out to investigate the effects of the caregiving behaviours of caregiver agents with different profiles to good care recipients, during prolonged negative stressors. Interaction between good caregiver and recipient shows that both agents have low long term stress levels, while the recipients stress buffer and the caregiver's expected personal gain are increasing [5], [7]. On the contrary, interaction between bad caregiver and good care recipient indicates that both agents are experiencing high long term stress levels. However, the care recipient experiences lesser long term stress compared to the caregiver.

5. Mathematical Analysis

In this section it is discussed which equilibria value are possible for the model, i.e., values for the variables of the model for which no change will occur. As a first step the temporal relations for both caregiver and care recipient will be inspected (refer to the equations (11),(12),(13),(14),and (20)). An equilibrium state is characterised by: $ExH_A(t+\Delta t) = ExH_A(t)$, $ScP_A(t+\Delta t)= ScP_A(t)$, $GlS_A(t+\Delta t)= GlS_A(t)$, $EpN_A(t+\Delta t)=EpN_A(t)$, and $RlS_B(t+\Delta t)= RlS_B(t)$. Assuming γ, ψ, φ, ϑ nonzero, and leaving out t, this is equivalent to:

$[(Pos(EsH_A-ExH_A).(1-ExH_A)) – Pos(-(EsH_A-ExH_A).ExH_A)] = 0$
$[(Pos(PgN_A-ScP_A).(1-ScP_A)) – Pos(-(PgN_A-ScP_A).ScP_A)] = 0$
$(GsS_A-GlS_A).(1-GlS_A).GlS_A = 0$
$[(Pos((ScP_A-GpS_A)–EpN_A).(1-EpN_A))-Pos(-((ScP_A-GpS_A)–EpN_A).EpN_A)] = 0$
$(RsS_B-RlS_B).(1-RlS_B).RlS_B = 0$

These equations are equivalent to:

$(EsH_A-ExH_A).(1-ExH_A) = 0$ and $(EsH_A-ExH_A).ExH_A = 0$
$(PgN_A-ScP_A).(1-ScP_A) = 0$ and $(PgN_A-ScP_A).ScP_A = 0$
$(GsS_A-GlS_A).(1-GlS_A).GlS_A = 0$
$((ScP_A-GpS_A) –EpN_A).(1-EpN_A)) = 0$ and
$((ScP_A-GpS_A) –EpN_A).EpN_A = 0$
$RlS_B = RsS_B$ or $RlS_B = 0$ or $RlS_B = 1$

These have the following solutions:

$EsH_A = ExH_A$ (21)
$PgN_A = ScP_A$ (22)
$GlS_A = GsS_A$ or $GlS_A = 0$ or $GlS_A = 1$ (23)
$ScP_A-GpS_A = EpN_A$ (24)
$RlS_B = RsS_B$ or $RlS_B = 0$ or $RlS_B = 1$ (25)

This means that for the caregiver short term and long term emotional exhaustion are equal (21). Also for both the caregiver and the care recipient short term and long term stress are the same, when the long term stress is not *0* or *1* (23) and (25). Moreover, for the caregiver social support provision is equal to expected personal gain (22), and on the other hand social support provision is equal to the sum of experienced personal gain and the caregiver's primary stressors (24).

6. Formal Verification of the Model

This section addresses the analysis of the informal caregiving interactions model by specification and verification of properties expressing dynamic patterns that are expected to emerge. The purpose of this type of verification is to check whether the model behaves as it should by running a large number of simulations and automatically verifying such properties against the simulation traces. A number of dynamic properties have been identified, formalized in the language TTL and automatically checked [2]. The language TTL is built on atoms state(γ, t) |= p denoting that p holds in trace γ (a trajectory of states over time). Dynamic properties are temporal predicate logic statements that can be formulated using such state atoms. Below, a some of the dynamic properties that were identified for the informal caregiving interactions model are introduced, both in semi-formal and in informal notation. Note that the properties are all defined for a particular trace γ or a pair of traces $\gamma1, \gamma2$.

P1 – Stress level of cg

For all time points t1 and t2 in traces γ1 and γ2
if in trace γ1 at t1 the level of negative life events of agent cg is x1
and in trace γ2 at t1 the level of negative life events of agent CG is x2,
and in trace γ1 at t1 the level of personal resources of agent cg is y1
and in trace γ2 at t1 the level of personal resources of agent cg is y1,
and in trace γ1 at t1 the level of long term stress of agent cg is z1
and in trace γ2 at t1 the level of caregiver stress of agent cg is z2,

  and x1 ≥ x2, and y1 ≤ y2, and t1 < t2,
then z1 ≥ z2.

$\forall\gamma1, \gamma2$:TRACE, $\forall$t1, t2:TIME $\forall$x1,x2, y1, y2, z1, z2:REAL
state(γ1, t1) |= negative_life_events(ag(cg), x1) & state(γ2, t1) |= negative_life_events(ag(cg), x2) & state(γ1, t1) |= personal_resources(ag(cg), y1) & state(γ2, t1) |= personal_resources (ag(cg), y2) & state(γ1, t2) |= long_term_stress(ag(cg), z1) & state(γ2, t2) |= long_term_stress (ag(cg), z2) & x1 ≥ x2 & y1 ≤y2 & t1 < t2
$\Rightarrow$ z1 ≥ z2

Property P1 can be used to check whether caregivers with more stressful life events and lack of resources will experience a higher level of caregiver (long term) stress. The property succeeded when two traces were compared where in one trace the caregiver had more (or equal) negative life events and less personal resources than the caregiver from the other trace. In this situation the first caregiver experienced more long term stress than the caregiver with more personal resources and less negative life events. Notice that since this property checks whether it is true for all time points in the traces, in some simulation traces the values for negative life events or personal resources change halfway the simulation trace, then the property succeeds for only a part of the trace, which can be expressed by an additional condition stating that t1 is at time point 500 (halfway our traces of 1000 time steps).

P2 – Stress buffering of cr

For all time points t1 and t2 in trace γ,
If at t1 the level of received social support of agent cr is m1
  and m1 ≥ 0.5 (high) and at time point t2 the level of the stress buffer of agent cr is m2
  and t2≥ t1+d,
then m2 ≥ 0.5 (high).

$\forall\gamma$:TRACE, $\forall$t1, t2:TIME $\forall$m1, m2, d:REAL
state(γ, t1) |= received_social_support(ag(cr), m1) & state(γ, t2) |= stress_buffer(ag(cr), m2) & m1 ≥ 0.5 & t2= t1+d
$\Rightarrow$ m2 ≥ 0.5

Property P2 can be used to check whether social support buffers the care recipient's stress. It is checked whether if the received social support in agent cr is high (a value higher or equal to 0.5), then the stress buffer of agent cr also has a high value after some time (having a value above or equal to 0.5). The property succeeded on the traces, where the received social support was higher or equal to 0.5.

Relating positive recovery of care receiver and social support from care giver

Property P3 can be used to check whether positive recovery shown by the care recipient, will make the caregiver provide more social support at a later time point. This property P3can be logically related to milestone properties P3a and P3b that together imply it: P3a & P3b $\Rightarrow$ P3. Given this, using the checker it can be found out why a hierarchically higher level property does not succeed. For example, when property P3 does not succeed on a trace, by the above implication it can be concluded that at least one of P3a and P3b cannot be satisfied. By the model checker it can be discovered if it is property P3a and/or P3b that does/do not succeed. Properties P3a and P3b are introduced after property P3 below.

P3 – Positive recovery of cr leads to more social support from cg

For all time points t1 and t2 in trace γ,
If at time point t1 the level of primary stressors of agent cg is d1
  and at time point t2 the level of primary stressors of agent cg is d2

and at time point t1 the level of received support of agent cr is f1
and at time point t2 the level of received support of agent CR is f2
and d2 ≥ d1, and t1< t2,
then f2 ≥ f1

∀γ:TRACE, ∀t1, t2:TIME ∀d1, d2, f1, f2:REAL
state(γ, t1) |= primary_stressors(ag(cg), d1) & state(γ, t2) |= primary_stressors (ag(cg), d2) &
state(γ, t1) |= received_social_support(ag(cr), f1) & state(γ, t2) |= received_social_support(ag(cr), f2) &
d2 < d1 & t1< t2
⇒ f2 ≥ f1

Property P3 succeeded in all generated simulation traces: when the primary stressors of the caregiver decreased, then at a later time point the received social support of the care recipient increased. In some simulation traces the property only succeeded on the first or second half of the trace. In these traces the primary stressors of the caregiver increased in the first part of the trace and then decreased in the second part of the trace. For this, a condition was added to the antecedent of the formal property, namely t1 = 500 or t2 = 500, so that the property is only checked on the second part or first part of the trace respectively.

P3a – Positive recovery of cr leads to more personal gain in cg

For all time points t1 and t2 in trace γ,
If at t1 the level of primary stressors of agent cg is d1
and at time point t2 the level of primary stressors of agent cg is d2
and at time point t1 the level of personal gain of agent cg is e1
and at time point t2 the level of personal gain of agent cg is e2
and d2 ≤ d1, and t1< t2
then e2 ≥ e1

∀γ:TRACE, ∀t1, t2:TIME ∀d1, d2, e1, e2:REAL
state(γ, t1) |= primary_stressors(ag(cg), d1) & state(γ, t2) |= primary_stressors (ag(cg), d2) &
state(γ, t1) |= expected_personal_gain(ag(cg), e1) & state(γ, t2) |= expected_personal_ gain (ag(cg), e2) & d2 < d1 & t1< t2
⇒ e2 ≥ e1

Property P3a can be used to check whether, the caregiver's expected personal gain will increase, if the primary stressors of the caregiver decrease. This property succeeded on the simulation traces where the primary stressors of the caregiver indeed decreased.

P3b – Personal gain in cg motivates cg to provide more social support to cr

For all time points t1 and t2 in trace γ,
If at time point t1 the level of personal gain of agent cg is e1
and at time point t2 the level of personal gain of agent cg is e2
and at t1 the level of received support of agent cr is f1
and at time point t2 the level of received support of agent cr is f2,
and e2 ≥ e1, and t1< t2,
then f2 ≥ f1

∀γ:TRACE, ∀t1, t2:TIME ∀e1, e2, f1, f2:REAL
state(γ, t1) |= expected_personal_gain(ag(cg), e1) & state(γ, t2) |= expected_personal_gain(ag(cg), e2) & state(γ, t1) |= received_social_support(ag(cr), f1) & state(γ, t2) |= received_social_support(ag(cr), f2) & e2 > e1 & t1< t2
⇒ f2 ≥ f1

Property P3b can be used to check whether the caregiver receives more social support if the expected personal gain of the caregiver increases. This property succeeded on the simulation traces where the expected personal gain indeed increased.

7. Conclusion

The challenge addressed in this paper is to provide a computational model that is capable of simulating the behaviour of an informal caregiver and care recipient in a caregiving process when dealing with negative events. The proposed model is based on several insights from psychology, specifically stress-coping theory, and informal caregiving interactions; see [3], [4]. Simulation traces show interesting patterns that illustrate the relationship between personality attributes, support provision, and support receiving, and the effect on long term stress. A mathematical analysis indicates which types of equillibria occur for the model. Furthermore, using generated simulation traces, the model has been verified against a number of properties describing emerging patterns put forward in the literature. The resulting model can be useful to understand how certain concepts in a societal level (for example; personality attributes) may influence caregivers and recipients while coping with incoming stress. In addition to this, it could be used as a mechanism to develop assistive agents that are capable to support informal caregivers when they are facing stress during a caregiving process. As part of future work, it would be interesting to expand the proposed model in a social network of multiple caregivers and care recipients.

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