Verification of an Integrated Computational Model of Self-Efficacy, Motivation and Anxiety for a Human Mental State

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ABSTRACT

Knowledge acquisition has been considered a major bottleneck in the development of knowledge base systems. This problem can be narrowed through the development of models that helps in defining the set of knowledge to be acquired from domain experts, hence decrementing unfruitful knowledge elicitation efforts. The constructs of self-efficacy, motivation and anxiety have been established to define human mental states leading to behavioural complexities in the selected domain. Current researches in the field of human-centred AI are beginning to formally represent these constructs as leeway to building systems that understand human complexities. However, in order to ensure that the solutions of such computational models comply with the conceptual description of the theoretical foundations of the constructs, the models must be evaluated. This paper applied two techniques of mathematical analysis and automatic verification using Temporal Trace Language (TTL) for the verification of the formalized integrated model of the constructs. The formalized integrated model is suitable for further validation using a human experiment. The results will serve as the first stage into the computational understanding of the human state influence for knowledge elicitation.

Keywords: formal model, human-aware system, mental state, knowledge acquisition, model verification.

I INTRODUCTION

The understanding of human behavioural dynamics in a simulated environment using the technique of cognitive modelling is providing a platform for innovative applications and solutions that leads to the building of intelligent systems (Zhang et al. 2013). Knowledge acquisition has been considered a major bottleneck in the development of knowledge base systems. One of the major obstacles is to explicitly recognize and capture knowledge relevant to the intended application especially from domain experts due to their human behavioural dynamics. This can be narrowed through the development of models which helps in defining the set of knowledge to be acquired from the domain experts, hence decrementing unfruitful knowledge elicitation efforts (Akhavan, Shahabipour, and Hosnavi 2018). The constructs of self-efficacy, motivation and anxiety have been established to define human mental states leading to behavioural complexities in many domains (Piniel and Csizér 2013, 2014). Harnessing the interplaying factors to integrate the constructs is an essential aspect of identifying the mental framework in human cognition (Piniel and Csizer 2015; Piniel and Csizér 2014). Therefore, the integrated model of the mental state constructs can serve as an intelligent

needed to be done to ascertain that the modelling processes are robust, and the attendant outcome is sufficiently accurate and credible (Antoniadou, Barthorpe, and Worden module of a computational framework for a human-aware system intended for a given domain knowledge acquisition (Robins, Margulieux, and Morrison 2019). There have been empirical studies with conflicting results on the interplays between these three distinct but related psychological constructs of self-efficacy, motivation and anxiety. Hence, a computational analysis of the integration of the constructs will narrow the contradictions.

However, for computational models to comply with authentic interpretations of the theoretical foundations of the constructs its meant to analyze, the models must go through a thorough evaluation procedure (Riedmaier et al. 2020). A model evaluation implies the sets of action taken to ensure that a model is developed correctly. It is a vital step in the computational modelling development process. It is the range of activities 2014). Therefore, model credibility and usability are related topics that are concerned with evaluation (Pace 2004). These procedures are used to evaluate evidence to determine the capabilities of simulation, its limitations and performance with the real-world situation or a given standard (Sarget 2013).

Mathematical analysis and logical verification are among well-known verification techniques for an agent-based computational modelling approach. Mathematical analysis methods have been applied such as stability analysis (mathematical proof for equilibrium point determination) (Bosse et al. 2014), and sensitivity analysis (the varying of the model parameters to observe the behaviour of the simulation).

Several techniques are available also for logical analysis or automatic verifications of models (Riedmaier et al. 2020). The formal verification of a program consists of proving that its execution satisfies a given specification of the possible temporal behaviours it should display (Antoniadou et al. 2014). In order to study the dynamics of a simulation model, specific dynamics statement (i.e., temporal logical expressions), which are either expected or not expected to hold, are automatically verified against simulation results (e.g., traces or patterns) (Ullah and Treur 2019). Temporal Trace Language (TTL) has been used extensively for automatic verification in cognitive models. TTL supports formal analysis of dynamic properties of a system, covering both qualitative and quantitative aspects. Dynamic properties are temporal statements that can be formulated concerning traces based on the state of the biological entity being analyzed. TTL is built on atoms trajectories (traces) of states over time (Hoogendoorn, Jaffry, and Van Maanen 2011). This technique has been implemented in (Azizi et al. 2016; Bouarfa, Blom, and Curran 2016; Hoogendoorn et al. 2014).

II METHODOLOGY

The tripartite constructs of motivation, cognition (self-efficacy), and affect (anxiety) is a fundamental part of an intertwined framework when the mental process is being investigated (Dörnyei and Macaro 2010). The review of these constructs has seen common external and internal factors as well as the output states of a construct causally influencing another construct. By leveraging on these interplays, an integrated model is designed and formalized.

In order to ensure the fidelity of the formalized integrated model, this paper adopts two verification methods, 1) mathematical verification using stability analysis, and 2) automatic verifications using temporal trace language. The integrated model consists of several temporal equations, which can be explored by analyzing the equilibrium points of the model. This concept is referred to as what stability analysis entails. Stability points are also verified using value substitutions to confirm if some sets of dynamic properties will behave when values are substituted. During this stage, a set of properties are identified from the literature to verify the correctness of the model. The identified properties are then specified by Temporal Trace Language (TTL). Once these techniques confirm the suitability of the equilibria points and conform with known facts from literature, then the model is ascertained else the model would have to be reconceptualized and formalized for further evaluation. The structural representation of this conceptual model and equations of the temporal relationships are visualized in Figure 1 and Table 1.

The cohesive integration of the model is conducted by considering the relationships between the factors of the three underlying models by applying merging and composition integration techniques.

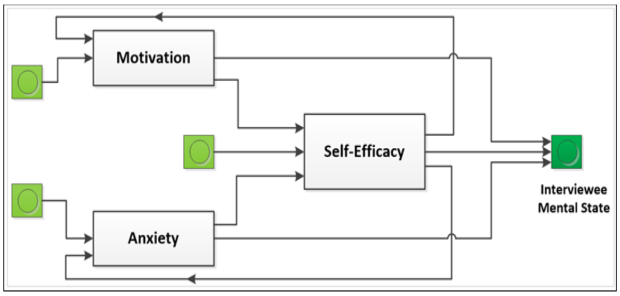

Figure 1. The architecture of the integrated mental states model

The three models got their common input factors with the same conceptual definitions fused. The output from one of the models can serve as input to another.

Table 1. Equations of the temporal relationships of the factors of the integrated model

Equation	Representation
$Lm(t+\Delta t) = Lm(t) + \alpha_{lm}.\begin{bmatrix} Pos(Sm(t)-Lm(t)).(1-Lm(t))- \\ Pos(-(Sm(t)-Lm(t)-\lambda)).Lm(t) \end{bmatrix}.\Delta t$	Long-time motivation
$Lw(t+\Delta t) = Lw(t) + \alpha_{lw}.\begin{bmatrix} Pos(Sw(t)-Lw(t)).(1-Lw(t))- \\ Pos\left(-(Sw(t)-Lw(t))\right).Lw(t) \end{bmatrix}.\Delta t$	Long-time worry (Anxiety)
$Lf(t+\Delta t) = Lf(t) + \gamma_{lf}.(Sf(t)-Lf(t)).Lf(t).(1-Lf(t)).\Delta t$	Long-time Efficacy)

III RESULTS AND DISCUSSION

A. Mathematical Analyses of the Integrated Model

The equations as re-stated below are used to derive the equilibria states of 3 temporal equations representing the three key observed outputs from the integrated model (self-efficacy, motivation and anxiety).

Verification of Stability through Value Substitutions of Lw, Lm, and Lf in the Integrated Model

The stability of the temporal factors in the integrated model shown in Figure 2 is used to illustrate this verification method as follows.

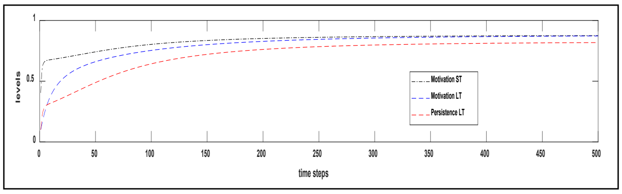

Figure 2. **Simulation results of the** integrated **model stability points**

Considering the high states of long-term efficacy (Lf), Long-term memory (Lm) and Long-term worry (Lw) using numerical representation at time t=400. The simulation result shows $Lf(400)$ = 0. 76214, $Lm(400)$ = 0.82046, $Lw(400)$ = 0.74231.

The accuracy of the simulation results can be confirmed by substituting the numerical values at the time t into the temporal equations to make comparisons.

The equations expressing that each of the states in the equations in Table 1 (i.e. *Lw, Lm, Lf*) is stabilized at time *t* are

$$Lm(t) = (Sm(t)) \quad (1)$$

$$Lw(t) = (Sw(t)) \quad (2)$$

$$Lf(t) = (Sf(t)) \quad (3)$$

⇨ For *Lm(400)*= 0.82046

the equation for Sm(t) is

$$Sm(t) = \psi_{sm}.Ve(t) + (1 - \psi_{sm}).Ep(t) \quad (4)$$

Where

$$Ve(400) = 0.78927, Ep(400) = 0.86101, and\ \psi_{sm} = 0.5$$

$$= (0.5).0.78927 + (0.5).0.86101$$

⇨ 0.82046 ≈ 0.82514

The result above shows that the equation is fulfilled with a negligible error margin (less than 10^{-2}). The result of the motivation, as implemented, is in tandem with the expected behaviour.

⇨ For *Lf(350)*= 0.76214

the equation for Sf(t) is

$$Sf(t) = \psi_{sf}.\left(\omega_{sf1}.Gp(t) + \omega_{sf2}.Ea(t) + \omega_{sf3}.LpE(t)\right) + (1 - \psi_{sf}).Be(t) \quad (5)$$

Where

$$Gp(350) = 0.78222, Ea(400) = 0.617516, LpE(400) = 0.78407, Be(400) = 0.8100$$

$$\psi_{sf} = 0.5, \omega_{sf1} = \omega_{sf2} = \omega_{sf3} = 0.33$$

$$= 0.5 * 0.33(0.78222 + 0.617516 + 0.78407) + 0.5 * 0.81000$$

⇨ 0.76214 ≈ 0.76533

With a negligible error margin of less than 0.01, the results above prove the fulfilling of the temporal equation. The result of the self-efficacy, as implemented in the model, agrees with the expected behaviour and therefore proven.

⇨ For *Lw(400)*= 0.74231

the equation for Sw(t) is

$$Sw(t) = (\varphi_{sw}.Bw(t) + (1 - \varphi_{sw}).Th(t)) * \left(1 - \left(\begin{matrix}\psi_{sw}.Cr(t) + \\ (1 - \psi_{sw}).Ap(t)\end{matrix}\right)\right) \quad (6)$$

Where

$$Bw(400) = 0.80841, Th(400) = 0.75340, Cr(400) = 0.06987, Ap(400) = 0.02564$$

$$\psi_{sw} = 0.5, \varphi_{sw} = 0.5$$

$$= (0.5 * 0.80841 + 0.5 * 0.75340) * (1 - (0.5 * 0.06987 + 0.5 * 0.02564))$$

⇨ 0.74231 ≈ 0.74361

The result shows an error margin of less than 0.001. This finding proves the fulfilling of the temporal equation of anxiety in the integrated model. The result of anxiety, as implemented in the model, equally agrees with the expected behaviour.

The three fundamental temporal equations which determine the behaviour of the integrated model have been proved to maintain stability. This is achieved by value substitution method above and each of the comparisons shows a negligible error. It is therefore correct to say that the integrated model achieves stability and behaving as expected.

B. Temporal Trace Language for Integrated Model

TTL is suitable for formal specification and analysis of dynamic properties of models and systems. TTL is an extension of order-sorted predicate logic with explicit facilities to represent dynamic properties of systems. It is assumed that the state language and the TTL define disjoint sets of expressions. Therefore, the same notations for the elements of the object language and their names in the TTL are used without introducing any ambiguity. Also used are t with subscripts and superscripts for variables of the sort TIME; and γ with subscripts and superscripts for variables of the sort TRACE. Some known cases from literature are analyzed as follows

VP1: The perceived sense of efficacy plays a crucial role in the arousal of anxiety.

VP1 ≡ ∀γ: TRACE, ∀t1, t2:TIME, ∀ V1, F1, F2, d:REAL
[state(γ,t1)|= perceived efficacy(V1) &
state(γ,t1)|= anxiety(F1) &
state(γ,t2)|= anxiety(F2)&
V1 < 0.2 & t2 ≥t1 +d] ⇒ F2 > F1

The social cognitive theory asserts that one's perceived sense of self-efficacy plays a key role in anxiety arousal (Wood and Bandura 2013). An individual experiences anxiety when they are relatively doubtful of their capabilities (low self-efficacy) to manage potentially detrimental events. Consistently, the two main references in this area show that low levels of self-efficacy are usually accompanied by high levels of anxiety capable to affect performance (Yang et al. 2020).

VP2: Threat affects motivation and anxiety

VP2 ≡ ∀γ: TRACE, ∀t1, t2:TIME, ∀ V1, F1, F2, D1, D2, d:REAL
[state(γ,t1)|= threat(V1) &
state(γ,t1)|= anxiety(F1) &
state(γ,t1)|= motivation(D1) &
state(γ,t2)|= anxiety(F2)&
state(γ,t2)|= motivation(D2)&
V1 > 0.7 & t2 ≥t1 +d] ⇒ F2 > F1 & D2 < D1

The threat is a psychological or a mental state in which an individual perceives himself/herself as being unable to cope with a task (Riskind and Calvete 2020). This condition happens when coping resources is not enough to manage the task demand. Therefore, it can be linked to loss of faith in personal competence which can lead to a state of worry (Hirsch and Mathews 2012) and fail in the efforts and perseverance which are the critical ingredients of motivation (Owusu, Larbie, and Bukari 2020).

VP3: Persistence in task mediate the complementary effects of motivation and self-efficacy

VP3 ≡ ∀γ: TRACE, ∀t1, t2:TIME, ∀X1,X2,X3:REAL
[state(γ,t1)|= persistence(v, X1) &
state(γ,t2)|= self_efficacy(v, X2) &
state(γ,t2)|= motivation(v, X3) &
X1> 0.8 tb ≤ t1 ≤ te & tb ≤ t2 ≤ te]
⇒ X2 ≥ 0.5 & X3 ≥ 0.5

Self-efficacy improves an individual's motivation to undertake projects and persists in the pursuit of his/her goals, in the face of setbacks and difficulties that may periodically test his/her drive (Hasanah et al. 2019). High sense of self-efficacy, therefore enhances one's strength to persevere and persistence is an instrument to improving motivation in a task. A positive association between intrinsic and extrinsic exercise motivation and exercise self-efficacy, mindfulness and intrinsic exercise motivation, and mindfulness and exercise self-efficacy have also been reported in (Neace et al. 2020).

IV DISCUSSION

The verification process ensures that a correct model has been built. First, the mathematical component of the verification analyses the possible equilibria points. The essential assumptions in such analysis are that external factors, that is, the inputs to the model are constant values and having non-zero parameters. Equilibrium of three temporal equations is verified through value substitution. The value an equilibria points is taken at a certain time *t* in the simulation and compared with the substituted numerical values at the time *t* into the temporal equations. The three substitutions show levels of consistency and accuracy as the values are almost equal.

Automatic verification of the traces in the simulation was carried out using TTL. The cases where this method is employed in this study are typical situations requiring a check of properties on a few sets of traces obtained by simulation. The resultant description in predicate logic format are statements that conform with known proven statement in the literature that was used to formulate the conceptual model. The models are built from concepts and theories that have been proven overtimes.

V IMPLEMENTATION

The verified integrated model of the constructs (self-efficacy, motivation and anxiety) would require validation with a human experiment in a natural environment to obtain a unified cognitive model in the domain. Consequently, the integrated cognitive agent model could serve as an underlying reasoning model to design an intelligent artefact that can provide supports to human actions in the domain. Therefore, the integrated cognitive model serves as an intelligent module of a computational framework for a proposed human-aware system intended for a specific domain. This type of system, known as an ambient intelligent system, can be developed by deploying the cognitive agent model as a reasoning engine (Robins et al. 2019). To this regard, therefore, more informed decisions based on the reasoning engine in a manner that show human-like behaviours can be achieved. Though this is still a developing concept, however, the intent is for a model that could be encapsulated within existing virtual agents to simulate a human mental state in addition to other verbal and non-verbal behaviours the systems are meant to realize.

VI CONCLUSION

This paper describes model verification which is the final stage of formalization of an integrated model of three psychological constructs (self-efficacy, motivation and anxiety) that have been studied to define the human mental state during activities. The equations of the temporal relationships of the integrated model were analyzed mathematically and TTL was used to verify known facts in literature against the simulated result of the final model. This result paved the way for further validation using human experiment.

The outcome is a first step to designing a human-aware system with an integrated model of mental state as an intelligent engine which can understand the dynamically changing human states. It will serve as a tool for knowledge elicitation from domain expert for a development of a knowledge-based system.

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