Computational Analysis of Dynamics in an Agent-Based Model of Cognitive Load and Reading Performance

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Abstract. To avoid the development of cognitive load during task-specific actions, technologies like companion robots or intelligent systems may benefit from being aware of the dynamics of related mental performance constructs. As a first step toward the development of such systems, this paper uses an agent-based approach to formalize and simulate cognitive load processes within reading activities, which may involve specific assigned task. The obtained agent-based model is analysed both by mathematical analysis and automated trace evaluation. Based on this description, the proposed agent-based model has exhibited realistic behaviours patterns that adhere to the psychological and cognitive literature. Moreover, it is shown how the agent-based model can be integrated into intelligent systems that monitor and predict cognitive load over time and propose intelligent support actions based on that.

Keywords: Agent-based model · Temporal Trace Language Cognitive load · Intelligent systems · Verification analysis

1 Introduction

Recent studies have shown a great focus placed upon the development of computational agent-based models as core foundations to understand and analyse physical and mental states of human [1]. These models equipped intelligent systems and robotic artefacts applications with the prime ability to reason in supporting people. The key success of integrating these agent-based models within intelligent systems extremely depends on the correctness of the model as provided by grounding theories in related domain of interest. Therefore, a thorough evaluation process of an agent-based model is essential to ascertain the process and its predictions are accurate and credible significantly [2]. From this spectrum a number of agent models have been developed and evaluated as in [3–5]. Therefore, it inspires this paper to focus on thorough computational analysis (through formal evaluation) of an agent-based model of cognitive load and reading performance that was previously developed in [6]. Two prominent approaches to evaluate the model are implemented namely; *mathematical analysis* and *automated logical analysis* [3, 5, 7, 8]. This paper is organized as follows. First, in Sect. 2, the underlying constructs and a set of factors related to cognitive load and

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reading performance concepts are introduced. Next, the model design and its implementation are shown in Sects. 3 and 4 respectively. The computational analysis of the agent-based model is presented in Sect. 5. Finally Sect. 6 concludes the paper.

2 Background in Cognitive Load and Reading Performance

The process to solve difficult tasks often subjected to a high level of cognitive load that may exceed individuals' cognitive resources and as a result they may not be able to regulate the load imposed by the task (e.g. reading process to solve assignments with certain levels of difficulties). This condition can be explained through some scenarios of monotonous decreases in individual's performance over time [9]. A number of grounding theories was developed to explain the development of a cognitive load level during reading processes through the interplays between related factors and its relationship [9, 11]. The factors are shown in Table 1 and its relationships between those factors are explained in Sect. 3.

Table 1. Nomenclatures for factors of cognitive load and reading performance

Factor	Formalization
Reading task complexity	*Tc*
Time pressure	*Tp*
Task presentation	*Tn*
Physical environment	*Pe*
Personal profile	*Pp*
Experience level	*Ev*
Prior knowledge	*Pk*
Reading norm	*Rn*
Reading demands	*Rd*
Situational aspects	*Sa*
Reading goal	*Rg*
Reading effort	*Rf*
Motivation	*Mv*
Expertise level	*Ev*
Intrinsic load	*Id*
Extraneous load	*Ed*
Germane load	*G*)
Germane resources	*Gr*
Mental load	*Ml*
Mental effort	*Me*
Mental ability	*Ma*
Cognitive exhaustion	*Ce*
Reading engagement	*Rm*

(*continued*)

Table 1. (*continued*)

Factor	Formalization
Critical point	*Ex*
Experienced exhaustion	*Cp*
Recovery effort	*Re*
Short term exhaustion	*Sh*
Accumulative experienced exhaustion	*Ax*
Accumulative exhaustion	*Ae*
Cognitive load	*Cl*
Reading performance	*Rp*
Persistence	*Pr*

It is noteworthy to mention that all the theoretical explanations of identified factors (from related grounded theories) are described in our previous works as in [10, 11].

3 Agent-Based Modeling Approach

This section explains the implementation of *Network-oriented Modeling* approach (based on *Temporal Causal Network*) to construct a computational agent-based model of cognitive and reading performance [1]. Consequently, the identified factors from Sect. 2 are used to conceptualize the causal computational agent model as depicted in Fig. 1.

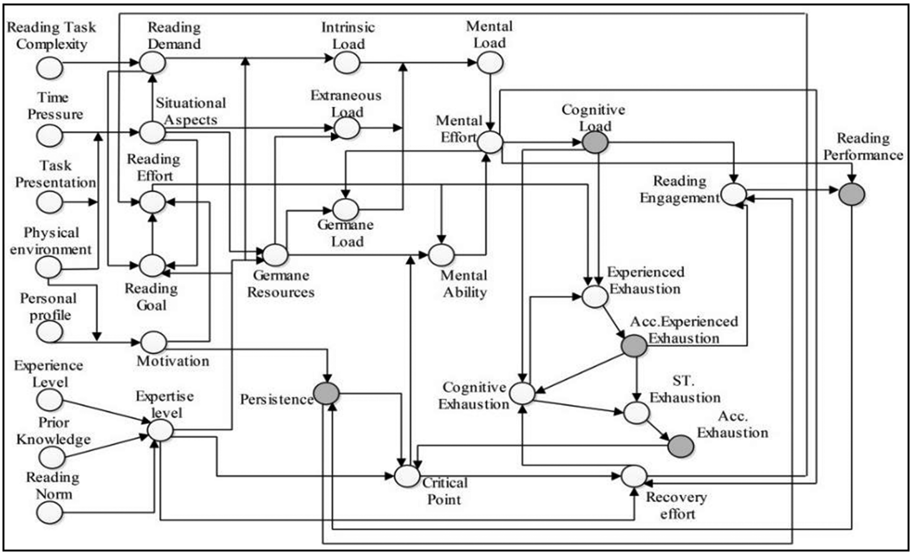

Fig. 1. Global relationships of variables involved in the cognitive load and reading performance

Once the structural relationships in the model have been determined, the formalization process will take place. In our proposed agent-based model, all nodes are designed in a way to have values ranging from 0 (low) to 1 (high). Furthermore, the model was formalized with respect to time using a set of First-Order Differential Equation specifications and can be divided into instantaneous and temporal relationships.

3.1 Instantaneous Relationships

Instantaneous relationships refer to the factors that have direct contribution with respect to time factor. For example, reading demand (*Rd*) is formalized as follows:

$$Rd(t) = \eta_{rd}.Tc(t) + (1 - \eta_{rd.\mathrm{Tc}}).Sa(t) \tag{1}$$

Equation (1) explains that the level of reading demand is determined by the proportional contribution of η_{rd} between basic of reading task complexity (*Tc*) and the level of the load imposed by the situational aspects (*Sa*). Similarly, this formal concept is used to formalize all concepts as in all Eqs. (2)–(19).

$$Gd(t) = \gamma_{\mathrm{Gd}}.Me(t) + (1 - \gamma_{\mathrm{Gd}}).Me(t).(1 - Gr(t)) \tag{2}$$

$$\begin{aligned} Sa(t) = \lambda_{\mathrm{sa}}.[\mathrm{w}_{sa1}.Tp(t) + \mathrm{w}_{sa2}.Pe(t)] + (1 - \lambda_{sa}) \\ .[Tp(t).Pe(t).(1 - Tn(t))] \end{aligned} \tag{3}$$

$$Ev(t) = \zeta_{ev}.(\mathrm{w}_{ev1}.El(t) + \mathrm{w}_{\mathrm{ev2}}.Pk(t)) + (1 - \zeta_{ev}).Rn(t) \tag{4}$$

$$Gr(t) = \omega_{gr}.Ev(t) + \left(1 - \omega_{gr}\right).Ev(t).(1 - Sa(t)) \tag{5}$$

$$Me(t) = (1 - Ma(t)).Ml(t) \tag{6}$$

$$Ml(t) = \mathrm{w}_{ml1}.Id(t) + \mathrm{w}_{ml2}.Ed(t) + \mathrm{w}_{ml3}.Gd(t) \tag{7}$$

$$Ma(t) = \mathrm{w}_{ma1}.Rf(t) + \mathrm{w}_{ma2}.Cp(t) + \mathrm{w}_{ma3}.Gr(t) \tag{8}$$

$$Id(t) = Rd(t).(1 - Ev(t)) \tag{9}$$

$$Ed(t) = \beta_{ed}.Sa(t) + (1 - \beta_{ed}).Sa(t).(1 - Gr(t)) \tag{10}$$

$$Sh(t) = \mu_{st}.Ce(t) + (1 - \mu_{st}).Ax(t) \tag{11}$$

$$Ex(t) = (\mathrm{w}_{ex1}.Cl(t) + \mathrm{w}_{ex2}.Ce(t)).(1 - Rf(t)) \tag{12}$$

$$Re(t) = \mathrm{Pos}((\mathrm{w}_{re1}.Cp(t) + \mathrm{w}_{re2}.Ev(t)) - Me(t)) \tag{13}$$

$$Rm(t) = Pr(t).[1 - (\mathrm{w}_{rm1}.Ax(t) + \mathrm{w}_{rm2}.Cl(t))] \tag{14}$$

$$Ce(t) = (\alpha_{ce}.Cl(t) + (1 - \alpha_{ce}).Ax(t)).(1 - Re(t)) \quad (15)$$

$$Cp(t) = \alpha_{cp}.Ev(t) + \left(1 - \alpha_{cp}\right).Pr(t).Ev(t).(1 - Ae(t)) \quad (16)$$

$$Rg(t) = \zeta_{rg}.\mathrm{Ev}(t) + \left(1 - \zeta_{rg}\right).\left[\mathrm{w}_{rg1}.Rd(t) + \mathrm{w}_{rg2}.(1 - (Sa(t).(1 - Ev(t))))\right] \quad (17)$$

$$Rf(t) = \gamma_{rf}.\left(\mathrm{w}_{rf1}.Mv(t) + \mathrm{w}_{\mathrm{rf2}}.Rg(t)\right) + \left(1 - \gamma_{rf}\right).Re(t) \quad (18)$$

$$Mv(t) = \lambda_{mv}.Pp(t) + (1 - \lambda_{mv}).(1 - Pe(t)) \quad (19)$$

3.2 Temporal Relationships

In an agent-based model, the temporal factors are changeable over time due to the interaction between two or more instantaneous factors and often imposed by the delay or accumulative effects of previous values. For example, in Eq. (20), the prolong exposure towards short-term exhaustion (*Sh*) contributed towards the new level of accumulative exhaustion (*Ae*) in a time interval between t and $t + \Delta t$.

$$Ae(t + \Delta t) = Ae(t) + \beta_{Ae}.[Sh(t) - Ae(t)].Ae(t).(1 - Ae(t)).\Delta t \quad (20)$$

Furthermore, the speed of change over time is proportionally determined by the change parameter β_{Ae}. This concept is used throughout temporal relationships as in (21)–(24).

$$Ax(t + \Delta t) = Ax(t) + \eta_{Ax}.Ex(t).[1 - Ax(t)].\Delta t \quad (21)$$

$$Cl(t + \Delta t) = Cl(t) + \beta_{Cl}.[Me(t) - Cl(t)].Cl(t).(1 - Cl(t)).\Delta t \quad (22)$$

$$\begin{aligned} Pr(t + \Delta t) = Pr(t) + \omega_{Pr}.\left[\left[\mathrm{w}_{\mathrm{pr1}}.Mv(t) + \mathrm{w}_{pr2}.Rp(t)\right] - Pr(\mathrm{t}) - \beta_{dp}\right] \\ .(1 - Pr(t)).Pr(t).\Delta t \end{aligned} \quad (23)$$

$$Rp(t + \Delta t) = Rp(t) + \eta_{Rp}.[((1 - Me(t))\,.Rm(t)) - Rp(t)].(1 - Rp(t)).Rp(t).\Delta t \quad (24)$$

In both of instantaneous and temporal equations, several parameters (ranges from 0 to 1) are used. For example, from Eqs. (11) and (18), parameters μ_{st} and γ_{rf} represent the regulation factors, while η_{Rp} (from Eq. (24)) represents the rate change for that particular temporal relationship.

4 Simulation Results

Thereafter, several simulation experiments are conducted by a set of initial variations in different agent exogenous inputs to visualize the patterns of the designed agent-based model. In this paper, different variations for three fictional readers (i.e., in a form of agent) are simulated. These simulated scenarios have taken into account the condition of demanding tasks are assigned to all agents but with different personalized settings. The variations are shown as the following; (1) agent ***A***: (expert reader but less motivated), (2) agent ***B***: (expert reader and highly motivated), and (3) agent ***C***: (non-expert reader and less motivated). For brevity in our discussion, our simulation results only cover intrinsic, extraneous, germane, and cognitive load as depicted in Fig. 2.

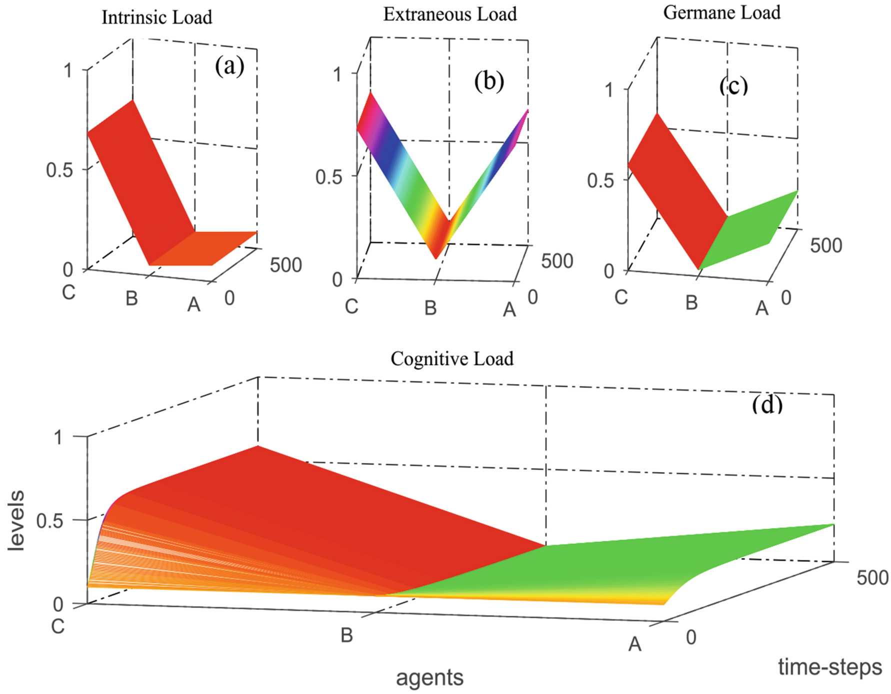

Fig. 2. Simulation results of (a) intrinsic, (b) extraneous, (c) germane, and (d) cognitive load

From Fig. 2, the simulation results show that an agent ***A*** is performing a demanding reading task that requires a high mental effort to be accomplished (e.g. difficult assignments and limited time duration). Nevertheless, the high expertise level has enabled the reader to cope with the demands and curbs the potential progression of cognitive load. However, due to reader's neurotic personality and situated in a non-conducive environment, the observed level of cognitive load is slightly increased. In a long run, this condition can be manifested as a result of high level of extraneous load as seen in Fig. 2(b). Contrary, a high motivation level reduces reader's cognitive load level [12].

In our simulation, similar scenario can be seen within an agent ***B*** (with high expertise level, highly motivated, positive personality (i.e., *openness*) and located within an ambience environment). However, an agent ***C*** shows the contradictory results due to intolerance towards the demands (e.g. *highly difficult task*), not well prepared, discomfort environment, and overwhelming time pressure. Moreover, an agent ***C*** is not motivated to perform the task with inadequate level of knowledge. Detailed explanations about thorough simulation results and settings were used in the experiments can be found in the previous work, as in [6].

5 Formal Verification

In modeling and simulation, correctness and reliability of the models are of the main challenges in developing any cognitive agent models. Within this context, the model correctness is generally understood to mean the extent to which a model implementation conforms to its formal specifications and is free of design errors [13]. The verification process can be defined as can be defined as; "*the process aids of ensuring that the conceptual description and the solution of the model are implemented correctly*". Furthermore, this process is implemented to improve important understanding of the system behaviour, improve computational models, estimate values of parameters, and evaluate (local/global) system performance.

In the light of the above, *mathematical analysis* and *automated logical analysis* are used to obtain an evaluated model of the proposed agent-based model. In mathematical analysis, the equilibrium or stability points are derived to ensure the model is

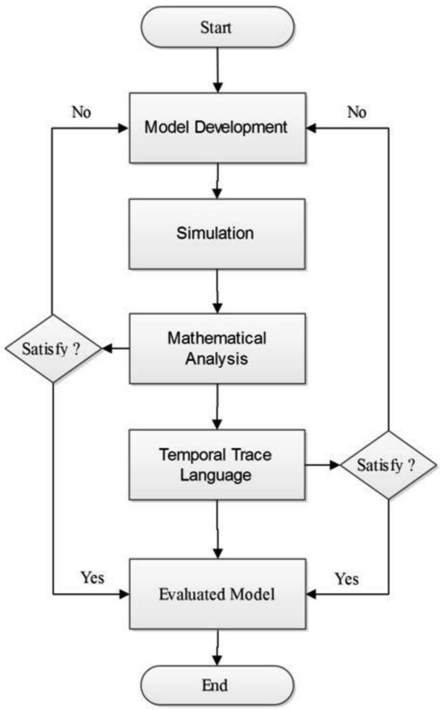

Fig. 3. An agent-based model formal evaluation process

developed as planned. While, automated logical analysis (using Temporal Trace Language) aims to evaluate the validity of the model, which means the generated results of the model adhere to the existing literature. The process of designing and evaluating cognitive agent models are summarized in Fig. 3.

5.1 Mathematical Analysis

The main goal of this approach is to check the theoretical correctness of the model using stable point's analysis of the agent-based model. It is a well-known technique whereas the existence of reasonable equilibria is an indication for the correctness of the model [5]. To analyse the equilibria, both instantaneous and temporal equations are replaced with values for the model variables such that the derivatives are all zero. For instance, the generic differential equation is used to formalize the model can be seen as follows:

$$Y(t+\Delta t) = Y(t) + \beta_y.Y.\langle change\_expression\rangle.\Delta t$$

This differential equation can be re-written into:

$$dY(t)/dt = \beta_y.Y.\langle \text{change\_expression}\rangle$$

Next, the equilibrium points will be generated when all $dY(t)/dt = 0$. The temporal variables of the model written in differential equations as follows:

$$dAe/dt = \beta_{Ae}.(Sh - Ae).Ae.(1 - Ae) \tag{25}$$

$$dPr/dt = \omega_{pr}.\left[\left[\mathrm{w}_{pr1}.Mv + \mathrm{w}_{pr2}.Rp\right] - Pr - \beta_{dp}\right].Pr.(1 - Pr) \tag{26}$$

$$dAx/dt = \eta_{Ax}.Ex.(1 - Ax) \tag{27}$$

$$dCl/dt = \beta_{Cl}.(Me - Cl).(1 - Cl).Cl \tag{28}$$

$$dRp/dt = \eta_{Rp}.[((1 - Me)\ .Rm) - Rp].(1 - Rp).Rp \tag{29}$$

Assuming the parameters ω_{pr}, β_{Ae}, η_{Ax}, β_{Cl}, η_{Rp} are nonzero, from Eqs. 25 to 29, the following cases can be distinguished:

$$(Sh - Ae).Ae.(1 - Ae) = 0,$$

$$\left[\left[\mathrm{w}_{pr1}.Mv + \mathrm{w}_{pr2}.Rp\right] - Pr - \beta_{dp}\right].Pr.(1 - Pr)\ = 0,$$

$$Ex.(1 - Ax) = 0,$$

$$(Me - Cl).(1 - Cl).Cl = 0,$$

$$[((1 - Me)\ .Rm) - Rp].(1 - Rp).Rp = 0.$$

Assuming $w_{pr1}.Mv + w_{pr2}.Rp = Aa$, and $(1 - Me).Rm = Bb$.

Later these cases can be solved into:

$$\begin{aligned}&(Sh = Ae) \vee (Ae = 1) \vee (Ae = 0)\\&(Pr = 1) \vee (Pr = 0) \vee \left(Pr = Aa - \beta_{dp}\right)\\&(Cl = Me) \vee (Cl = 1) \vee (Cl = 0)\\&(Rp = 1) \vee (Rp = 0) \vee (Rp = Bb)\\&(Ex = 0) \vee (Ax = 1)\end{aligned}$$

From here, a first conclusion can be derived as the equilibrium can only occur when $Sh = Ae$, $Ae = 1$, or $Ae = 0$. By combining these three conditions, it can be re-written into a set of relationship in $(A \vee B \vee \mathrm{C}) \wedge (D \vee E \vee \mathrm{F})$ expression:

$$\begin{aligned}&((Ae = Sh) \vee (Ae = 1) \vee (Ae = 0)) \wedge \left((Pr = 1) \vee (Pr = 0) \vee \left(\mathrm{Pr} = Aa - \beta_{dp}\right)\right)\\&\wedge ((Cl = Me) \vee (Cl = 1) \vee (Cl = 0)) \wedge ((Rp = 1) \vee (Rp = 0) \vee (Pr = Bb))\\&\wedge ((Ex = 0) \vee (Ax = 1))\end{aligned}$$

This expression can be elaborated using the *law of distributivity* $(A \wedge D) \vee (A \wedge E) \vee, \ldots, \vee (C \wedge F)$ as:

$$\begin{aligned}&((Ae = Sh) \wedge (Pr = 1) \wedge (Cl = Me) \wedge (Rp = 1) \wedge (Ex = 0))\\&\vee ((Ae = Sh) \wedge (Pr = 0) \wedge (Cl = 1) \wedge (Rp = 0) \wedge (Ax = 1))\\&\vee \ldots \left((Ae = 0) \wedge \left(Pr = Aa - \beta_{dp}\right)\right) \wedge ((Cl = 0) \wedge (Rp = Bb) \wedge (Ax = 1))\end{aligned}$$

Therefore, large number of possible equilibrium points are generated (in this case $(2(3^4)) = 162$). In addition, mathematical analysis cannot be performed to all equilibrium cases because some of them are not existed in the simulation traces or even in the literatures. For example;

$$\begin{aligned}&\left((Ae = 0) \wedge \left(\left(w_{pr1}.Mv + w_{pr2}.Rp\right) - \beta_{dp} = Pr\right)\right)\\&\wedge ((Cl = 0) \wedge ((Rp = (1 - Me).Rm)) \wedge (Ax = 1))\end{aligned}$$

This case shows accumulative exhaustion level is equal to zero ($Ae = 0$) and in the same time the accumulative level of experienced exhaustion is equal to one ($Ax = 1$). Despite the possible combinations in a theoretical construct, this case is not existed in the real-world. Note here, due to the large number of possible combinations, it is hard to provide a complete classification of equilibria. However, for some cases the analysis can be pursued further.

Case #1: *Cl* = 1 ∧ *Rp* = 0 ∧ *Ax* = 1 ∧ *Pr* = 0 ∧ *Ae* = *Sh*
For this case (it can be seen in Fig. 4(a–c), by Eq. (11) it follows that

$$Sh = \mu_{st}.Ce + (1 - \mu_{st}) \text{ and } \mu_{st} = 0.5$$

Thus, *Sh* = *Ce* which depicts the level of short term exhaustion (*Sh*) is always determined by the current level of cognitive exhaustion (*Ce*). In other words, the level of short-term exhaustion is always high when the level of cognitive exhaustion is high and the vice versa. The effect of the stability points in short-term exhaustion and cognitive exhaustion levels can be seen in Fig. 4(c).

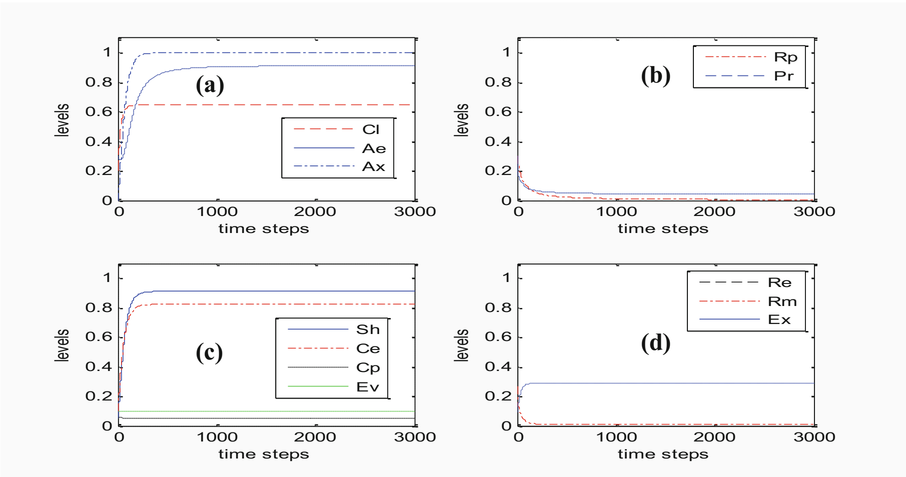

Fig. 4. Simulation results of the stability points in Case #1.

Moreover, by Eq. (12) it follows that:

$$Ex = (w_{ex1} + w_{ex2}.Ce).(1 - Rf), \text{ and } w_{ex2} = 1 \text{ then } Ex = Ce.(1 - Rf)$$

This concept shows recovery effort is negatively contributed to the level of experienced exhaustion. Also, experienced exhaustion is positively correlated with the high cognitive exhaustion level. The simulation result of this analysis can be visualized in Fig. 4 (c and d). Moreover, the Eq. (14) yields: *Rm* = 0 which depicts the level of reading engagement is equal to zero when the reader experiences high level of cognitive load, accumulative experienced exhaustion, and accumulative exhaustion. Figure 4(b) and (d) depicts the effects of the stable points in *Rm*. Next, by Eq. (15)

$$Ce = (\alpha_{ce} + (1 - \alpha_{ce})).(1 - Re)$$

Assuming α_{ce} is nonzero, then this is equivalent to $Ce = 1 - Re$.

The condition explains the negative correlation between cognitive exhaustion and recovery efforts. The result can be seen in Figs. 3(d) and 4(c).

Finally, Eq. (16) follows that

$$Cp = \alpha_{cp}.Ev \text{ and } \alpha_{cp} \text{ is nonzero } \rightarrow Cp = Ev$$

This condition explains the development of critical point levels is completely depending to the level of expertise a reader has in tackling difficulties of the tasks (as depicted in Fig. 4(c)).

The same concept is also implemented in Cases 2 and 3, and the results were satisfied. The detailed description is as follows:

Case #2: *Cl* = 1
For this case, by Eq. (12) it follows

$$Ex = (\mathrm{w}_{ex1} + \mathrm{w}_{ex2}.Ce).(1 - Rf)$$

Hence by Eq. (14), it is equivalent to:

$$Rm = Pr.[1 - (\mathrm{w}_{rm1}.Ax + \mathrm{w}_{rm2})]$$

Moreover, by Eq. (15) it follows $Ce = (\alpha_{ce} + (1 - \alpha_{ce}).Ax).(1 - Re)$.
Assuming $\alpha_{ce} \neq 0$, this equivalent to $Ce = Ax.(1 - Re)$.
Since it can recall that $Ax = 1$, this leads to $Ce = (1 - Re)$.

Case #3: *Ae* = 1 ∧ *Ax* = 1
From Eq. (11) it follows the case is equivalent to

$$Sh = \mu_{st}.Ce + (1 - \mu_{st})$$

Assuming μ_{st} equal to 1, this equals to $Sh = Ce$.

By Eq. (14), it follows

$$Rm = Pr.[1 - (\mathrm{w}_{rm1} + \mathrm{w}_{rm2}.Cl)]$$

Moreover, the results in Eq. 15, $Ce = (\alpha ce.Cl + (1 - \alpha_{ce})).(1 - Re)$.

Equation (16) is equivalent to $Cp = \alpha_{cp}.Ev$.

5.2 Automated Analysis

To check the model truly yields results adhere to the existing cognitive load literatures, a set of properties have been identified from the literatures. These properties have been specified in a language called Temporal Trace Language (TTL). TTL is built on atoms referring to states of the world, time points, and traces. This relationship can be presented as holds ($state(\gamma, t), p$) or $state(\gamma, t)| = p$, which means that state property p is true in the state of trace γ at time point t (details on TTL can be found in [14]). Based on that concept, the dynamic properties can be formulated using a hybrid sorted predicate logic approach, by using quantifiers over time and traces and First-Order Logical connectives (FOPL) such as ¬, ∧, ∨, ⇒, ∀, and ∃. TTL is used by generating a finite state space of a formal model of a system and later verifies a property written in some temporal logic specifications, through an explicit state space search. It can provide an answer in a few minute or even seconds for many models as the search always terminates (due to the finite search space). A number of simulations including the ones described in Sects. 4 and 5 have been used as basis for the automated verification of the identified properties and were confirmed.

VP1: Readers with a high level of persistence tends to reduce cognitive load level.

$$\begin{array}{l} \text{VP1} \equiv \forall\gamma\text{:TRACE}, \forall \text{t1,t2:TIME}, \forall \text{D,B1,B2, R1,R2:REAL}, \forall \text{X:AGENT} \\ [\text{state}(\gamma, \text{t1}) |= \text{persistence(X, B1)}\ \& \\ \ \text{state}(\gamma, \text{t2}) |= \text{persistence(X, B2)}\ \& \\ \ \text{state}(\gamma, \text{t1}) |= \text{cognitive\_load(X,R1)}\ \& \\ \ \text{state}(\gamma, \text{t2}) |= \text{cognitive\_load(X,R2)}\ \& \\ \ \text{t2} > \text{t1} + \text{D}\ \&\ \ \text{B2} > 0.6\ \&\ \text{B2} \geq \text{B1}] \Rightarrow \text{R2} < \text{R1} \end{array}$$

The property VP1 is used to check the impact of reader's persistence level on the level of cognitive load. It shows that readers with high level of persistence (having a value greater or equal to 0.6) tend to experience low cognitive load. This result is in line with the literature as in [12].

VP2: Readers with high level of expertise possess high critical power [16].

$$\begin{array}{l} \text{VP2} \equiv \forall\gamma\text{:TRACE}, \forall \text{t1, t2:TIME}, \forall \text{X1, X2, C, D:REAL}, \forall \text{A:AGENT} \\ \text{state}(\gamma, \text{t1}) |= \text{expertise\_level(A, C)}\ \& \\ \text{state}(\gamma, \text{t1}) |= \text{critical\_power(A, M1)}\ \& \\ \text{state}(\gamma, \text{t2}) |= \text{critical\_power(A, M2)}\ \& \\ \text{C} \geq 0.8\ \&\ \text{t2} = \text{t1+D} \Rightarrow \text{M2} \geq \text{M1} \end{array}$$

VP3: Non-conducive learning environment increases cognitive load [17].

$$\begin{array}{l} \text{VP3} \equiv \forall\gamma\text{:TRACE}, \forall \text{t1, t2:TIME}, \forall \text{V1, V2, Q, D:REAL}, \forall \text{A:AGENT} \\ \text{state}(\gamma, \text{t1}) |= \text{ambience\_room(A, Q)}\ \& \\ \text{state}(\gamma, \text{t1}) |= \text{cognitive\_load(A, V1)}\ \& \\ \text{state}(\gamma, \text{t2}) |= \text{cognitive\_load(A, V2)}\ \& \\ \text{Q} < 0.2\ \&\ \text{t2} = \text{t1+D} \Rightarrow \text{V2} \geq \text{V1} \end{array}$$

VP4: Reading performance is high when cognitive load is low.

$$\begin{array}{l} \text{VP4} \equiv \forall\gamma\text{:TRACE}, \forall \text{t1,t2:TIME}, \forall \text{D,V1,V2, R1,R2:REAL}, \forall \text{X:AGENT} \\ [\text{state}(\gamma, \text{t1}) |= \text{cognitive\_load(X, B1)}\ \& \\ \ \text{state}(\gamma, \text{t2}) |= \text{cognitive\_load(X, B2)}\ \& \\ \ \text{state}(\gamma, \text{t1}) |= \text{reading\_performance(X,R1)}\ \& \\ \ \text{state}(\gamma, \text{t2}) |= \text{reading\_performance(X,R2)}\ \& \\ \ \text{t2} > \text{t1} + \text{D}\ \&\ \ \text{B1} < 0.2\ \&\ \text{B1} \geq \text{B2}] \Rightarrow \text{R2} \geq \text{R1} \end{array}$$

This property used to check the impact of cognitive load on reading performance. It depicts that low level of cognitive load (having a value below 0.2) increases reading performance level [15].

6 Conclusion

Cognitive and psychological models of humans' physical and mental states have been showing a great success in creating intelligent systems able to analyse and perform human-like understanding and base on this understanding a personalize support can be provided. From this standpoint, an agent model of cognitive load and reading performance was developed and formally analysed to ensure the correctness of the model. This paper presented two widely-used approaches to evaluate the cognitive and reading performance model. These approaches are mathematical analysis and automated logical analysis. The results showed that the model is correctly developed and it exhibited realistic behaviour patterns of the intended domain. For the future work, more cases are required to be analysed to consolidate the internal validation of the model. Furthermore, parameter tuning is of much interest to be implemented to confirm the external validation which means individuals experiments to fit with individual differences.

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