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COMPUTATIONAL ANALYSIS AND EVALUATION FOR AN AGENT-BASED MODEL OF STRESS AMONG FLOOD VICTIMS

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Abstract
One of the serious negative psychological ramifications that leads to one's life destruction during natural disaster (e.g., flood or earthquake) is stress. Stress has been widely studied to know its mechanism but little work has been conducted to understand its dynamic impacts on natural disaster victims. This paper intends to present evaluation results made on an agent model that was developed previously. The designed model simulates the dynamics of stress effect in natural disaster victims and its evaluation processes show its correctness. Of importance to mention that two evaluation approaches were implemented to prove the validity of the model and ensure the model is adhere to psychological and cognitive literature. The evaluated model can be used as a basis in designing intelligent agents that have reasoning and analytical capability in providing intelligent, social, and proactive support to natural disaster victims suffering of stress negative impacts.

Keywords-- Mathematical Analysis; Cognitive Modelling; Agent-based Modelling; Intelligent Software Agent.

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INTRODUCTION

The last decades have seen a rapid growth of developing cognitive (behavioural or neural) models as a method to understand human mental state. These models have been used to understand the dynamic of human-functioning process such as stress, fatigues, and unipolar depression(Aziz, Ahmad, and Hintaya 2012; Both et al. 2008; Mohammed et al. 2016). Then, this obtained knowledge can be used to create intelligent software agents that possess human-like understanding. As a first step to achieve this, the correctness of these models must be ensured. These models' correctness is of crucial importance as these models give clear understanding on how reasoning properties can be attained to create intelligent support systems that own reasoning ability while providing support. This paper shows the undertaken activities that prove the correctness of a computational model that was developed earlier.

In the domain of natural disasters, a large number of people will be influenced with its negative impacts through an extension number of potential adverse effects, for example causalities, displacement, and property damage, which can destroy people life. Furthermore, negative psychological effects resulted from natural disaster effects have been examined and shown victims always suffer from stress symptoms, which normally occur when individuals are not able to cope with their losses. Several studies were carried out to study stress antecedents, impacts, and symptoms on victims during natural crisis. However, the dynamics of the interplay among stress factors is not computationally investigated thus a computational model of stress reaction on victims was made. The model was designed to include seven main groups, namely; predisposed factors, resilience, resources, individual attributes, coping, appraisal, and stress reaction. Additional information and discussions related to the developmental processes of the computational model can be found in(Mohammed et al. 2016).

Computational model evaluation refers to a range of activities carried out to prove that the process of developing a model and its expectations are correct, error-free and credible in a significant manner (Antoniadou, Barthorpe, and Worden 2014). Two well-studied mechanism to prove the validity of the developed computational agent model of stress reaction are introduced in this research work. These approaches are used in the literature to evaluate computational agent models for dynamic behaviours, called; mathematical analysis and automated analysis(Aziz, Ahmad, and Hintaya 2012; Bosse et al. 2009; Both et al. 2008; Mohammed et al. 2016; Sharpanskykh and Treur 2010). This paper is written in different sections as follows: Section 2 elaborates in a brief way the formation of the previously developed agent model of victims' stress reaction. Section 3 introduces the main concepts of mathematical analysis and automated analysis that have been largely used as computational techniques in checking agent-based models' correctness. After that, in Section 4 mathematical analysis is conducted to determine the equilibrium states of the model. Section 5 presents logical or automated analysis based on a number of selected cases/conditions identified from related psychological and cognitive empirical literatures. At last, the paper is concluded in Section 6.

AGENT BASED MODEL

Figure 1 gives a conceptual overview of the model developed in(Mohammed et al. 2016), which is based on the major theories in stress response among natural disasters victims. In this model, twelve different inter-related factors were established to construct the conceptual model of victims' stress. Once the constructional interplays of the model have been determined and depicted, the model was mathematically designed using a set of differential equations. This stage is done by following the *Network Oriented Modelling* Approach. Note here, all the interconnected nodes were linked to carry values varying from low (0) to high (1).

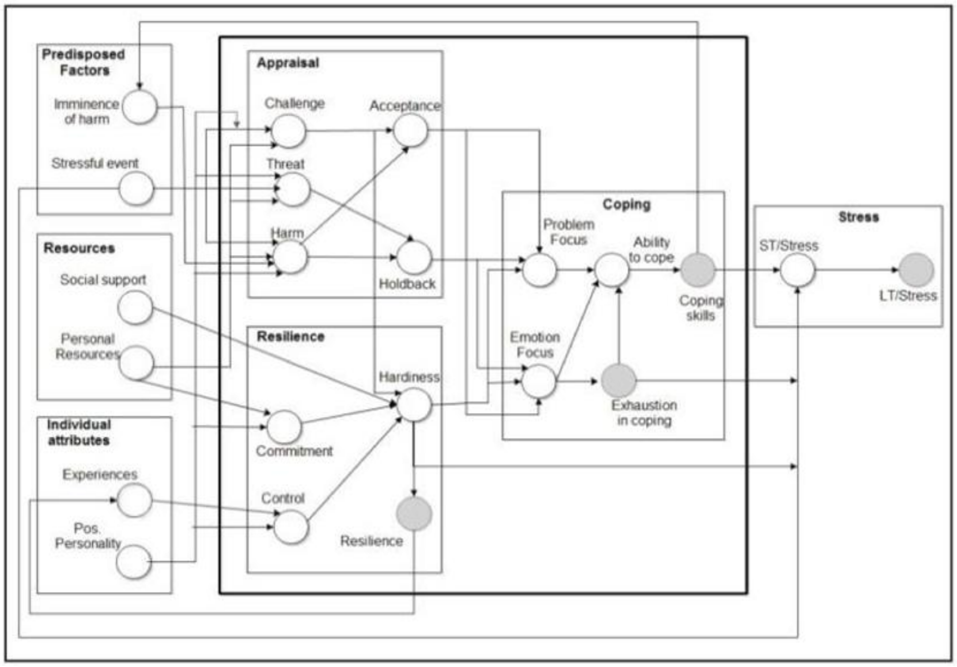

Figure 1. A Graphical Representation of the Interplay among Victims' Stress Factors

FORMAL SPECIFICATIONS

The interplays between the aforementioned factors (as in Figure 1) were grouped into two types based on their relationships; 1) instantaneous and 2) temporal factors. Instantaneous factors refer to the instant contribution, direct contribution to the entire behaviour, while temporal relationships are the accumulative effects (as depicted by Δt) of particular elements. Figure 2 presents all the model's equations, instantaneous and temporal relations that related to the computational agent model of victims' stress. More discussion of the model's equations can be seen in (Mohammed et al. 2016).

No	Concept	Specifications
1	Challenge	$Ch(t) = \lambda_{ch}.Ps(t) + (1-\lambda_{ch}).[1-(Se(t).(1-Pr(t)))].Ps(t)$
2	Harm	$Hm(t) = [1-(\beta_{hm}.Ps(t) + (1-\beta_{hm}).Pr(t))].[\beta_{hm}.Se(t) + (1-\beta_{hm}).Ih(t)]$
3	Threat	$Th(t) = [\omega_{th}.Se(t) + (1-\omega_{th}).(1-Pr(t)).Se(t)].(1-Ps(t))$
4	Imminence of Harm	$Ih(t) = Ph(t).(1-Cs(t))$
5	Acceptance	$Ap(t) = Ch(t).(1-Hm(t))$
6	Short-term Stress	$Ss(t) = \delta ss.[Se(t).(1-Cs(t))] + (1-\delta ss).[Ex(t).(1-Hd(t))]$
7	Exhaustion	$Ex(t+\Delta t) = Ex(t) + \mu_{ex}.(1-Ex(t)).[Ef(t) - Ex(t)].Ex(t).\Delta t$
8	Coping skills	$Cs(t+\Delta t) = Cs(t) + \beta_{cs}.(1-Cs(t)).[Ac(t) - (Cs(t)].Cs(t).\Delta t$
9	Long-term Stress	$Ls(t+\Delta t) = Ls(t) + \zeta_{ls}.(1-Ls(t)).[Ss(t) - Ls(t)].Ls(\Delta t)$
10	Ability to Cope	$Ac(t) = w_{ac1}.Pf(t) + w_{ac2}.Ef(t).[1-Ex(t)]$
11	Problem-focus Coping	$Pf(t) = (1-Hb(t)).[\beta_{Pf}.Ap(t) + (1-\beta_{Pf}).Hd(t)]$
12	Emotional-focus Coping	$Ef(t) = Hb(t).[(1-[\alpha_{Ef}.Ap(t) + (1-\alpha_{Ef}).Hd(t)])]$
13	Commitment	$Cm(t) = \alpha_{cm}.Ps(t) + (1-\alpha_{cm}).Pr(t)$
14	Holdback	$Hb(t) = \mu_{hb}.Th(t) + (1-\mu_{hb}).Hm(t)$
15	Hardiness	$Hd(t) = \omega_{h1}.Sc(t) + \omega_{h2}.Cm(t) + \omega_{h3}.Ch(t) + \omega_{h4}.Cl(t)$
16	Control	$Cl(t) = \beta_{cl}.Ps(t) + (1-\beta_{cl}).Ep(t)$
17	Experiences	$Ep(t) = \lambda_{ep}.Ep_{norm}(t) + (1-\lambda_{ep}).Rs(t)$

Figure 2. Concepts and Mathematical Specifications

All the defined formal specifications were programmed using numerical programming language (i.e., Matlab) and a set of reasonable simulation traces were generated for evaluation purpose. The simulated traces were generated to explain the important patterns that give an answer to why victims develop a level of stress (or does not develop stress) during stressful event like natural disaster. Figure 3 depicts the example of some simulation traces generated from the experiments. Later, these simulated traces were compared with the findings from the literature and were analyzed using mathematical analysis and automated logical verification.

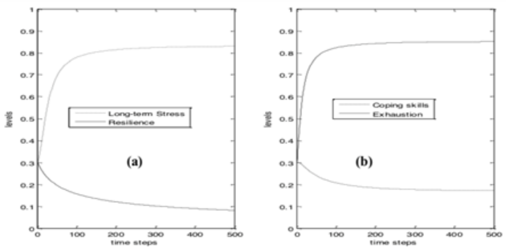

Figure 3. Example of Simulation Traces for (a) Long-term Stress and Resilience and (b) Coping Skills and Exhaustion

AGENT MODEL EVALUATION

The primary purpose in testing a numerical model is to ensure that the conceptual explanations and the model solutions are accurate. In other words, the validation stage is a method of ensuring that the concept is being appropriately developed and applied. This process will also give clear understandings of the behavior of the system and improve the computational models as well. Moreover, the evaluated model should reflect the real world to make sure that the model is correct and valid. In this paper, two well-known approaches will be used to verify the accuracy of the model, namely; mathematical analysis and logical verification. Mathematical analysis is carried out to test the model's conceptual and theoretical validity. Equilibrium analysis was performed to addresses the stability of solutions of differential equations and trajectories of temporal dynamic systems under a number of perturbations of initial conditions. It means equilibrium points hold long time behavior of real-world models. Solutions in particular frequently reach (or remain similar to) stable points of equilibrium as time gets large. For example, if given the difference equation;

$y_x+1= Ay_x + B$,

then an equilibrium value of y is given by,

$y^*=B/(1-A)$, if $A \neq 1$

and y^* is stable if and only if $-1 < A < 1$, unless y_x is constant. Therefore, a movement from the equilibrium value is equal to a new solution with different starting conditions, and thus a stable equilibrium can be defined as one for which any displacement from equilibrium is followed by a sequence of values of y which again converge to equilibrium.

Second approach is the logical verification which used as an alternative for manual proof as it is only feasible for formal specification of small systems. The Temporal Trace Language (TTL) is used as an automated verification approach where this proof-checking tool uses the presence of a set of generated traces and TTL proof checker implemented on a computer (Bosse et al. 2009). It can provide an answer in a few minutes or even seconds for many models as the search always terminates (due to the finite search space). TTL provides method for scientists to evaluate qualitative and quantitative specifications of given domains. Fundamentally, this formal language is based on a set of atoms to represent three main concepts, namely; 1) states of the world and its environment (world action), 2) time points (temporality), and 3) simulation traces. The interplay between these three concepts can be formalized as

state (γ, t)|= p

which means that state property p is true in the state of trace γ at time point t. TTL has a high expressive power. For example, the possibility of explicit reference to time points and time durations enables modelling of the dynamics of continuous real-time phenomena, such as cognitive behavioral analysis and neural models. If the verification results do not meet expected outcomes, the model was then revised. Otherwise, the model can be regarded as a model that can simulate the respected domain. The implementation of these two approaches will be covered in Section 4 and 5.

MATHEMATICAL ANALYSIS

In this section, the possible equilibrium points are analysed. There ought to be one essential assumption; all the exogenous variables have a constant value. Provided the assumption that all parameters are non-zero, this leads to the following equations where an equilibrium state is characterized by:

$dRs(t)/dt= \kappa_{rs}.(1-Rs)(Hd - Rs).\ Rs$ (18)
$dEx(t)/dt= \mu_{ex}.(1 - Ex).(Ef - Ex).\ Ex$ (19)
$dCs(t)/dt= \beta_{cs}.(1- Cs).\ (Ac - Cs).\ Cs$ (20)
$dLs(t)/dt= \zeta_{ls}.(1 - Ls).(Ss- Ls).\ Ls$ (21)

Next, the equations are identified,
dRs(t)/dt= 0, dEx(t)/dt= 0, dCs(t)/dt= 0, dLs(t)/dt= 0
Assuming adaptation rates are equal to 1, therefore, these are equivalent to,

$(Ss\text{-}Ls) \vee (Ls=0) \vee (Ls=1)$ (22)
$(Ac\text{-}Cs) \vee (Cs=0) \vee (Cs=1)$ (23)
$(Hd\text{-}Rs) \vee (Rs=0) \vee (Rs=1)$ (24)
$(Ef\text{-}Ex) \vee (Ex=0) \vee (Ex=1)$ (25)

Therefore, a first inference can be drawn where the equilibrium points will exist only when Cs =1, or Cs =0, or Ac=Cs as in equation 5). If all three conditions were combined, therefore a new set of relationships as in $(A \vee B \vee C) \wedge (D \vee E \vee F)$ expression can be formed:

$(Ss\text{-}Ls \vee Ls=0 \vee Ls=1) \wedge (Ac\text{-}Cs \vee Cs=0 \vee Cs=1) \wedge (Hd\text{-}Rs \vee Rs=0 \vee Rs=1) \wedge (Ef\text{-}Ex \vee Ex=0 \vee Ex=1)$ (26)

This expression can be elaborated using Law of Distributivity as $(A \wedge D) \vee (A \wedge E) \vee (A \wedge F) \vee, \ldots, \vee (C \wedge F)$ and this will result:

$(Ss\text{-}Ls \wedge Ac\ Cs \wedge Hd\text{-}Rs \wedge Ef\text{-}Ex) \vee (Ss\text{-}Ls \wedge Cs=0 \wedge Rs=0 \wedge Ex=0) \vee,\ldots, \vee(Ls=1 \wedge Cs=1 \wedge Rs=1 \wedge Ex=1)$ (27)

Equation 27 later provides possible combinations of equilibria points to be further analyzed. This leads to the difficulties to have a full analysis of complete equilibrium cases due to the large number of combinations that occurred (in this case 3^4 =81 probabilities). There are only five equilibria cases are discussed in this paper.

Case #1: Ex= 1 ^ Cs=0

In this case, from equation (10), this case is equivalent to:
$Ac = w_{ac1}.Pf$
If w_{ac1}=1, this case equivalent to $Ac = Pf$
Moreover, from equation (6) it follows that:
$Ss = \delta_{ss}.Se + (1-\delta_{ss}).\ [(1-Hd)]$
Assuming δ_{ss}=1, this case equivalent to $Ss = Se + (1 - Hd)$
Finally, from deeper analysis for equation (4), this case can be summarized to Ih = Ph.

Case #2: *Rs*=1

In this case, equation (17) will provide:
$Ep= \lambda ep.Ep_{norm}$
If $\lambda ep=1$, $\rightarrow Ep= Ep_{norm}$

Case#3: Ex=Ef ^ Cs=1

Equation (6) provides a set of equilibrium points through:
$Ss = (1 - \delta_{ss}).\ [Ef.\ (1 - Hd)]$
and if $\lambda_{ep} = 1$ therefore $Ss = 0$
In addition, from equation (14), the equilibria can be found
$Ac = w_{ac1}.Pf + w_{ac2}.Ef.\ [1 - Ef]$
Assuming $w_{ac1} = 1$, this case is equivalent to:
$Ac = Pf + Ef.\ [1 + Ef]$
Finally, from equation (4), this case is equivalent to $Ep=0$

Case #4: Rs=Hd

Consider equation (10), therefore this is equivalent to:
$Ep = \lambda_{ep}.Ep_{\mathrm{norm}} + (1 + \lambda_{ep}).Hd$
Assuming $\lambda_{ep}=1$ and $Ep_{norm}=1$, this is equivalent to $Ep = Ep_{norm}$ and $Ep = Hd$

Case #5: Ap=0

From equation (5), it leads to:
$Ch.\ (1 - Hm) = 0$, this leads to $Ch=0$ or $Hm=1$

AUTOMATED LOGICAL ANALYSIS

A number of experimental results from the simulation traces have been used as a foundation to evaluate the identified cases obtained from the literatures and were successfully confirmed. Following are some of the evaluated cases.

VP1: High resilience results low stress while encountering a stressful event (Tung, Ning, and Kris 2014)
VP1 ≡∀γ: TRACE, ∀t1, t2: TIME, ∀D1, D2: REAL, ∀X: INDIVIDUAL
[state (γ , t1)|= resilience_value(X, D1) &
state (γ , t2)|= long_stress_value(X, D2) &
D1 ≥ 0.8 & t2= t1+d] ⇒D2 ≤ 0.4

VP2: Hardiness works to control stress level (Abdollahi et al. 2015; Garrosa et al. 2008)**.**
VP2 ≡∀γ: TRACE, ∀t1, t2: TIME, ∀D1, B1, B2: REAL, ∀X: INDIVIDUAL
[state (γ , t1)|= hardiness_value(X, D1) &
state (γ , t1)|= high_stress_level(X, B1) &
state (γ , t2)|= high_stress_level(X, B2) &
D1 ≥ 0.8 & t2= t1+d] ⇒B1 ≤ B2

VP3: Problem-focused coping strategy will help to reduce the level of stress during stressful event (Dimiceli, Steinhardt, and Smith 2010)
VP3 ≡∀γ: TRACE, ∀B1, B2, D1, D2: REAL, t1, t2: TIME, ∀X: INDIVIDUAL
[state(γ,t1)|= problem_focus_coping(X, B1) &
state(γ,t2)|= problem_focus_coping(X, B2) &
state(γ,t1)|= high_stress_value(X, D1) &
state(γ,t2)|= high_stress_value(X, D2) &
tb ≤ t1 ≤ te & tb ≤ t2 ≤ te &
t1< t2 &B2 ≥ B1] ⇒D2 ≤ D1

VP4: Emotion focus strategy leads to exhaustion in coping (Clarke and Goosen 2009)**.**
VP4 ≡∀γ: TRACE, ∀B1, B2, D1, D2: REAL, t1, t2: TIME, ∀X: INDIVIDUAL
[state(γ,t1)|= emotion_focus_coping(X, B1) &
state(γ,t2)|= emotion_focus_coping(X, B2) &
state(γ,t1)|= high_stress_value(X, D1) &
state(γ,t2)|= high_stress_value(X, D2) &
B1 ≥ 0.6 & t2 = t1+d &B2 ≥ B1] ⇒D2 ≥ D1

VP5: This condition explains the value when it stays above or below another variable value for a specified interval.
VP5 ≡ ∀γ: TRACE, ∀B1, B2: REAL, t, tb, te: TIME, ∀X: INDIVIDUAL
[state(γ,t)|= has_value(X, B1) &
state(γ,t)|= has_value(X, B2) &
tb ≤ t ≤ te]⇒B2 ≥ B1

CONCLUSION

A computational agent model of stress reaction of victims' natural crisis was developed earlier as a first step towards developing an intelligent artefact that proactively mitigates natural disaster victims' stress (Mohammed et al. 2016). Evaluation process of the developed model is conducted in this paper to ensure its correctness and applicability. Accordingly, two approaches were implemented, namely; mathematical analysis and automated analysis. Mathematical analysis was performed to prove the occurrence of equilibria as a basis to describe convergence or stable points of the proposed model while automated analysis was performed to prove the adherence of simulation traces to psychology and cognitive literature. It can be concluded that the proposed model can be used as an analytical tool of a software agent that will support natural disaster victims at the evacuation centres. Future work will focus on the integration of pervasive and ubiquitous sensing technology with the proposed model.

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