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Bush Fire Simulation through Emotion-based BDI Methodology

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Abstract*— This paper introduces an emotion-based BDI (Belief, desire, intention) methodology to model decision-making during fire evacuation simulations while considering human emotions. The methodology is designed to represent human decision-making processes in graphical representations, which can be simply translated for the implementation phase to simulate various case studies. The methodology utilizes the Belief, Desire, and Intention architecture and the OCEAN Openness, Conscientiousness, Extraversion, Agreeableness, and Neuroticism) personality behavior to represent decision-making processes graphically, making it easy to translate into a simulation. The methodology aims to create a more realistic simulation closer to real human behavior by incorporating emotions that affect decision-making. In this paper, we validate the emotion-based BDI methodology by replicating the bushfire Australia case study and benchmarking with the previous work on BDI fire evacuation. From the comparison, we found that both results share almost similar patterns. The results show "dead while still unaware" (0% vs. 0%), "dead while deciding what to do" (69% vs. 48%), "dead while defending" (6% vs. 8%), and "dead while preparing to defend" (6% vs 28%), "dead while preparing to escape" (4% vs 0%) and "dead while escaping" (15% vs 20%). The results show that in our Simulation, there is a death related to preparing to escape (4% vs 0%). However, the other causes of death have an almost similar percentage of death causes. Hence, based on the comparison, supporting and validating our emotion-oriented simulation model is considered adequate. Therefore, this emotion-based BDI methodology can systematically reproduce human cognition and emotion.

***Keywords*—Emotion based modelling; BDI; multi-agent.**

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I. INTRODUCTION

Emotion-based BDI methodology is created based on the Belief, Desire, and Intention architecture and the OCEAN personality behavior [1] to represent decision-making during a fire evacuation simulation while considering human emotion. The methodology in [1] is designed to represent human decision-making processes in graphical representations, which can be simply translated for the implementation phase, such as to simulate various case studies. The methodology focuses on modeling a more realistic simulation closer to real human behavior where human emotion is used as one of the factors affecting decision-making. Hence, the personality and behavior from the OCEAN personality model [2] are used as the affecting factors that trigger certain emotions and actions based on different scenarios. Therefore, in this paper, a fire bush simulation will be done using emotion-based BDI methodology.

Some studies highlighted the importance of considering emotion's influence in multi-agent decision-making and producing more believable agents [3], [4]. In addition, integrating the emotional empathy of intelligent agents can increase the adaptability of the agent in dynamic situations [5]. Meanwhile, human cognition modeling with emotion is important in real-world AI application development [6]. According to Zena et al. [7], emotion determines the moving speed of an individual during crowd evacuation. Several works have been done on creating a simulation considering complex human emotion in various scenarios or case studies, especially in multi-agent simulations.

Argente et al. [3] introduced the computational models of emotion and integrated emotion and norm in multi-agent systems. In this case, an abstract architecture of a Normative emotional agent is presented. Emotion is important in decision-making processes, in which emotion is taken into account apart from rules and consequences of human actions. Taverner et al. [8] proposed the representation of emotion for multi-agent systems by incorporating culture and language in the definition of emotion. Gratch et al. [9] propose the integration of emotion with decision-making policy. Another emotion-based agent is based on fuzzy logic [10]. Sanchez et al. [4] highlighted the good practices for designing emotional BDI agents that should influence all BDI reasoning processes. Furthermore, emotion will influence the perception, motivation, and agent decision-making. Meanwhile, the emotional state must be explicitly modeled and influence the agent behavior [11].

The details of the existing works are summarized in Table I. It is worth noting that our paper is in line with the effort to design believable agents in Simulation [10], [12]–[15]. Meanwhile, the work is not about deep learning on emotional AI technologies to read, classify, and respond to human emotions, as stated in [16].

TABLE I
COMPARISON OF DIFFERENT WAYS EMOTION CREATION IN SIMULATIONS

Emotion creation	Approach	Advantages	Disadvantages
Reactive creation [12], [13]	The perception of particular events is directly responsible for generating emotions.	No cognitive process is involved, and all agents who encounter the same situation will experience identical emotions.	The process of creating emotions is too complex for this simplistic approach to be effective, and it lacks backing from a psychological theory.
Fuzzy appraisal [2], [14], [15]	[15] employ fuzzy logic to capture all aspects of their agents. In their emotional model, each pair of emotions is assigned a value between 0 and 100, which is then translated into an actual emotion using a fuzzy inference rule.	It is suitable for emotions that are expressed as basic numerical values, and can be easily implemented.	The approach is not sophisticated enough to realistically handle the complex process of emotion creation, and it necessitates familiarity with fuzzy logic. Moreover, there is no confirmation from any psychological theory.
Creation through cognitive appraisal theories [17]–[23]	They have incorporated emotional behavior into their agents by utilizing cognitive appraisal theories introduced in psychology.	The method is based on psychological theories of emotion creation and seeks to imitate the human process of emotional response. It regards emotions as an integral part of the agent's cognitive behavior.	Familiarity with theories of emotions is necessary, and the implementation can be challenging.

II. MATERIALS AND METHOD

This section presents the modeling and simulating of bush fire through Emotion-based BDI methodology and Unity3D emotion plugin. Our methodology is to promote Agent-oriented modeling for modeling a complex socio-technical system [24]–[28]. As stated in [29], the Simulation consists of a residential area surrounded by a forest with 100 houses. One occupant stays in each house. The residential area also consists of two shelters, one on the upper right and one on the lower left. On a normal day, the residents are doing their everyday activities. Suddenly, a bushfire outburst affected the residential area. The occupants begin to defend their homes or escape to a safer area.

A. Step 1: Actor Identification

Based on the description of the case study, there is only one actor which is the occupant involved in the scene. Figure 1 shows the organization model for this case.

Fig. 1 Organizational model

B. Step 2: Primary Emotion Modelling

Primary emotion modeling involves modeling the first emotion an agent or actor feels during an event or situation. The modeler can list all possible emotions according to each role responsibility. The role model is adopted to model the primary emotion of the actor. Table 2 shows the role model for the occupant. The responsibilities of the Occupant are to "defend the home, evacuate, avoid fire, avoid obstacles". The constraints are "fire cannot be controlled, have an obstacle, fire can't be controlled, the obstacle cannot be controlled". The possible emotions that relates to the responsibilities and negative emotions are listed in Table 2. For example, in the responsibility of "defending home," the occupant might have the fear emotion or the opposite of fear emotion, which is the hope emotion. This means the occupant can either feel hopeful or fearful when defending their home. The determination of positive emotion will be related to the responsibilities and what the actor might feel when fulfilling the responsibility, respectively. While the negative emotion will represent what the actor feels when the constraints happen or when the responsibility is not met.

TABLE II
THE ROLE MODEL FOR THE ROLE OCCUPANT

Role	Occupant		
Description	**Respond to Fire**		
Responsibilities	**Positive Emotion**	**Constraints**	**Negative Emotion**
Defend home	Hope	Fire cannot be controlled	Fear
Evacuate	Hope	Have an obstacle	Fear
Avoid fire	Hope	Fire cannot be controlled	Fear
Avoid obstacles	Hope	Obstacles cannot be controlled	Fear

C. Step 3: Belief Modelling with Primary Emotion Modelling

This step involves modeling actors' primary emotions, facts, or general beliefs. The domain model is adopted to model the primary emotion and the belief further. In domain modeling, the primary emotions will be represented based on the different entities and the relationship between different entities when an event occurs. The emotions will be represented by a heart shape (positive emotion) and a spade shape (negative emotion).

As shown in Figure 2, there are domain entities in the case study of the fire evacuation during a bushfire. The agent with the role of the occupant is situated in a residential area. The "residential area layout" consists of "Physical objects" of the types "Shelter", "Fire" and "House". With the role of occupant, the agent perceives events and performs actions on physical objects. Decision-making for the agent's action is affected by the emotion of hope or fear. Then, "Memory" will update the agent's belief whenever the agent perceives an event.

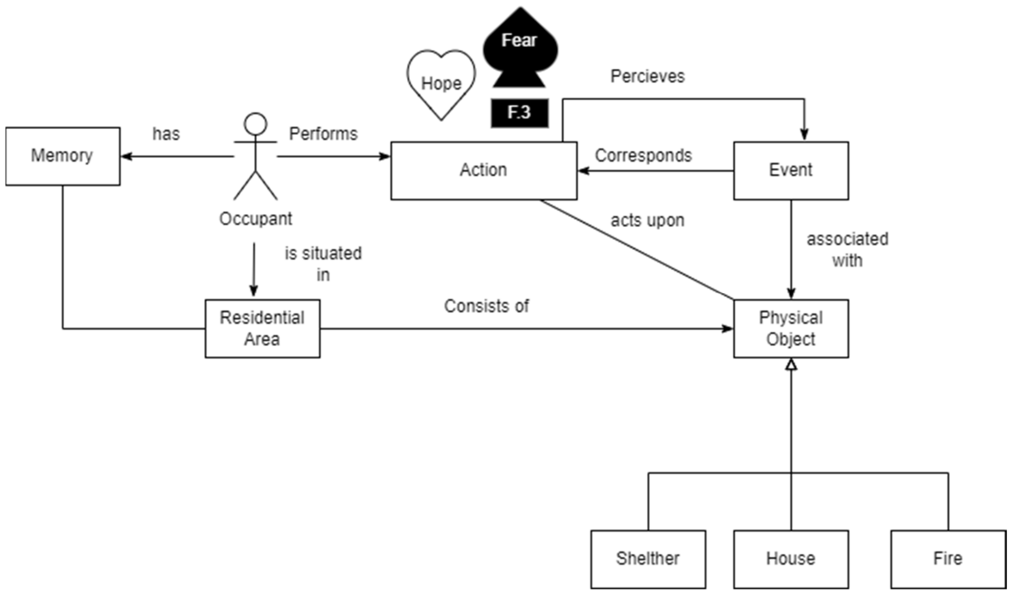


Fig. 2 Emotion-oriented domain model

D. Step 4: Modelling Emotion, Desires and Intention (Secondary Emotion)

This step models the secondary emotions, desires, and intentions of the emotion-oriented BDI cognitive architecture. The secondary emotions are the emotion that appears after the primary emotion, which can also replace the primary emotion.

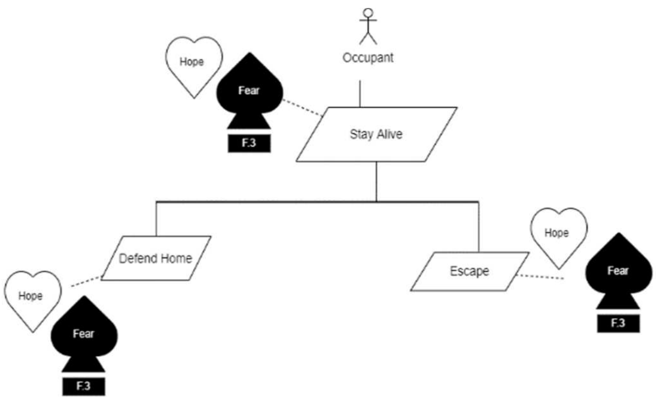


Fig. 3 Emotion-Oriented ROADMAP goal model

For example, in a fire evacuation situation, the primary emotion or the first emotion the victim feels is calm. After seeing the fire spread, the actor's emotion can change to become fear, which is considered a secondary emotion. Hence, two layers of the modeling layer are introduced in this step. The first level represents the higher-level desires and primary emotions related to the goals through the ROADMAP goal model, as shown in Figure 3.

The goals provide an overview of the functionalities that an agent system should achieve. The goals can be divided into sub-goals. There are two types of goals: functional goals and quality goals, representing non-functional requirements for a system. In the emotion-oriented methodology, at the first level, the modeler can model the primary emotion associated with every goal. The goals related to a role indicate the actor or agent involved in achieving the goal. Using the OCEAN personality type described by [2], we can model decision-making based on human behavior, as shown in Figure 4.

Figure 4 shows the second level of goal modeling with the emotion-oriented i* Tropos goal model. In this case study, we include three personality types, which are type-N(O+C+E+A+N-), type-C(O-N+), and type-AEO(O-C-E-A-N+). Based on the bushfire case study, the behavior of the three types of personalities is listed below:

- Type-C(O-N+) Have their ideas - These people are conservative, dependent, and sensitive. They will evacuate or defend blindly without considering the surrounding environment.
- O-C-E-A-N+ Irrational behavior - These people are sensitive, introverted, solitary, negative, and give up easily. They may express irrational behavior during evacuation. In the case study, this type of personality will keep trying to escape when they perceive fire without considering their surroundings and do not defend their home.
- O+C+E+A+N- Leading behavior - These people have opinions and stable emotions. They are independent and may be a leader in the evacuation. They can make a decision based on the surrounding environment and are often calm.

The emotion-oriented i* goal model in Figure 4 represents a more detailed goal decomposition of an agent with personality type-N (O+C+E+A+N-), roles of the occupant, and the secondary emotion, which involved the different levels of fear emotions. The models also represent the beliefs of the actor. Besides, in the emotion-oriented i* goal model, the task is affected by the emotional state of every subgoal according to the different types of agent's personalities described previously.

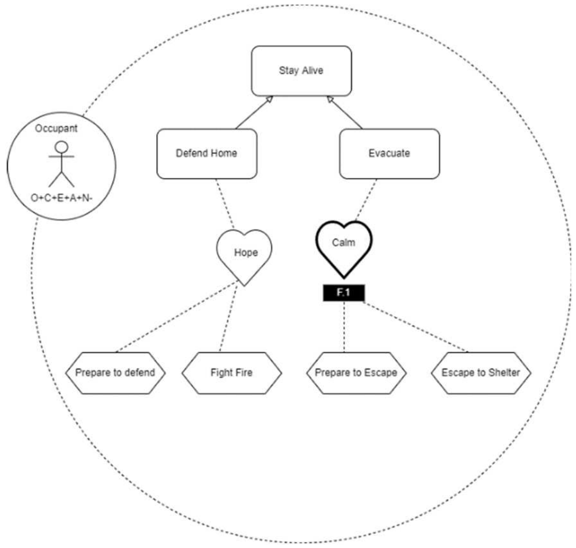


Fig. 4 Level 2: Emotion-oriented i* goal model for Victim with personality type-N (O+C+E+A+N-)

E. Step 5: Deliberation Modelling

Figure 5 illustrates the knowledge model. The knowledge model is used for deliberation modeling and further elaborates and expands the belief. Table 3 describes the instantiation of the knowledge model.

TABLE III
SCENARIO MODEL FOR ACHIEVING THE GOAL "STAY ALIVE" FOR PERSONALITY TYPE N: (O+C+E+A+N-)

Goal	**Stay Alive**				
Initiator	**Occupant with personality type O+C+E+A+N-**				
Trigger	**Has Fire**				
Description					
Belief	Step	Desire	Emotion	Plan	Soft goal/ goal or plan
Fire	1	Defend Home	Hope	<Prepare to defend> Fight the fire	Fire Near to Fire
Fire	2	Evacuate	Calm	<Prepare to escape> Escape to shelter	Danger and Hope

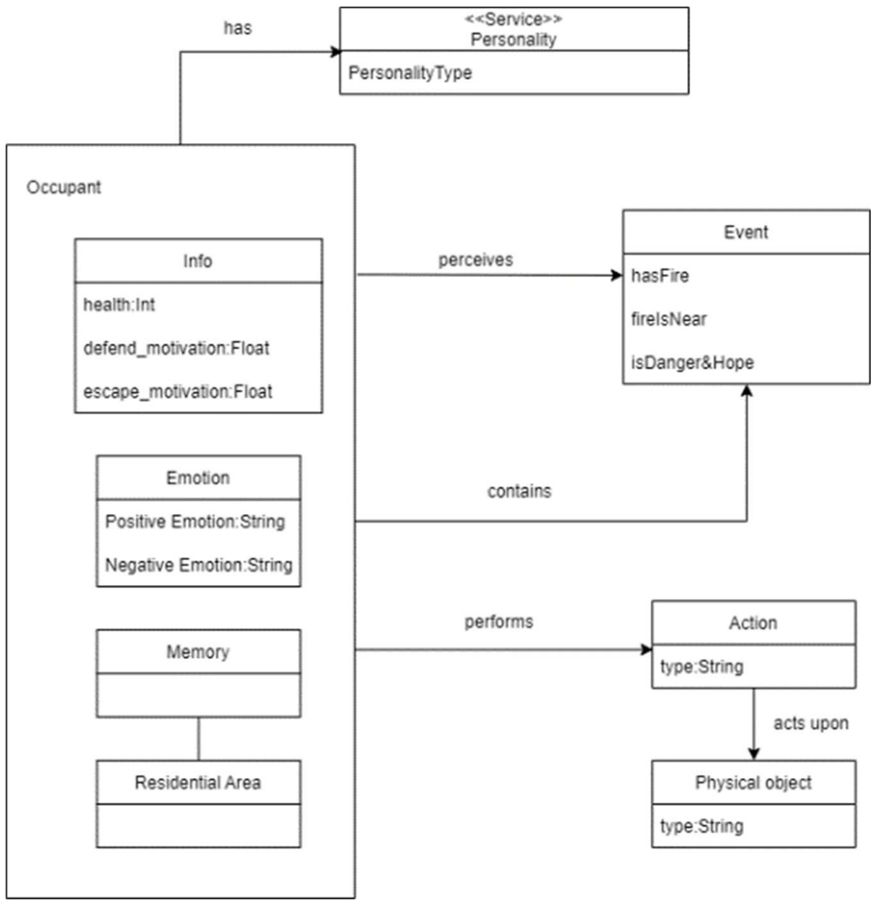


Fig. 5 Belief details representation through the knowledge model

In the emotion-oriented scenario modeling, all possible emotions are listed with the activity, which includes both the positive and negative emotions as modeled in i* goal model based on the different personality types respectively, as shown in Table 3

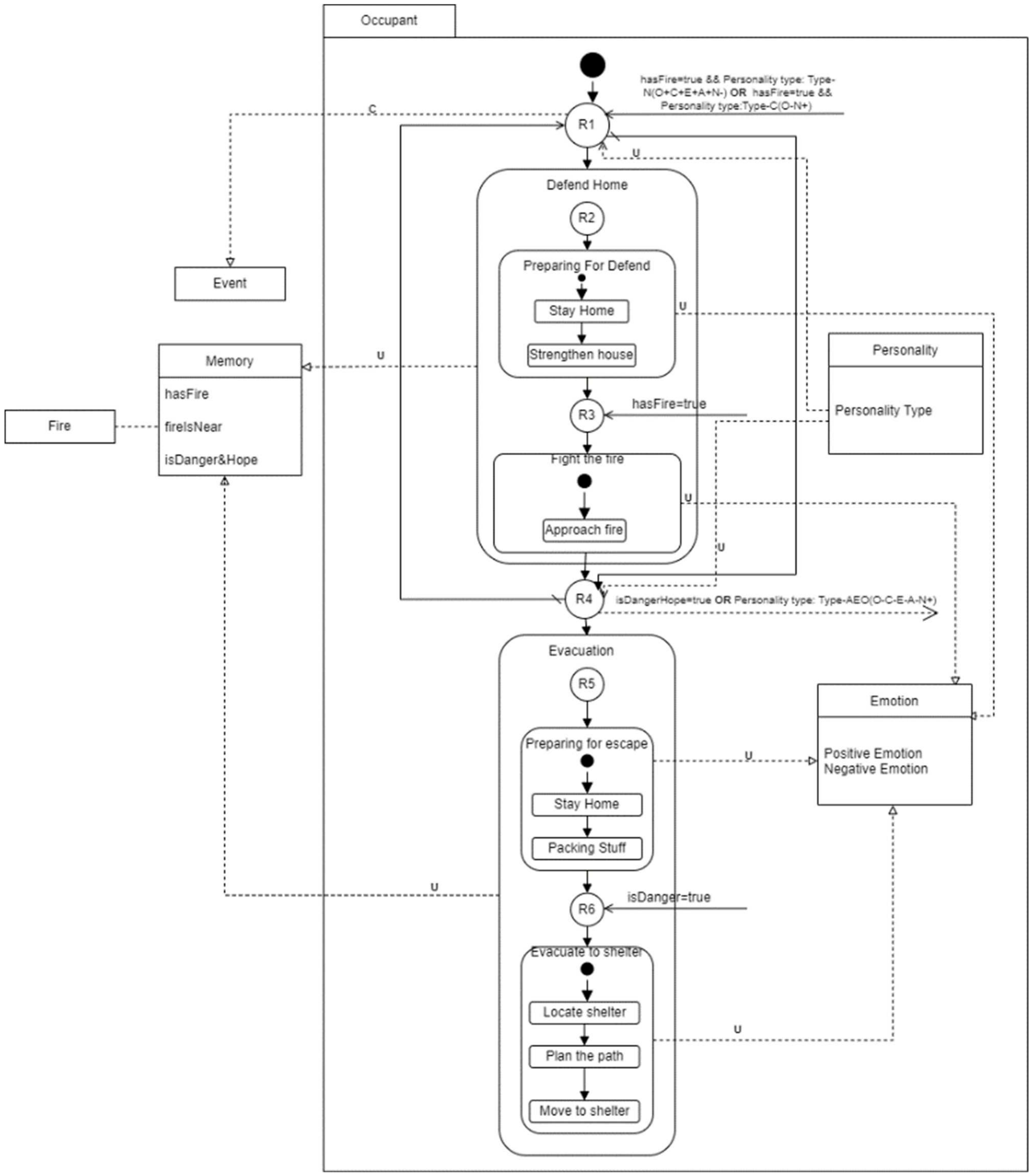


Fig. 6 Behavior Model for Occupant

F. Step 6: Implementation/Platform-Specific Design

In this section, we demonstrate the viability of the proposed methodology. From the replication of a case study [30] done by [29], we extended the BDI tool [29] by adding the emotional properties to the tools to create a similar simulation scene with the same fire evacuation case study. As stated in [29], the Simulation consists of a residential area surrounded by a forest with 100 houses. Each house had one occupant. The residential area also consists of two shelters, one on the upper right and one on the lower left. On a normal day, the residents are doing their everyday activities. Suddenly, a bushfire outburst affected the residential area. The occupants begin to defend their homes or escape to a safer area.

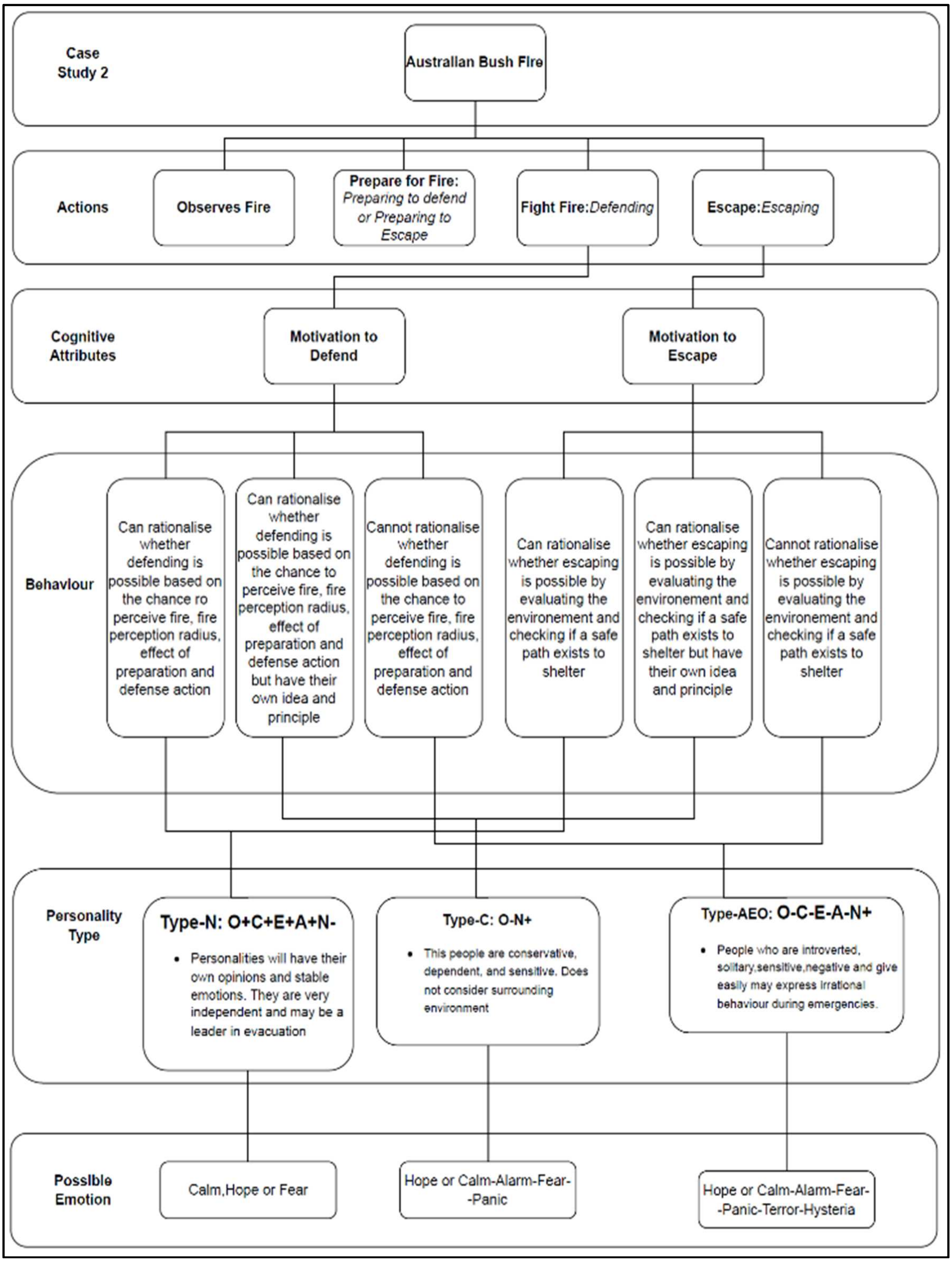


Fig 7 Classification of emotional factors based on case study 2

As a preparation to run the experiment with case study 2, the occupant behavior from related works [30] is extracted to create the agent behavior and classify the behavior description to the appropriate personality and emotion, as shown in Figure 7. From there, the agent modeling is done based on the emotion-based BDI methodology. The agent models are transformed into a BDI-based simulation Unity platform. The emotion-based BDI methodology can be transformed into the emotion-based BDI simulation by adopting our previous work [29]. A BDI plugin tool has been created by [29] using the programming language provided by Unity3D to develop the BDI simulation model. Hence, to develop the emotion-based fire evacuation simulation through the emotion-based BDI methodology, the same Unity3D tools will be used to implement the proposed methodology. Using a transformation guideline, the models were transformed from Steps 1 to 6 into Unity3D constructs. To map the emotion factor to the Unity Construct, we combined emotion with belief, as emotion is described to be a part of the agent's belief.

Figure 8 shows the simulation interface for a fire evacuation simulation. The interface contains the Simulation's settings similar to those described in [29]. In the emotion-based BDI agent simulation settings, the difference is that the action is considered based on the personality type. Hence, there are three types of agents "Occupants" which are Occupant Type N: (O+C+E+A+N-), Type-C: (O-N+) and Type-AEO: (O-C-E-A-N+).

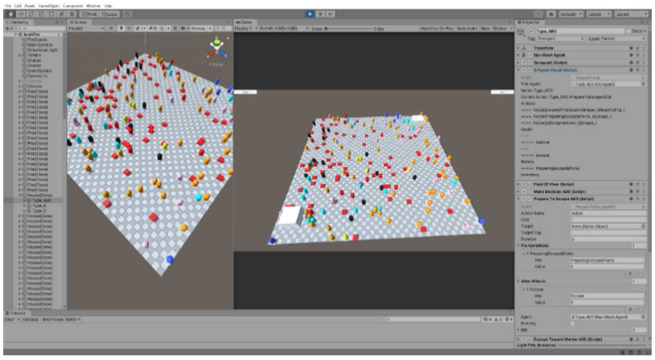
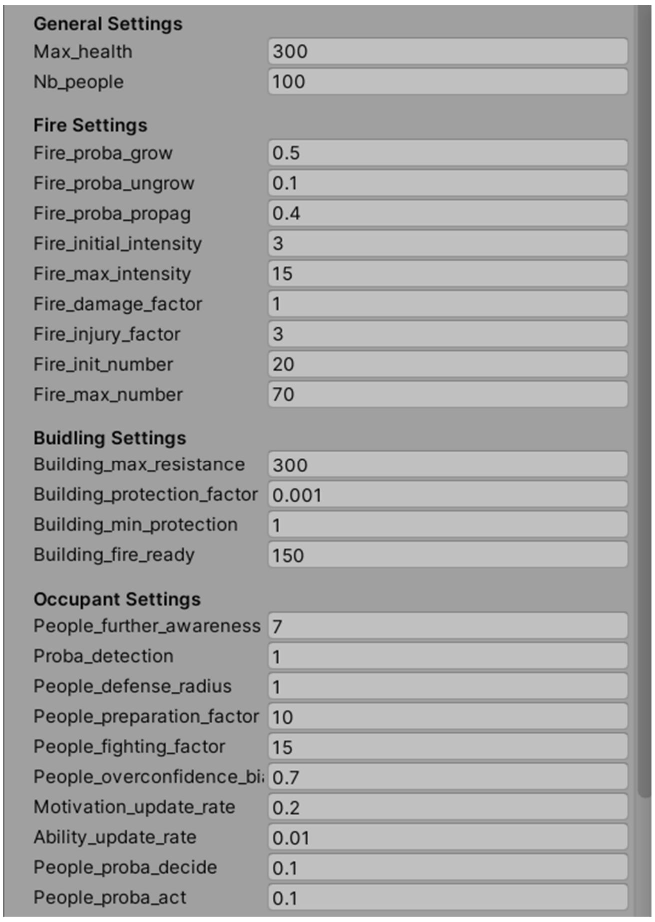


Fig. 8 The interface of the fire evacuation simulation in Unity3D

Figure 9 shows the parameters used in our experiment. The parameters, formulas, and calculations are similar to [29] and [30], as we extended the simulation tool created by [29].



General Settings	
Max_health	300
Nb_people	100
Fire Settings	
Fire_proba_grow	0.5
Fire_proba_ungrow	0.1
Fire_proba_propag	0.4
Fire_initial_intensity	3
Fire_max_intensity	15
Fire_damage_factor	1
Fire_injury_factor	3
Fire_init_number	20
Fire_max_number	70
Buidling Settings	
Building_max_resistance	300
Building_protection_factor	0.001
Building_min_protection	1
Building_fire_ready	150
Occupant Settings	
People_further_awareness	7
Proba_detection	1
People_defense_radius	1
People_preparation_factor	10
People_fighting_factor	15
People_overconfidence_bi	0.7
Motivation_update_rate	0.2
Ability_update_rate	0.01
People_proba_decide	0.1
People_proba_act	0.1

Fig. 9 Parameters Used

III. Results and Discussion

Figure 10 shows the percentage of causes of death in our Simulation. The result obtained is as follows: 69% of the occupants died while still passive (indecisive); 15% died while escaping; 6% died while defending; 6% died while preparing to defend; 4% died while escaping. The percentage of death is calculated by the formula below:

$$\frac{Number\ of\ people\ died}{Total\ number\ of\ death} \times 100\% = Percentage\ of\ death \quad (1)$$

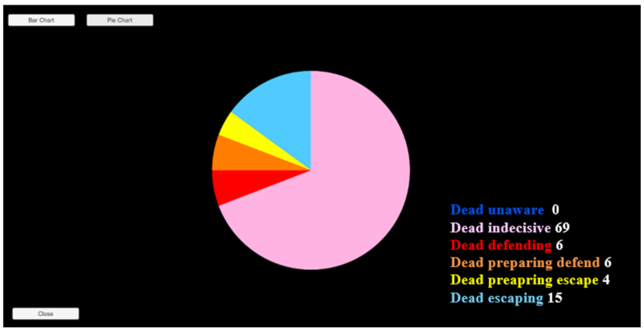


Fig. 10 Causes of death in our experiment

It shows that from our Simulation the highest percentage of death is caused by dying while indecisive. This shows that the occupant does not know how to respond to a fire or is still making decisions. To evaluate the correctness of the model, we compared our results from Figure 11 with the results from Figure 12. From the comparison, we found that both results share almost similar patterns. The results show "dead while still unaware" (0% vs 0%), "dead while deciding what to do" (69% vs 48%), "dead while defending" (6% vs 8%), and "dead while preparing to defend" (6% vs 28%), "dead while preparing to escape" (4% vs 0%) and "dead while escaping" (15% vs 20%). From the results, it shows that in our Simulation there is a death related to preparing to escape (4% vs 0%), however, the other causes of death have an almost similar percentage of death causes. Hence, based on the comparison, supporting and validating our emotion-oriented simulation model is considered adequate.

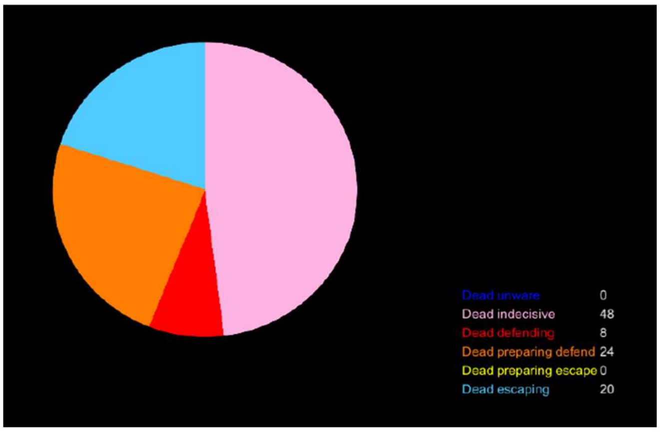


Fig. 11 The Simulation results from [30]

Our result is then compared with a statistic from the 2009 Australian bushfire, as described by [30], to further validate our model together with the simulation result. The comparison of actual death rates, Simulation with BDI death rates, and Simulation with emotion-based BDI death rates is shown in Figure 12. We discovered that the Simulation done with our method shows very similar death rates to the actual death rate compared to the Simulation done only with BDI.

The comparison shows that the "passive" death rate in our Simulation is similar to the actual results (69% vs 69%). While "escape" death rates (14% vs 15%) and "active" death rates (17% vs 16%) are also quite similar.

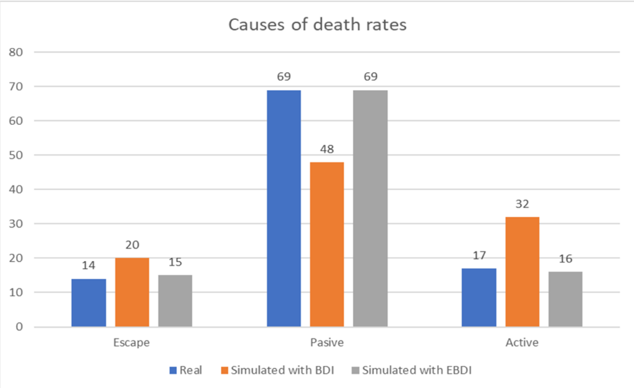


Fig. 12 Comparison between real, simulated with BDI and simulated with EBDI (our Simulation) rates of death causes.

However, in the experiment done with only BDI, the results are quite different from the actual result and emotion-based BDI (48% vs. 69% vs. 69%). This is because the simulations done by [30] and [29] do not have a "passive sheltering" state. This means that an agent that started actively preparing cannot return to a passive state. Therefore, with the introduction of emotion with the emotion-based BDI methodology, the agent can now go back to a passive state or passively wait for rescue based on the behavior, personality type, and emotion reaction description. The action and plan of the agent are obtained based on the personality type, which then portrays the emotion of the agent, allowing the agent to go back to being passive or indecisive (deciding on what to do). This shows how the added personality and emotional factors affected the decision-making and allowed the simulation to be simulated closer to the real situation. This means our method can be used to model human emotion during evacuation to create an emotion-oriented simulation model that can replicate actual situations.

IV. Conclusion

This paper shows how to model a complex fire evacuation simulation while considering the emotional properties and converting the models into our proposed Unity3D bdi plug. It has shown the potential of emotion-based BDI methodology can systematically reproduce human cognition and emotion. In future work, we will integrate and expand our methodology with emotion and mood in line with works like [11], [31], and [32] to integrate mood and emotion for agents. Another work is to model the inference of other information based on individual emotional expressions [33]. Meanwhile, we will further enhance our current model based on the theory of constructed emotion as stated in [34]–[36] and the taxonomy of emotion [37].

Furthermore, we will continue to improve our emotion-based BDI platform based on the components presented by Mascarenhas et al. [38]. As emotion-based AI is still actively researched [39], [40], evaluation case studies on this research are needed. One way is to evaluate the effectiveness of the emotion-based technology with a group of people to understand the user's perception when interacting with an emotion agent [40], [41].

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