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A Model Combining BDI Logic and Temporal Logics for Decision-Making in Emergency Situations

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Abstract

Nowadays, we are dealing with panic and unpleasant situations in which, we are constrained to make crucial decisions in a limited delay, due to the mixed emotions that may affect our decision, especially FEAR, this kind of emotion occurs when unwanted or uncontrollable events are present in the environment. These recent years, fear modelling has been well researched and since this emotion is usually associated with the fact that one or more fundamental desires are at stake Unluckily, most of these models miss that FEAR does not always occur similarly in all agents. This paper proposes a new conceptual architecture with a new component by extending BDI logic with the emotion of FEAR, so that the new Emotional-BDI agents may better cope with extremely dynamic unpleasant situations in their surroundings. We also address how we verify the emotional properties by employing a model checker NuSMV. The proposed architecture confirms that NuSMV can be applied to verify the emotional specifications we can program agents that are capable of reasoning over emotions, our experimental results indicate the viability and efficiency of our model.

Keywords: *Emotional-BDI, Model checking, NuSMV, CUDD, Unpleasant situations.*

1 Introduction

One of the most famous and best-researched architectures for software agents is the BDI architecture. The architecture is widely acknowledged because of its philosophical underpinnings [1], [2] and its logical frameworks for modelling and reasoning artificial agents [3], and a large number of software systems that use the architecture's ideas [4], [5]. However, there were some limitations regarding adding various emotions to these agents known as Emotional Agents, which take findings from research into the positive elements of human emotions [6] and apply artificial models of them to Rational Agents.

This paper proposes a solution to this problem, which is a new conceptual Emotional-BDI architecture that aims at expanding the standard BDI architecture with Emotions and some psychological traits. These traits could play an important factor in modelling emotions artificially that may be implemented computationally. These new BDI architectures with these new implementations will focus on the level of people's awareness of fear, where people can consciously manipulate these concepts and communicate them to others [7]. This allows easy mapping of expert knowledge to agent behaviour and helps non-computer scientists understand agent behaviour.

We also outline the first steps towards the creation of an agent architecture that would support psychologically realistic models of human emotion variability while taking into account individual variations and external effects. We have used research from psychology and cognitive science normally from the OCC theory to create a framework that encompasses many of the known mechanisms that drive emotions.

We have based our approach on the OCC model's emotional expansion of the BDI model [8] and we add the emotion of fear as a new modulator of this extended model.

This paper is organized as follows. Section 2 describes the related works, and some previous research, Section 3 gives a demonstration of the BDIE model, and BDIE logic proposed, in section 4, an overview of the proposed architecture with a simulation of two case studies will be given, and Section 5 discuss some results. Finally, Section 6 concludes the paper and outlines some future work.

2 Related Work

At least 150 psychological and philosophical theories of emotion have been put forward [11]. The OCC emotion theory is one that computer scientists frequently employ. For this, it leverages ideas that are widely understood and rather simple to codify, and as a result, it offers a clear classification of a wide range of emotion types and includes succinct explanations of the circumstances that trigger emotions [12, 13]. Based on the OCC theory, certain rigorous formalizations that expand the logical theories of agents to include emotions have been put forward (see Table 1).

Table 1: Main papers contributing to BDI and OCC theory

Reference	Title	Contribution
[14]	Reasoning about emotional agents. Int. J. Intell	Meyer and colleagues formalized the belief-desire preconditions of the four fundamental emotions (happiness, sadness, anger, and fear) provided in Oatley and Johnson-theory Laird's of emotion using KARO, the agent logic based on dynamic logic enhanced with BDI-type modal operators.
[15]	Formal modelling of emotions in BDI agents	According to Pereira et al., the influence of emotions on thinking and decision-making is just as important as an agent's beliefs, wants, and intentions in determining their behaviour.
[12]	A logical formalization of the OCC theory of emotions	Adam et al. are committed to formalizing feelings in BD items by including OCC's assessment variables in an enhanced version of the Cohen-Levesque logic.
[13]	A formal model of emotion triggers: an	The cognitive motivational preconditions of the emotions taken into account by the OCC theory

	approach for BDI agents	were formalized by Steunebrink et al. using KARO.
[16]	A probabilistic formalization of the appraisal for the OCC event-based emotions.	To compute and express the strength of the event-based emotions of the OCC model, Gluz and Jaques use a probabilistic version of the BDI model based on affective probabilistic logic (AfPL).
[19]	A Computationally Grounded Model of Emotional BDI-Agents	Instead of extending emotions to the semantic model, which would allow for the formal verification of emotional properties using model-checking tools, the study solely employs modal operators (such as B, D, and I) to establish the logical definitions of emotions.
[31]	The Perception of Emotion in Artificial Agents	As we get closer to fully emotional artificial agents, Ruud Hortensius et al. offered an assessment of the state of emotional expression and perception in social robots as well as a clear articulation
[32]	Sentiments and emotions evoked by news headlines of the coronavirus disease (COVID-19) outbreak	Faheem Aslam et al have extracted and classified sentiments and emotions from 141,208 headlines of global English news sources regarding the coronavirus disease (COVID-19) then were classified into positive, negative and neutral sentiments, Their analysis revealed that the news headlines had high emotional scores around 52% for negative sentiments and only 30% evoked positive sentiments while 18% were neutral. Fear, trust, anticipation, sadness, and anger were the main emotions evoked by the news headlines
[33]	BEN: An Architecture for the Behaviour of Social Agents	The BEN architecture was developed by Mathieu Bourgais and colleagues and included modules to add emotions, emotional contagion, personality, social interactions, and norms to agent behaviour. It was subsequently integrated into the GAMA simulation platform. Then they demonstrated how to use BEN to simulate the evacuation of a burning nightclub
[34]	Bridging the gap between emotion and joint action	Marta M.N. Bieńkiewicz et al made a review about the gap between emotion and joint action they first identified the gap and then stockpile evidence showing the strong entanglement between emotion and acting together from various branches of sciences then they proposed their integrative approach to bridge the gap and link them in behavioural neuroscience and digital sciences.

The challenge of determining whether an emotional model functions as intended and how to keep its logic simple still exists despite all the opportunities to extend the BDI architecture. The work mentioned above lacks some temporal expressivity, such as the semantics of models mentioned above that are defined over the Kripke semantics in terms of possible worlds and accessibility relations, and it is still unclear how to obtain concrete emotional agent models using the BDI architecture [14].

3 Proposed Approach

In this section, we introduce the conceptual system model and the interpreted BDI system model. Next, we follow the representation in [18], where the agent has local observations.

3.1 The Fearful Emotional BDI System Model

This section gives a brief overview of the Ortony, Clore, and Collins (OCC) theory of emotion, which aims to expand on the BDI-system model by incorporating well-being emotion modalities (fear) and certain psychological characteristics. After that, we started creating a new conceptual model of emotion triggers for BDI agents using the interpreted-based BDIE system model (also known as the BDIE model for short). A schema describing the proposed architecture is presented in Fig 1.

The OCC Theory of Emotion. A cognitive appraisal theory of emotion, put out by Ortony, Clore, and Collins, describes the triggering circumstances of 22 emotion kinds categorized into six groups. The OCC theory is organized as a three-branch typology, which corresponds to three categories of stimuli: outcomes of events, agent actions, and facets of objects. Refer to Fig. 2 below.
In this essay, we emphasize the feeling of well-being (fear). This group of feelings occurs when a person feels terrified by a recent incident while ignoring the possibility that it will have negative effects on them personally. In other words, when an agent is worried about a bad occurrence, it feels Fear.
The Fearful Interpreted BDIE System Model. The main goal of this BDIE model is to represent an agent's emotions, in this case, FEAR, as a collection of runs (computing pathways), which perfectly corresponds to a system in the interpreted system model.
Here we follow the introduction given in [18] we can address the fearful BDI interpreted system
Given a set G of global states and a system K over G, an agent i 's mental states (belief, desire, intention) and emotional states (joy and distress) over the system K are defined as a tuple $\mathcal{M}_i =< \mathcal{B}_i, \mathcal{D}_i, \mathcal{I}_i, fear_i >$ where $fear_i$ is a system (sets of runs over G). The runs in $fear_i$ are computing that the agent i feels unpleasant. According to the OCC theory, the desirable consequences (or goals) are achieved after the intentional choices of possible actions.

Then, a BDIE system S is defined as a structure $S =< K, M_1, \ldots M_n >$, where K is a system and for each i, M_i is the agent's mental states (believe, desire, and intention) and emotional states (FEAR) over K.

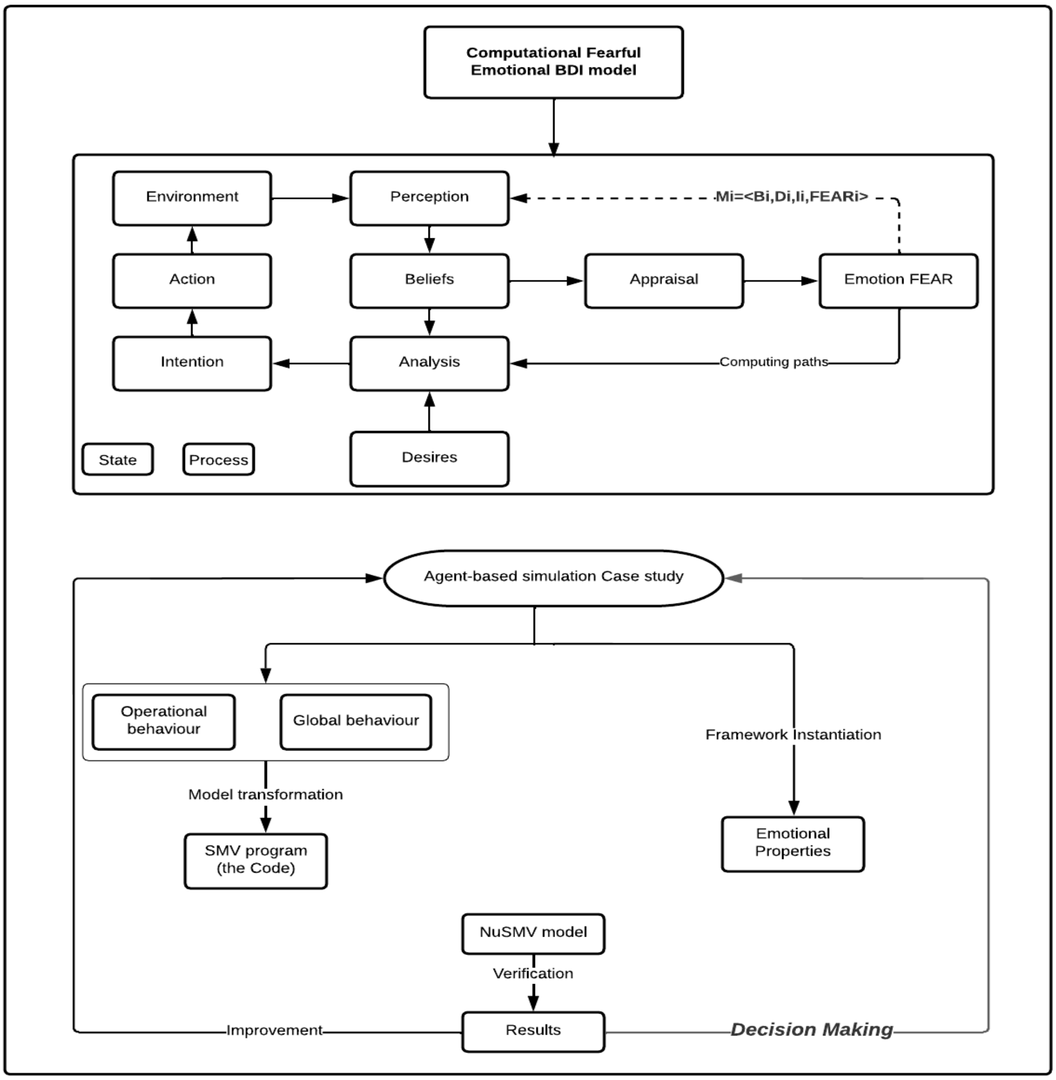

Fig 1: A schema of the proposed architecture

Suppose we have a set of Φ primitive propositions that describe basic facts about the agent and its environment. An interpreted BDIE system $I = (S, \pi)$ consists of a pair of BDIE systems S and an evaluation function π that makes the original proposition set true at every point in G.

3.2 The Fearful Emotional BDI System Logic

3.2.1 BDIE Logic Syntax

The syntactic primitives of our logic of emotions are as follows: a nonempty finite set of agents $A = \{1,2, \ldots, n\}$, and a non-empty finite set of atomic propositions $\Phi = \{p_1, p_2, \ldots, p_m\}$. The variables i denotes the agent's number and p denotes propositional letters (propositional atoms). The following BNF (Backus Naur Form) notations shown in Eq. (1) define the language of BDIE logic:

$$\varphi ::= \perp \ |p|\neg\varphi|\varphi \wedge \varphi|\bigcirc\varphi|\varphi U\varphi| \\ B_i\, \varphi|D_i\, \varphi|I_i\, \varphi \ | \\ Fear_i\varphi \tag{1}$$

Where p rangers over φ, i ranges over A. The classical Boolean connectives $\vee$ (disjunction), $\rightarrow$ (material implication), $\leftrightarrow$ (material equivalence), and $\top$ (tautology) are defined from $\neg$ (negation), $\wedge$ (conjunction), and $\perp$ (contradiction) in the usual manner.

BDIE logic is the modal logic augmented with the future-time connectives $\bigcirc$ (next) and **U** (until), modal operators B_i , D_i , I_i, and emotional modal operator Fear i for each agent i. Linear-time temporal logic (LTL) operators F and G can be defined as follows in Eq. (2)):

$$F\varphi \stackrel{\text{def}}{=} \top U\varphi \quad (2)$$

$$G\varphi \stackrel{\text{def}}{=} \neg F\neg\varphi$$

Informally, $B_i\varphi$ means, "the agent i believes that φ is true". Belief is understood as subjective knowledge, alias truth in all worlds that are possible for the agent. $D_i\varphi$ Indicates " is unpleasant for the agent i ". In our view, every goal is about something unpleasant. Thus, if a consequence of an event is a goal, then this consequence is unpleasant. $I_i\varphi$ denotes that " φ holds under the assumption that the agent i acts based on its intention".
Fear i φ means, "the agent i feels fear for φ ".

- $(I, r, u) \vDash_{BDIE} B_i\varphi$ iff $(I, r', v) \vDash_{BDIE}\varphi$ for all (r', v) such that $r' \in B_i$ and $(r, u) \sim i\ (r', v)$;
- $(I, r, u) \vDash_{BDIE} D_i\ \varphi$ iff $(I, r', v) \vDash_{BDIE}\varphi$ for all (r', v) such that $r' \in D_i$ and $(r, u) \sim i\ (r', v)$;
- $(I, r, u) \vDash_{BDIE} I_i\ \varphi$ iff $(I, r', v) \vDash_{BDIE}\varphi$ for all (r', v) such that $r' \in I_i$ and $(r, u) \sim i\ (r', v)$;

$(I, r, u) \vDash_{BDIE} fear_i\ \varphi$ iff $(I, r', v) \vDash_{BDIE}\varphi$ for all (r', v) such that $r' \in fear_i$ and $(r, u) \sim i\ (r', v)$;

3.2.2 BDIE Logic Semantics

We now proceed to interpret BDIE logic formulas in terms of the interpreted BDIE system. Given an interpreted BDIE system $I = (\mathcal{S}, \pi)$, suppose that $S = < K, M_1, \dots, M_n >$ and for each $i, i \in \{1, \dots, n\}$, $M_i =< B_i, D_i, D_i, fear_i, >$. Let r be a run in k and u be a natural number, in the following, we inductively define the satisfaction relation $\vDash BDIE$ between a formula φ and a pair of the interpreted BDIE system I and a point (r, u), (check Table 2).

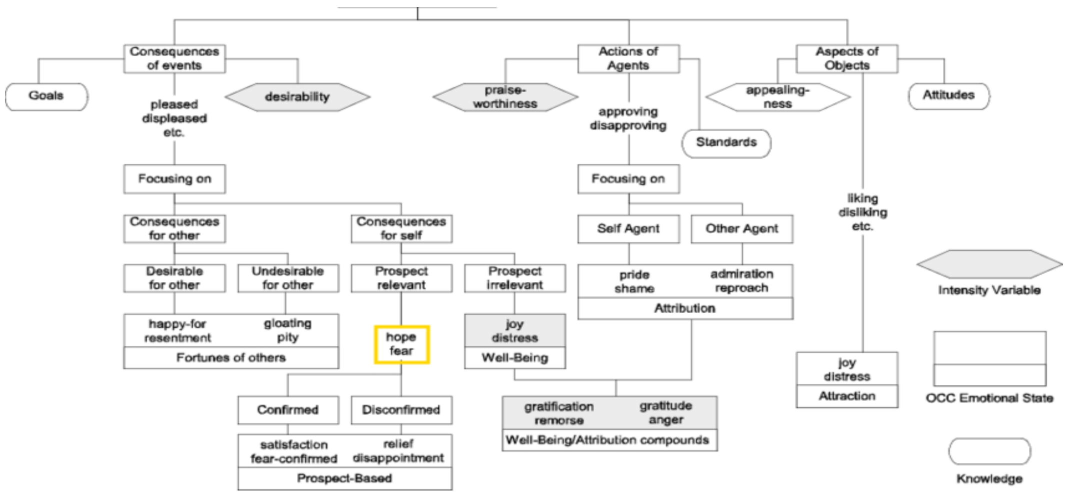

Fig 2: The OCC model [35]

Table 2: Satisfaction relation ⊨ _BDIE between a formula φ and a pair of the interpreted BDIE system

BDIE system (I, r, u)	BDIE system (I, r', u)	$r' \in$
$\models_{BDIE} B_i\varphi$ (Belief)	$(I, r', v) \models_{BDIE} \varphi$	B_i and $(r, u) \sim i\ (r', v)$
$\models_{BDIE} D_i\varphi$ (Desire)	$(I, r', v) \models_{BDIE} \varphi$	D_i and $(r, u) \sim i\ (r', v)$
$\models_{BDIE} E_i\varphi$ (Intention)	$(I, r', v) \models_{BDIE} \varphi$	E_i and $(r, u) \sim i\ (r', v)$
$\models_{BDIE} fear_i\varphi$(the emotion: Fear)	$(I, r', v) \models_{BDIE} \varphi$	$fear_i$ and $(r, u) \sim i\ (r', v)$

3.3 Propositions

Proposition 1: The following axioms are valid concerning both ⊨ BDIE and $\models^{spr}_{BDIE}$:

• $\Delta\ i\ (\varphi \Rightarrow \psi) \Rightarrow (\Delta_{i\ \varphi} \ \Rightarrow\ \Delta_{i\ \psi})$, where Δ stands for B, D, I, Fear.

• Relationship between belief, and intention $B_{i\ \varphi} \ \Rightarrow\ D_{i\ \varphi}$

• Relationship between desire, intention, Fear $fear_{i\ \varphi} \ \Leftrightarrow\ D_{i\ \varphi} \ \wedge\ I_{i\ \varphi}$

• Temporal operators is explained in Eq. (3)

$$\begin{gathered}\bigcirc(\varphi \Rightarrow \psi) \Rightarrow (\bigcirc\varphi \Rightarrow \bigcirc\psi) \\ \bigcirc(\neg\varphi) \Rightarrow \neg\bigcirc\varphi \\ \varphi\mathbf{U}\psi \Leftrightarrow \psi \vee (\varphi \wedge \bigcirc(\varphi\mathbf{U}\psi))\end{gathered} \tag{3}$$

Proposition 2: The following axioms are valid for $|^{spr}_{BDIE}$: $\Delta\bigcirc\varphi \Rightarrow \bigcirc\Delta\varphi$, where Δ stands for any modality of B_i , D_i , I_i , $fear_i$, The formula $D_i\bigcirc\varphi \Rightarrow \bigcirc D_i\varphi$ says that if the agent i's current goal implies φ holds at the next point in time, then at the next point in time its goal will imply φ, that is, the agent i persists on its goal.
And the formula $Fear\bigcirc\varphi \Rightarrow \bigcirc Fear_{\varphi\, i}$ says that if the agent's current emotional state is Fear for φ holding at the next point in time, then at the next point in time its emotional state is still Fear for φ.
And the formula $Fear\bigcirc\varphi \Rightarrow \bigcirc F\ ear\ \varphi\ i$ says that if the agent's current emotional state is Fear for φ holding at the next point in time, then at the next point in time its emotional state is still Fear for φ.

4 Experimentations

We now show how to use the open-source inspection tool NuSMV [20] and the CUDD library [21] to inspect the relevant sentiment attributes.

● all experiments were performed on a dual-core 3.5 GHz Intel Core i5 computer with 16 GB RAM running Windows 10.

● the model-checking tool we use is NuSMV, a reimplementation and extension of SMV, the first BDD-based model-checking tool. It is designed as an open architecture for model checking, can be used reliably for validating BDI proxies, currently supports BDIE logic, and requires reduction of BDIE logic to LTL based on Binary Decision Diagram (BDD) [22] with PSPACE complete complexity [23].

4.1 Case study 1: auction

In this subsection, we specify a simplified auction scenario to illustrate the construction of the BDIE model and the BDIE logic specification.

In [19], they propose an auction scenario similar to ours, but they consider a scenario where two agents (ag1 and ag2) participate in the auction. There are four global states: s0, s1, s2, and s3. In state s0, each agent bids, and in states s1, s2, and s3, a winner will be declared. Specifically, in s1, the winner is ag1, in s2 the winner is ag2, in s3 the winner cannot be determined because ag1 and ag2 offer the same prize. Furthermore, each agent has an initial belief about what it bids, and each one desires to win [19].

4.1.1 Framework Instantiation

Now we define a BDIE system $S = \langle K, M_1, M_2 \rangle$, where

●K is the set of those runs r such that, for every natural number m, for each j, $j \in \{1,2,3\}$, if $r(m) = S_j$, then $r\,(m+1) = S_j$, which means that if the winner is announced, then it will keep so.

●$M_i = < B_i, D_i, I_i, Fear_i, Not\ Fear_i >$, for each $i, i \in \{1,2\}$.

●B_i is the set of those runs $r_i \in K\ r_i\ (O) = s_0$. This means that each agent believes in how much it can bid. Notice that belief is just the information state of the agent, and there is no guarantee that the agent will win the auction.

• D_i is a subset of B_i such that, for each run, $r_i \in D_i$ there is a number m with $r_i\ (m) = s_i$. This means that each agent desires to win the auction.

• I_i is a subset of K such that, for each run $r_i \in I_i$ and every natural number m,if $r_i\ (m) = s_0$, then $r_i\ (m + l) = s_j (j \in \{1,2,3\})$. This indicates that each agent will bid immediately.

• $Not\ Fear_i = D_i \cap I_i$, that is, $Not\ Fear_i$ is the set of runs r_i such that for every natural number m, if $r_i\ (m) = s_0$, then $r_i\ (m + 1) = s_i$. This means that the agent i doesn't feel fear if it wins the auction after bidding.

• $Fear_i = \sim D_i \cap I_i$, that is, $Fear_i$ is the set of runs r_i such that for every natural number m, if $r_i\ (m) = s_0$, then $r_i (m + l) = s_j\ (j \in \{1,2,3\}\ and\ j \neq i)$.. This means that the agent i feels Fear if it does not win the auction after bidding.

Now we can formulate these emotional attributes in the auction scenario to make our decision cycle of the two agents:

- **F** (NOT Fear $ag1$ (winner 1)) indicates that eventually, the agent $ag1$ will be in a state of not fear for winning the auction.
- **F** (Fear $ag2$ (¬ winner 2)) indicates that eventually, the agent $ag2$ will be in fear of losing the auction.

4.1.2 Emotional Properties Verification

Each agent can express emotions based on our formal description of emotional triggers. The NuSMV checker model tool can be used to verify these emotional attributes in the auction scenario. Specifically, the NuSMV along with CUDD was employed to verify the following two specifications.

In the first specification after each agent bids, the **ag1** wins and does not feel fear, Table 3 below shows the verified properties after 10 rounds of **ag1,** the computation of complexity needed for running this specification is shown in Fig 3.

As for the second specification, after each agent bids, the ag2 loose and will eventually feel fear, Table 4 below shows the verified properties after 10 rounds of **ag2,** the computational complexity needed for running this specification is shown in Fig 4.

Table 3: The results of the auction scenario when the state is S1 after 10 rounds

Number of rounds	**State**	**Number of rounds**	**State**	**Number of rounds**	**State**
1st round (S1)	S1=NOT FEAR	2nd round	S1=NOT FEAR	3rd round	S1=NOT FEAR
4th round	S1=NOT FEAR	5th round	S1=NOT FEAR	6th round	S1=NOT FEAR
7th round	S1=NOT FEAR	8th round	S1=NOT FEAR	9th round	S1=NOT FEAR
10th round	S1=NOT FEAR				

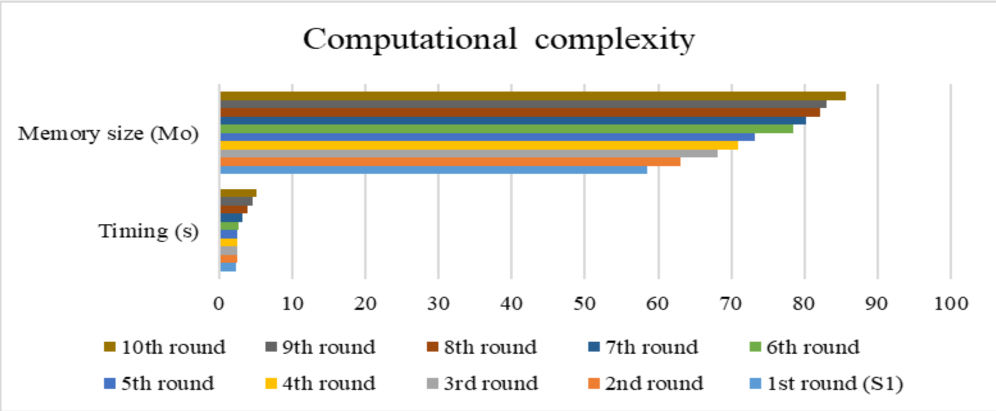

Fig 3: Bar chart showing the computational complexity during executing the auction scenario when the state is S1 after 10 rounds

Table 4: The results of the auction scenario when the state is S2 after 10 rounds

Number of rounds	**State**	**Number of rounds**	**State**	**Number of rounds**	**State**
1st round (S2)	S2= FEAR	2nd round	S2= FEAR	3rd round	S2= FEAR
4th round	S2= FEAR	5th round	S2= FEAR	6th round	S2= FEAR
7th round	S2= FEAR	8th round	S2= FEAR	9th round	S2= FEAR
10th round	S2= FEAR				

As mentioned in [19] they have proposed a case study for auctions that encompasses Joy and distress as emotion modalities, in the other hand our approach takes that: Each agent expects to win at the start of each auction round. Using Agent 1 as an example, ag1 decides to play again if it wins since it is content and does not sense anxiety because the desired outcome, that it wins, occurs after bidding. Agent 2, on the other hand, experiences Fear because, after bidding, it will lose the game, which is undesired, and it will decide not to participate again.

The experimental results in Table 5 verify these formulas (ag1 & ag2). The following can be observed: The results of the above two emotional specifications are all true and consistent with the OCC emotional theory.

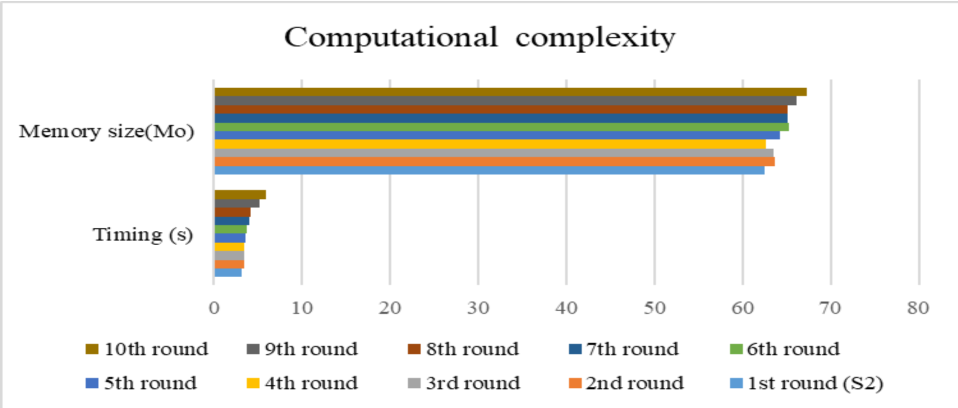

Fig 4: Bar chart showing the computational complexity during executing the auction scenario when the state is S2 after 10 rounds

Table 5: Verification results

ag_i	Results	Timing(s)	BDD nodes
ag1=F(agent 1 Not fear (winner=agent1))	TRUE	**2.32193**	38458
ag2=F(agent 2 Fear (looser = agent2))	TRUE	**3.12243**	38458

4.1 Case Study 2: Simulation System for Aircraft Maintenance Based on Fear of the Agent

The specification of this case study is to formalise an operational and control behaviour of some random flight agent and focus on its own emotion in our case "FEAR" from our BDIE architecture [24]. Control behaviour expresses the general behaviour of any process related to aircraft maintenance [25].

In the sub-sections below, we introduce the definition of the agent's global behaviour and the operation behaviour, in fact, the global behaviour describes the behaviours based on emotions happening in the life cycle of planes from the global point of view [27], where the operational behaviour is employed to describe the inner behaviour of the component taking into account one specific emotion in our case FEAR.

4.2.1 Presentation of Simulation System for Aircraft Maintenance Based on Fear of the Agent

We can now address our fearful agent-based system to reason about the knowledge and temporal properties of the plane and flight agents [28]. The formalism is illustrated as follows (see Fig 5): The agent will do a mapping between state-to-state (S-S) and transition-to-transition (TT) from the global behaviours to the control behaviours based on the emotion of fear, firstly it will initialise the connection with flight agent by invoking the plane ⟶, Then it will start plane checking to make sure that everything is in a good position and safe ⟶, if the time of checking is too long, the agent will consider this delay as an unpleasant situation and it will feel FEAR⟶ it will immediately schedule maintenance for any problems within the plane ⟶ after the maintenance it will invoke the plane again for analysing⟶ it will start repairing the problems⟶ it will invoke the plane again for checking⟶ now the plane is prepared⟶ Now after the flight was delayed because of maintenance the plane will be cancelled and start the loop again until the agent doesn't find the situation unpleasant thus won't feel fear and the flight will be ready.

4.2.2 Framework Instantiation

We define the same BDIE system $S = \langle k, M_1, M_2 \rangle$, as what we did for the previous case study, where:

• K is the set of those runs r such that, for every natural number m, for each j, $j \in \{1,2,3\}$, if $r(m) = s\ j$, then $r(m+1) = s_j$, which means that if the plane is cancelled, then it will keep so.

• $M_i = \langle B_i, D_i, I_i, fear_i, D_i, I_i, fear_i \rangle$, for each i, $i \in \{1,2\}$.

• B_i is the set of those runs $r_i \in K\ with\ r_i(0) = s_0$. This means that each plane agent believes in how long the time takes for plane checking. Notice that belief is just the information state of the agent, and there is no guarantee that the agent will find the situation unpleasant.

• D_i is a subset of B_i such that, for each run, $r_i \in D_i$there is a number m with $r_i(m) = s_i$. This means that each agent desires to cancel the plane.

• I_i is a subset of K such that, for each run $r_i \in I_i$ and every natural number m, if $r\ i\ (m) = s\ 0$, then $r_i(m+l) = s_j (j \in \{1,2,3\})$.This indicates that the plane agent will immediately send the plane for maintenance.

• $Fear_i = \sim D_i \cap I_i$, that is, $Fear_i$ is the set of runs r_i such that for every natural number m, if $r_i(m) = s_0$, then $r_i(m+l) = s_j (j \in \{1,2,3\}\ and\ j \neq i)$.. This means that the plane agent feels Fear and finds the situation unpleasant if the time of checking the plane is too long.

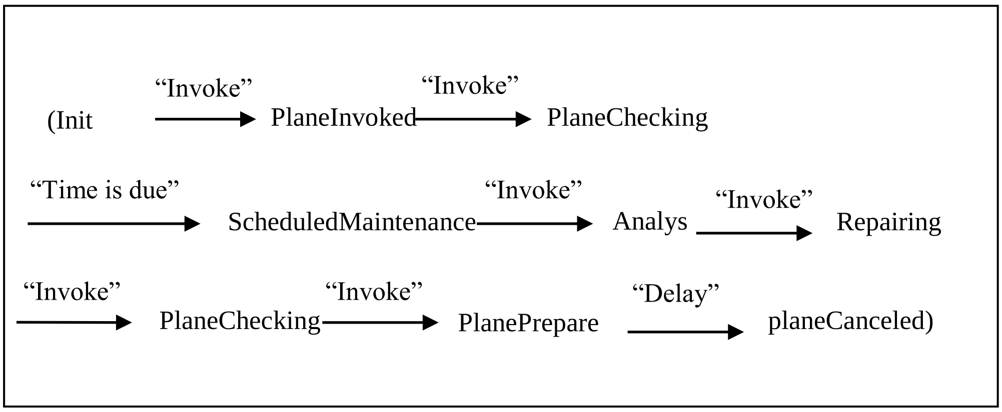

Fig 5: Flowchart showing the conversations between the plane agent and flight agent

4.2.3 Model Properties Verification

In this sub-section, the verification model transformation from the BDIE to the NuSMV model is provided to verify all the properties including the CUDD library and linked it to the MiniSat SAT solver To make the verification clearer. All the states in the state chart of global behaviours will correspond to the state names of the control behaviour[29].

The mapping between global and control behaviours can be seen in Table 5. In addition, the states of PlaneScheduled, PlaneServiced; PlaneArrived of the global behaviour correspond to the state Processed of the control behaviour. The NuSMV code is given just by capturing the transitions of messages between the plane agent and flight agent [37].

Now we can address the NuSMV code for our case study, and see how our agent makes its own decision based on the cycle of verifying the state of the plane and the emotion of the agent: which means if the time of the plane by the plane agent checking is too long, the agent will consider this delay as an unpleasant situation and it will feel FEAR, and based on this it will make the decision of cancelling the plane and if not the plane agent will always message the flight agent to proceed with the flight READYTOFLY until the decision making cycle of the agent is fulfilled.

4.2.6 Simulation Results

In this subsection, we illustrate the NuSMV model checker validation results by running the above SMV code for the aircraft and flight agents that we already have mentioned.

Experimental environment: All of the experiments were performed on a dual-core

3.5 GHz Intel Core i5 computer with 16 GB of RAM running windows 10.

After running, the code and making simulations the results below show that the Flight agent has assured that the Plane agent will cancel the flight if it is in a state of Fear due to the delay of time of plane checking. It has successfully improved the safety of the BDIE agent in terms of cancelled flights, which illustrates the feasibility of the implementation of the NuSMV model of the simulation system in these real-life situations [30]. The experimental results in Table 6 verify the states of plane and flight agents' states. The following can be observed: when time checking is below 0.2 seconds the flight agents will not consider this as a delay and don't find the situation unpleasant so they will not fear but if the time checking exceeds 0.2 seconds, the plane agent will consider this delay as an unpleasant situation and it will feel fear and cancel the flight.

The results of the above model case study specifications using fear are all true and consistent with the OCC emotional theory.

Table 6: *Verification results*

Number of flights	State of Plane agent	State of the flight	Results	Timing (s)	BDD nodes
Ag.flight A1	FEAR(Delay)	CANCELLED	TRUE	0.245	38458
Ag.flight A2	FEAR(Delay)	CANCELLED	TRUE	0.275	45923

Ag.flightA3	FEAR(Delay)	CANCELLED	TRUE	0.255	45812
Ag.flight A4	FEAR(Delay)	CANCELLED	TRUE	0.345	35907
Ag.flight A5	FEAR(Delay)	CANCELLED	TRUE	0.314	23681
Ag.flight A6	NOT FEAR	READY TO FLY	TRUE	0.143	34517

From the previous definitions, our fearful agent-based system not only concentrates on the behaviour of individual agents but also addresses the interactive behaviour between agents.

5 Discussion

The outcomes of the simulation trials for the two case studies show how effective our approach is. The method enables us to more thoroughly examine FEAR behaviour in uncomfortable circumstances in addition to emotion types behaviours. and To increase the effectiveness of model checking, it focuses less on expanding formal logic and more on how to test system behaviour from various angles. Our way of verifying global behaviour is quite similar to the work of Bentahar et al [35]; Table 7 below is showing the major differences between our approach and theirs.

Table 7: Showing the main differences between our approach and Bentahar et al approach

Our approach	Bentahar et al approach
Our approach is suitable to add any conditions to the agent for emotional verification	Their method is ineffective for evaluating system behaviour if circumstances are linked to transitions [35].
Easy implementation of our approach in the NuSMV software	There have been no messages using their verified system. If their system is changed to a system of transitions with conditions, NuSMV will never be able to validate the emotional requirements for the overall behaviour" [35].
In our approach, we provided the agents with the capability of message transformation after knowing what emotional state it's in	The approach is not verified by consequence, analyse of global sense is impossible
we propose additional verification for the whole state of the situation in addition to the verification of the emotional behaviour of the system itself	Their technique for verify the system's operational behaviour is essentially an addition to the system's overall state [35].

This work makes a valuable contribution and differs from what has been conducted before. First, it is an independent approach built on BDI logic, which is already utilized in a variety of agent designs. As a result, this model is ready to be applied to any BDI agents, regardless of their application, making the building of intelligent virtual agents with effective skills easier. In addition, it only focuses on one emotion, which makes the accuracy of the verification high, and eventually, the agents will have a better data analysis from the environment.

As a result, we have proposed an approach to verify the behaviours of these unpleasant situations from the point of view of the system itself.

6 Conclusion and Future Work

In this paper, we have extended the BDI model of agency logic by incorporating Fear emotion modalities and proposing a new computationally interpreted fearful model of emotion triggers so that the new Emotional-BDI agents may better cope with extremely dynamic unpleasant situations and their surroundings.

In this study, we have introduced a fearful agent, which exhibits a very careful

behaviour, considering any threat as a fear factor and considering all uncomfortable events at the same level that may be used to create an agent program that allows cognitive agents to automatically calculate many types of fear emotions throughout runs: unpleasantness and discomfort.

We have used NuSMV the open-source checker tool as an implementation tool to verify our two case studies one was the auction scenario and the other was a simulation system for aircraft maintenance based on fear of the agent which allowed us to do a simulation of experiments of the two case studies demonstrating the efficiency of our method and also allowed us to not only verify emotion modalities behaviours but check more accurately FEAR behaviour in unpleasant situations.

Finally, this multidisciplinary effort makes a valuable contribution to our domain:

the independent approach is built on BDI logic, which is already utilized in a variety of agent designs. As a result, our model is ready to be applied in any BDI agent, regardless of its application, making the building of intelligent virtual agents with effective skills easier.

In terms of future work, we intend to look into the formalization of the OCC model's other emotions and see how model-checking tools can validate other emotion properties.

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