An Appraisal Transition System for Event-Driven Emotions in Agent-Based Player Experience Testing

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Abstract. Player experience (PX) evaluation has become a field of interest in the game industry. Several manual PX techniques have been introduced to assist developers to understand and evaluate the experience of players in computer games. However, automated testing of player experience still needs to be addressed. An automated player experience testing framework would allow designers to evaluate the PX requirements in the early development stages without the necessity of participating human players. In this paper, we propose an automated player experience testing approach by suggesting a formal model of event-based emotions. In particular, we discuss an event-based transition system to formalize relevant emotions using Ortony, Clore, & Collins (OCC) theory of emotions. A working prototype of the model is integrated on top of Aplib, a tactical agent programming library, to create intelligent PX test agents, capable of appraising emotions in a 3D game case study. The results are graphically shown e.g. as heat maps. Visualization of the test agent's emotions would ultimately help game designers to produce contents that evoke a certain experience in players.

Keywords: Automated player experience testing · Emotional modeling of game player · Formal model of emotion · Intelligent agent · Agent-based testing

1 Introduction

With the growing interest of industry and academia in assessing the quality in-use of a system, product or service, the term *User eXperience* (UX), which refers to quality characteristics related to internal and emotional state of a user, has emerged [19,22]. UX evaluations become essential for designers to predict how users would interact with a system. In the context of computer games, evaluating *player eXperience* (PX) plays an important role to design a well-received game according to players' preferences and expectations. PX has different dimensions such as flow [21], immersion [13] and enjoyment [8] which need to be addressed in a game design to evoke certain experience.

To assess the UX quality of a game, relatively novel UX evaluation methods such as questionnaire methods, psycho-physiological measurement and eye-tracking have been used [4,22,28]. Currently, PX testing techniques not only impose excessive hours of

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testing but they might also not be representative enough to cover all player types and their possible emotions towards the game. Despite some attempts towards automation, most of these techniques are either costly or still manually demanding [4,22,28]. Moreover, similar to UX evaluations in non-game applications, most of PX testing methods measure PX toward the end of the game development [2,4,28], so there is still a need for more efficient techniques to do these evaluations in *early stages* of game development. This allows PX problems to be addressed early during the development.

All of these factors led us to propose an automated approach for PX testing in computer games; the envisaged main use case is to assist designers in early development phases to develop their games more efficiently. To meet this aim, here, we proposes to employ a *computational model* of players to automatically assess PX properties of a computer game. Such a model is necessarily tied to cognition and emotion. Additionally, emotions that a player can feel under certain conditions would eventually affect their overall experience. We, therefore, suggest to deploy a well-known *theory of emotions* called **OCC** [17] to facilitate modeling players with respect to their emotions.

We present a formal model of the appraisal for OCC emotions using an event-based transition system to serve as the foundation of our automated PX testing approach. It deviates from existing formalization e.g. [1,10,26]; they have never been used in the software engineering (SE) domain. This might explain why these formal models have not been utilized for UX/PX testing. A more fundamental reason is that these models are given in the form of BDI[1] logic [15]. Although expressive, BDI logic is more a reasoning model rather than a computation model. In contrast, our formalization is given in terms of a transition system that directly specifies how to compute the emotional state. Having a transition system provides an opportunity for developers to simply deploy the model in their own systems, whereas a BDI-based formal model would also need a BDI reasoning engine before it can be used for computing. Furthermore, discrete transition systems have been used to do model checking in software for decades. This opens a way to express UX/PX properties in e.g. LTL or CTL [3] and verify them through model checking or model checking related techniques.

A prototype implementation of the formal model is also presented in this paper, along with a demonstration of what it can do on a small case study. The appraisal model prototype is integrated with Aplib [20], a Java library for agent-based game testing, to create an **emotional test agent** that uses the OCC theory for emotional appraisal to assess PX requirements in games.

The paper is structured as follows: Sect. 2 introduces the OCC theory. Section 3 gives an overview of the proposed framework architecture as well as the role of appraisal in PX evaluations. Section 4 details the formal model of appraisal for event-based emotions. Section 5 explains the early results of the framework in a 3D case study. Section 6 discusses some related work and finally Sect. 7 concludes the paper and presents future work.

2 OCC Theory of Emotion

Ortony, Clore, and Collins [17] presented a cognitive structure of emotions which characterizes 22 emotion types (e.g. joy, hope, disappointment, distress and fear).

[1] Belief-Desire-Intention.

According to their 'OCC' theory, emotions are valenced reactions which can be turned on by outcome of events, outcome of agents' actions, or attributes of objects. Event-based emotions that are applicable to most game setups are highlighted in blue in Fig. 1. We selected them to be the basis of our proposed event-based transition system for emotions in our PX testing framework (further explanation in Sect. 3.1). Each of the emotion types listed in Fig. 1 is specified as described in [17].

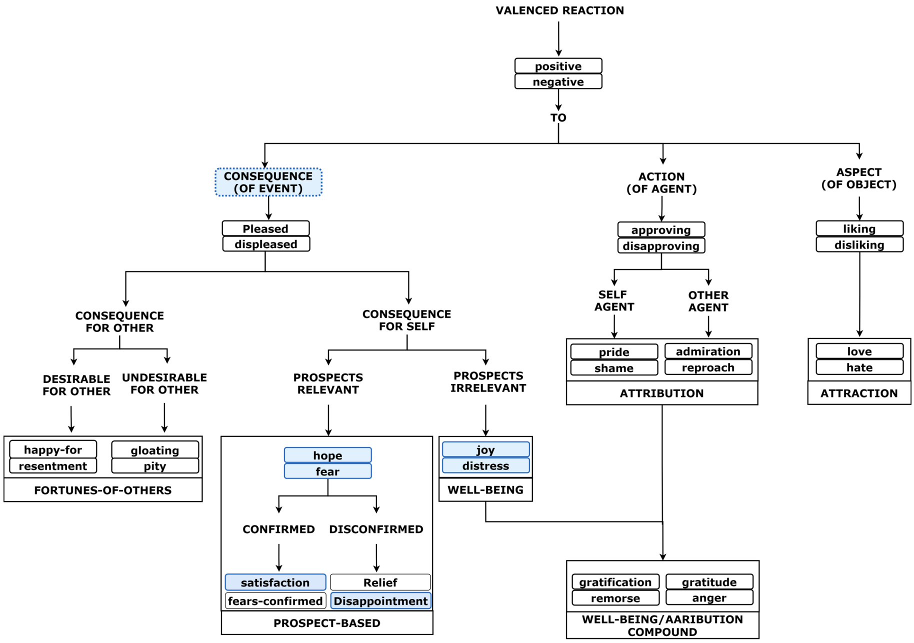


Fig. 1. OCC structure of emotions [17]. (Color figure online)

Table 1 summarizes OCC specifications of the highlighted emotion types; e.g. the OCC theory defines joy as *is being pleased about a desirable consequence of event*. For example, consider a maze game in which an agent is looking for gold. When the agent finds a room with a gold pile, and it takes one step toward the gold, this has a desirable consequence (the agent is certain that it gets closer to the gold), so the agent feels pleased and as a result it starts to feel joy for the gold. However, satisfaction is different. It is defined as *being pleased about the confirmation of the prospect of a desirable consequence*. This emotion needs achievement confirmation whereas joy can be triggered whenever the agent becomes certain that the goal is achievable, although not fulfilled yet. In the above example, satisfaction is triggered when the agent actually acquires the gold. Additionally, while joy affects satisfaction, the agent might not be satisfied towards every goal which it is joyful about. In the earlier set-up, the agent, when proceeding to collect the gold, faces guardians that need to be defeated first, and ends up consuming a unique item to win the combat. Thus, despite reaching the goal that it is joyful about, it would not be satisfied for failing to keep all its prized possessions.

Table 1. Selected emotions specifications according to the OCC theory [17].

Joy:	pleased about a desirable consequence of event
Distress:	displeased about an undesirable consequence of event
Hope:	pleased about the prospect of a desirable consequence of event
Fear:	displeased about the prospect of an undesirable consequence of event
Satisfaction:	pleased about the confirmation of the prospect of a desirable consequence
Disappointment:	displeased about the disconfirmation of the prospect of a desirable consequence

In general, dealing with emotions involves *appraisal* and *coping* [17]. When an agent receives an event, the appraisal process is triggered to form emotions. Afterward, the agent responds to those emotions based on coping strategies which affects the agent behavior towards the environment. In other words, emotions regulate the agent's actions during the coping process. In this paper, we focus on modeling of appraisal —the proposed appraisal model of event-based emotions will be presented in Sect. 4.

3 Agent-Based Player Experience Testing Framework

In this section, we will explain the proposed framework architecture with their components and demonstrate appraisal in PX testing with some examples.

3.1 The Framework Architecture

The general architecture of the proposed framework is presented in Fig. 2, showing appraisal model of emotions, player characterization, Aplib and PX evaluation as the key components. They are defined below.

Appraisal Model of Emotions. A test agent's emotions are modeled based on the OCC theory. Game dynamism can be mostly interpreted in terms of events in computer games, so the framework needs to evaluate the emotions that are driven by the game events for the start. To model these emotions, a *transition system approach* is proposed, which is formalized in Sect. 4. It calculates the event-based emotions with their respective intensity. We will focus on a single test agent setup, thus we leave out emotions that are only valid in multi-agent settings. Appearance of objects can also influence PX but this is technically more challenging to deal with (e.g. how to interpret "appearance"). However, there is a room for extending the model, in the future, to test aspects of PX that are formed in social contexts and those influenced by object aspects.

Player Characterization. Some properties of the appraisal model of emotions need to be specified by game designers with respect to the game under test as well as the player characteristics. For example, the designers should specify what goals are relevant for players (e.g. winning the game, collecting in-game money), what in-game events are relevant to these goals, and in what way they are related to the goals (are they desired towards reaching a goal, or else undesirable?). Additionally, the desirability of an event might differ from one player character to another. Thus, player or set-up dependent

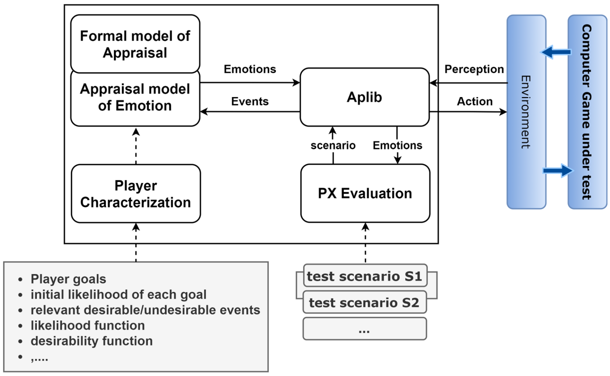


Fig. 2. Automated PX testing framework architecture.

properties must be initially set in this part of framework, before running the model of appraisal. Having such a component in our framework also provides an opportunity to enhance it in the future with more advanced characteristics such as players' moods and play-style (e.g., exploratory or aggressive [25,29]).

Aplib[2] [20]**.** A Java library for programming intelligent agents. It provides an embedded Domain Specific Language (DSL) to use all benefits of the Java programming language. Aplib has a BDI architecture [12] with a novel layer for tactical programming to control agents behavior more abstractly. Despite other use cases, the library has been developed for testing tasks in highly interactive software like games.

PX Evaluation. Designers give test scenarios to the framework to check whether their newly developed content indeed triggers the expected emotions. This part is responsible for the visualization of the emotional state of the test agent as it pursues dedicated goals in a game environment with a given test scenario. Generated emotion types with their upward/downward trends during the test would assist designers to alter game parameters to optimize the experience in a certain degree.

3.2 Appraisal Theory in PX Testing

As mentioned earlier, the appraisal process is an essential part of computational models of emotions. So, to automatically test the player experience based on emotions, we need to include this process in our framework for creating emotions. This would allow us to check whether the designers' expected emotions are as same as the triggered players' emotions when exposed to certain situations in the game.

For instance, educational games are often evaluated based on the engagement level of learners to promote learning. Traditionally, to do this, players' emotions are tracked using either self-reports or automated facial emotion detection during a game-based task [16], Identifying positive and negative emotions plays an essential role in deciding

[2] https://iv4xr-project.github.io/aplib/.

if some game-based conditions and tasks need to be changed to optimize learning. Our proposed framework would help in performing this process automatically using model of emotions to create emotions with respect to events.

Users of a more traditional, non-game, system typically need to feel higher levels of positive emotions and low levels of negative emotions to reach a satisfactory experience, while moderate levels of positive emotions and a high level of negative emotions such as distress, fear and disappointment could end up in an unsatisfactory experience with the system [18]. These negative emotions reflect users' feelings when they are unable or unsure of how to use the system in some situations. This lead to the poor usability of the system [23]. However, computer games, e.g. those in the RPG and combat genres, can be deliberately designed to invoke certain negative emotions for certain experience in players because it can ultimately contribute to their enjoyment [5] or even lead to high level of positive emotion when the player overcomes reasons that evoked negative emotions like fear and frustration [14]. Thus, unlike UX testing, in PX testing designers also need be able to analyze relations between positive and negative emotions. Our proposed framework can automatically check whether these emotions are appraised during playing the game. The prototype further refines this by also tracking when and where these emotions occur, thus enabling refined analyses. If the patterns of these emotions do not meet expectation, designers can change properties of the game and iterate the emotional testing process to achieve the expected emotions.

Ultimately, modelling a player's coping process improve the ability of the framework in PX testing. This is discussed briefly in Sect. 7. However, being able to model the coping behavior does not change the fact that the framework needs to also support the appraisal process of emotions in the first place. For this reason, our proposed framework first focuses on the appraisal process.

4 Event-Based Formal Model of Emotion

Imagine that a software testing agent which takes the role of the player is deployed on a computer game to do PX testing. The agent is modelled as an event-based transition system which can appraise emotions to emulate the emotional state of a player. Its state consists of its 'belief' (perception) over the game and its emotions which can eventually affect its behavior to resemble the player behavior. In this section, we describe the essential part of the formalization of this event-based emotion transition system to conduct an approach for formal modeling of automated PX testing.

In the following, we assume an agent to have beliefs and goals, based on which it decides which actions should be taken in the environment. Being able to differentiate between different goals is useful for PX testing, as games often offer various optional plots and goals to players to improve their non-linearity and replay value. A goal g is represented as a pair $\langle id, x \rangle$, with id as its unique identifier and x as its significance or priority of the goal. Goals and their significance are static in this setup. We also assume that an agent senses its environment by means of events. For simplicity, it is assumed that the agent observes one event at a time, causing the agent to transition from one state to another. Whereas the agent's own actions are events, there are also events that arise from environmental dynamism such as hazards and updates by dynamic objects. We also add the event *tick* to discretely represent the passing of time. We represent emotion types as $Etype = \{ Joy, Distress, Hope, Fear, ...\}$. In the sequel, *etype* ranges over this set.

Definition 1. An emotional testing agent is represented by a transition system M, described by a tuple:

$$\langle \Sigma, s_0, G, E, \delta, \Pi, Thres \rangle$$

where:

- G is a set of the agent's goals.
- Σ is the set of M's possible states. Each state s in Σ is a pair $\langle K, Emo \rangle$ where:
  - K is a set of propositions representing the agent's beliefs. We additionally require that for every $g \in G$, K includes a proposition representing the goal's confirmation or dis-confirmation status, and a proposition representing the likelihood of reaching this goal from the current state. The former is represented by $status(g, p)$ where $p \in \{achieved, failed, proceeding\}$ and the latter by $likelihood(g, v)$ where $v \in [0..1]$.
  - Emo is a set containing the agent's active emotions, each is represented by a tuple $\langle etype, w, g, t_0 \rangle$ specifying the emotion type *etype*, its intensity w with respect to a goal g, and the time t_0 at when the emotion is triggered.
- $s_0 \in \Sigma$ is the initial state. It should specify the agent's initial belief on the likelihood of every goal, as well as initial prospect-based emotions (hope and fear). The rationale for the latter is that having an initial prospect towards a goal implies that there is also hope for achieving it, as well as some fear of its failure.
- E is the set of events the agent experiences.
- $\delta : \Sigma \times E \to \Sigma$ is the state transition function that describes how M moves from one state to another upon perceiving an event. The definition is rather elaborate, and will be given separately in Definition 2.
- $\Pi = \langle Des, Praisew, DesOther, Liking \rangle$ is a tuple of appraisal dimensions according to the OCC theory. This determines how an event is appraised in terms of its *desirability*, *praiseworthiness*, *desirability by others* and *liking*.
- $Thres$ is a set of thresholds, one for every type of emotion.

As an example, Fig. 3 illustrates first few transitions. We, additionally, assume the agent maintains an emotional memory, called *emhistory*, which keeps the history of active emotions (*Emo*) for a reasonable time window in the past:

$$emhistory \;=\; \overbrace{Emo_{t-d}\;,\;\;\dots\;\;,\;Emo_{t-1}}^{\text{time window } d}$$

where t is the current system time and d is the size of the memory's time window. Emo_{t-i} indicates the active emotional at time $t-i$ in the past.

Before presenting the rest of the formal model, we feel the necessity to bring more clarity into the concept of goals' likelihood and status. The transition system is defined in a way that there is a slight difference between $likelihood(g, 1)$ and $status(g, achieved)$. When an agent experiences $likelihood(g, 1)$, it is possible that the

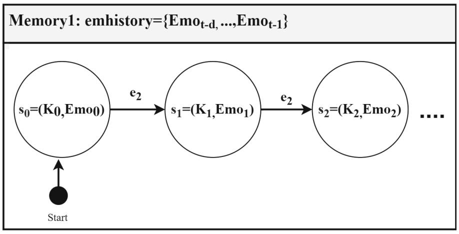


Fig. 3. An agent's state transitions, as it receives an event e_1 followed by e_2.

goal g does not get confirmed in the same state. In other words, the agent comes to believe that the goal is reachable with 100% certainty, but the achievement of the goal has not been confirmed yet in the current state. A similar relation holds for $likelihood(g,0)$ and $status(g, failed)$.

The next key point is the agent's appraisal component Π, which has four dimensions. They help in modeling how events are appraised with respect to every goal in the corresponding dimension. Each appraisal dimension is described as a function over the agent's beliefs, an event and a goal: $\Pi_{\mathbf{Dim}}(K,e,g)$, where $Dim \in \{Des, Praisew, DesOther, Liking\}$. For example, $\Pi_{\mathbf{Des}}(K,e,g)$ determines the desirability of an event e with respect to the goal g, judged when the agent believes K; the latter implies that this desirability might change when K changes. Depending on the emotion, one or multiple appraisal dimensions might be triggered. Currently, $\Pi_{\mathbf{Des}}$ is the only dimension being actively used in our model because according to the OCC theory, the only appraisal dimension which affects our selected emotion types is the desirability function. However, we keep the structure in the general form for possible future extension of the emotion types.

Below we will explain how emotions will be calculated, but importantly we should note that PX designers must provide some information as well, namely the following components of the tuple in Definition 1: (1) the goal set G, along with the significance and initial likelihood of each goal ($likelihood(g, v_{init})$), (2) likelihood functions modelling how events affect the agent's belief towards goals' likelihood, (3) the appraisal dimensions, in particular $\Pi_{\mathbf{Des}}(K,e,g)$, (4) the thresholds *Thres* and (5) decay rate $decay_{etype}$. In the simplest form, $\Pi_{\mathbf{Des}}(K,e,g)$ can be described by a mapping that maps events to the goals they are perceived as desirable/undesirable. In a more refined description this can be a function that monotonically increases with respect to the goal significance and likelihood. In terms of the architecture in Fig. 2, the above components are described in the *Player Characterization* part.

Definition 2. *Event-based Transition.* As mentioned earlier, the agent's state transition is driven by one incoming event at a time. The transition function (δ in Definition 1) is defined as follows. Let e be an occurring event:

$$\langle K\ ,\ Emo\rangle \ \xrightarrow{\ e\ }\ \langle K'\ ,\ \overbrace{newEmo(K,e,G)\ \oplus\ decayedEmo(Emo)}^{\text{updated emotion } Emo'}\rangle$$

where:

- $K' = e(K) \setminus H$, where $e(K)$ is the agent's new beliefs obtained by updating K with event e; here, the event e is assumed to have a semantic interpretation as a function that affects K, including the parts that concern goals' likelihood and status. H expresses likelihood information that can be removed from $e(K)$, because the corresponding goals are achieved or failed. More precisely, H is the set $\{\ likelihood(g,v) \mid status(g,p) \in e(K),\ p \in \{achieved, failed\},\ v \in \{0,1\}\ \}$.
- $Emo' = newEmo(K,e,G) \oplus decayedEmo(Emo)$ is the agent's emotions updated by the perceived event e and the agent's new beliefs. Importantly, the $newEmo(K,e,G)$ specifies the *newly* triggered emotions (see Definition 3), whereas $decayedEmo(Emo)$ (see Sect. 4.1) is a set of active emotions that decay over time. The operator $\oplus$ merges all these emotions after applying some constraints to have the updated emotional state of the agent. The emotional update is explained in Sect. 4.3.

When an agent perceives an event (except *tick* event), new emotions may be triggered. This is done by calculating a so-called'emotion function' $\mathcal{E}$ for every emotion type, as follows:

$$\mathcal{E}_{etype}(K,e,g) = w$$

This function specifies the activation intensity w of the emotion *etype* towards the goal g, as a consequence of the occurrence of e and having beliefs K. Importantly, note that the function expresses *goal oriented* emotions, whereas the OCC theory includes e.g. emotions towards events or objects. We focus on goal oriented emotions due to the importance of goals, ranging from defeating monsters to getting the highest score, for game players. A *tick* event is used to represent the passing of time. This event would cause decays of active emotions in the transition system. The definition of newly triggered emotion, mentioned in Definition 2, is given below. It is used whenever a new emotion is triggered or an existing emotion reoccurs in the system. The way these new emotions are merged with existing emotions in *Emo*, as mentioned in Definition 2, will be explained in Sect. 4.3. We also need to remind that some hope and fear already exist in the system at the beginning which can be re-triggered by this function. Their initial values are set according to goals' significance and initial likelihoods of goals.

Definition 3. *New Emotions.* The set of new emotions triggered by e is:

$$newEmo(K,e,G) = \ \{\langle etype,g,w,t\rangle\ \mid etype \in Etype,\ g \in G,\ w = \mathcal{E}_{etype}(K,e,g) > 0\}$$

where t is the current system time that the emotion is triggered.

In the above definition E_{etype} is a so-called activation emotion function that calculates the activation intensity for different newly triggered event-based emotion types. Each activation emotion function has an activation potential and a threshold which form the activation intensity of the newly triggered emotion (see Definition 4). The level of desirability an event respecting a goal and the agent's goal likelihood are the main variables affecting the activation potential as hinted in the OCC theory. To trigger a new emotion type, its activation potential value needs to pass the corresponding threshold. The concept of threshold is needed if we want to support setups with different agent's moods because the thresholds depend on the moods (e.g. Steunebrink et al. [26] pointed out that with a good mood, the thresholds of negative emotions increase, hence bringing about a lower degree of intensity in negative emotions when they are triggered). All activation functions of emotions defined below have the same structure. However, the potential part might differ. They are as follows[3]:

Definition 4. *Joy*

$$\mathcal{E}_{\mathbf{Joy}}(K,e,g) = \overbrace{\underbrace{\Pi_{\mathbf{Des}}(K,e,g)}_{\text{activation potential}} - Thres(Joy)}^{\text{activation intentsity}}$$

provided $g \in G$, $likelihood(g,1) \in e(K)$[4], and $\Pi_{\mathbf{Des}}(K,e,g) > 0$.

Definition 5. *Distress*

$$\mathcal{E}_{\mathbf{Distress}}(K,e,g) = |\Pi_{\mathbf{Des}}(K,e,g)| - Thres(Distress)$$

provided $g \in G$, $likelihood(g,0) \in e(K)$, and $\Pi_{\mathbf{Des}}(K,e,g) < 0$. Unlike *Joy*, *Distress* is triggered when an event is deemed as undesirable towards the goal.

Definition 6. *Hope*

$$\mathcal{E}_{\mathbf{Hope}}(K,e,g) = v' * x - Thres(Hope)$$

provided $g = \langle id,x \rangle \in G$, $likelihood(g,v) \in K$, $likelihood(g,v') \in e(K)$, and $v < v' < 1$.

It is assumed that the increase in likelihood of a goal is only possible if the incoming event is desirable towards the goal. Thus, with this assumptions, there is no need to check the desirability of the event $\Pi_{\mathbf{Des}}(K,e,g)$ for prospect-based emotions.

Definition 7. *Fear*

$$\mathcal{E}_{\mathbf{Fear}}(K,e,g) = (1-v') * x - Thres(Fear)$$

provided $g = \langle id,x \rangle \in G$, $likelihood(g,v) \in K$, $likelihood(g,v') \in e(K)$, and $0 < v' < v$.

Definition 8. *Satisfaction*

$$\mathcal{E}_{\mathbf{Satisfaction}}(K,e,g) = x - Thres(Satisfaction)$$

provided $g = \langle id,x \rangle \in G$, $status(g,achieved) \in e(K)$, $\langle Hope,g \rangle \in emhistory$, and $\langle Joy,g \rangle \in emhistory$.

Definition 9. *Disappointment*

$$\mathcal{E}_{\mathbf{Disappointment}}(K,e,g) = x - Thres(Disappointment)$$

provided $g = \langle id,x \rangle \in G$, $status(g,failed) \in e(K)$, $\langle Hope,g \rangle \in emhistory$, and $\langle Distress,g \rangle \in emhistory$.

[3] For convenience, we only define the functions partially. The cases where they are undefined will be ignored by Definition 3 anyway, where they are used.

[4] Unlike prospect-based emotions, well-being emotions are certain. So, joy and distress towards a goal only happen if the goal's likelihood becomes 1 and 0 respectively. In particular, obtaining certainty of achieving/failing the goal is seen as notable desirable/undesirable consequence of an event to justify these emotions. There might other practical consequences, but we will mostly focus on the aforementioned types of consequences.

4.1 Decay of Emotions

Every emotion has a duration called *emotion episode* in which the peak of its intensity, its decay rate, possible recurrences, and the time that the emotion is triggered are shown [26]. As indicated earlier in Definition 1, *tick* is a time event to show the passing of time in our transition system. We can reflect decays of emotions using this event:

$$\langle K, Emo\rangle \xrightarrow{e=tick} \langle K', Emo'\rangle$$

where K' and Emo' refer to the updated beliefs and updated active emotions after the transition. The intensity of active emotions in Emo would decrease as follows:

$$\begin{aligned} decayedEmo(Emo) \ = \ & \\ & \{\langle etype, g, w', t_0\rangle \mid \langle etype, g, w, t_0\rangle \in Emo, \ w' = \mathsf{intensitydecay}_{\mathbf{etype}}(w_0, t_0) > 0, \\ & \quad w_0 = emhistory(etype, g, t_0)\} \end{aligned}$$

where $w_0 = emhistory(etype, g, t_0)$ denotes the initial intensity of $etype$ with respect to g which can be obtained from $emhistory$. There is not a unique quantitative formalization for the decay function $\mathsf{intensitydecay}$. This function can be defined in a way which relates the usage and the interpretation of decay [6, 27]. However the peak of intensity (w_0), the time at which the emotion is triggered (t_0) and the decay rate ($decay_{etype}$) are essential parameters that must be taken into account. While an inverse sigmoid decay function is proposed by [27] to reflect the gradual decrease of intensities, [6] is making use of a negative exponential function with almost the ame parameters. We used the latter decay function [6] in our model although the sigmoid decay function [27] can be used as well.

$$\mathsf{intensitydecay}_{\mathbf{etype}}(w_0, t_0) = w_0 \ * \ e^{\ c \ * \ decay_{etype} \ * \ (t - t_0)}, -1 < c < 0$$

where t is the current system time and t_0 is the time at which the emotion starts.

4.2 Inconsistent Emotions

Emotions are triggered regarding the goals, so technically the agent might have several emotions towards the same goal. Nevertheless, the OCC theory states that some emotions are mutually exclusive which means a human can not have them simultaneously for the same goal [26]. These mutual exclusions, which should then also be held in every state of our transition system, are as follows:

$$\begin{aligned} Emo' &\models \neg(\langle Hope, g\rangle \wedge \ \langle Joy, g\rangle) \\ Emo' &\models \neg(\langle Fear, g\rangle \wedge \ \langle Distress, g\rangle) \end{aligned}$$

As it is explained in Sect. 2, whereas emotions such as hope and fear are prospect-based emotions which means they are uncertain ($likelihood(g, v)$), emotions like joy and distress are certain [26], so it is illogical to have both in the system. For example, when a player is joyful of acquiring the key to an in-game treasure room, because now the treasure should certainly be within his/her reach, this joy would now replace what was merely hope for getting the treasure. In general, in case of happening a certain emotion, it replaces the corresponding prospect-based emotion, so the mutual exclusions are always maintained. We formulated our formal model in a way that in case of the conflicting emotions, the new certain emotion would take the place of the prospect-based emotion. However, the set of inconsistent emotions can be expanded based on the test purpose or the game under test. The designer can specify these as assumptions in the *Player Characterization* component. A notation as $axiomset(\langle etype, g\rangle)$ is used to access every rule containing $\langle etype, g\rangle$.

4.3 Emotional State Update

To update the emotional state, newly triggered emotions, *newEmo*, need to be merged with existing active emotions whose intensities are decreasing gradually, *decayedEmo*, to yield the new emotional state Emo'. There are three cases to consider. Case-1 involves existing emotion types that decay without having the same emotion type or the conflicting type in the *newEmo*; these will be kept. Case-2 involves newly triggered emotion types that do not exist in *decayedEmo*; these are added to Emo'. Case-3 involves emotion types in *decayedEmo* that reoccurs in *newEmo*. Only emotions from these three cases will be included in Emo'. In particular, this implies that in the cases of inconsistent emotions, the newly triggered emotion takes precedence over the emotion which has already existed by taking its place in order to uphold the mutual exclusions discussed before. The new one is added to Emo' based on Case-2. This comes from the rationale that new belief and perceptions convey more accurate information than past information, and therefore the triggered new emotions have more weight for the player. The last case, Case-3, is about existing emotions that get *re-stimulated by* the new perceived event. To date there is no definitive answer to the question of how this should be reflected to the intensity of the corresponding emotions. We decided to take the maximum intensity value of the emotion (the dominant value). However, a more proper answer to the question would need further research. The update is formally shown below, with the Cases indicated accordingly:

$$Emo' = \begin{cases} ① \ \{\langle etype, g, w, t_0\rangle \mid \langle etype, g, w, t_0\rangle \in decayedEmo \\ \qquad \wedge \neg\exists\, w', t_0'.\ \langle etype, g, w', t_0'\rangle \in newEmo \\ \qquad \wedge \neg\exists\, w', t_0'.\ \langle \overline{etype}, g, w', t_0'\rangle \in newEmo\ \} \\ \cup \\ ② \ \{\langle etype, g, w', t_0'\rangle \mid \langle etype, g, w', t_0'\rangle \in newEmo \\ \qquad \wedge \neg\exists w, t_0. \langle etype, g, w, t_0\rangle \in decayedEmo\ \} \\ \cup \\ ③ \ \{\mathsf{max}(\langle etype, g, w, t_0\rangle, \langle etype, g, w', t_0'\rangle) \mid \langle etype, g, w, t_0\rangle \in decayedEmo \\ \qquad \wedge \langle etype, g, w', t_0'\rangle \in newEmo\} \end{cases}$$

where t_0 is the time at which an emotion is triggered (starts) and the outcome of max is the one with the higher intensity. An emotion that is in conflict with *etype* is referred as $\overline{etype}$. The above update scheme will uphold the axiom $\neg(\langle etype, g\rangle \wedge \langle \overline{etype}, g\rangle) \in axiomset(\langle etype, g\rangle)$.

4.4 Goal Chain

As indicated earlier, the beliefs K gets updated according to the new event. In particular, this might affect the agent's belief towards the likelihood of achieving certain goals. Recall that this is modelled in the *Player Characterization* component in our approach, e.g. by means of some update rules. However, modern games often offer multiple goals that players can go after, and furthermore have dependency. E.g. obtaining a unique item Excalibur might be an optional goal in a game, but achieving this might improve the likelihood of defeating the end boss. To capture this, we can extend the Player Characterization with 'chained' rules, for example $R = \{e_1 \to g_1,\ g_1 \to g_2,\ g_2 \to g_3\}$ to express that the event e_1 affects the likelihood or status of the goal g_1, which in turn affects the likelihood of g_2 and so on. We do not write down how exactly the likelihood should be adjusted, but imagine that the rules also specify this. When the agent received e_1, it should now not only apply the rule/update $e_1 \to g_1$, but also other rules in R whose antecedent is transitively triggered by $e_1 \to g_1$. While the rules in R above can indeed be equivalently described by more direct rules of the form $\{e_1 \to g_1,\ e_1 \to g_2,\ e_1 \to g_3\}$, the chained form arguably captures inter-goal dependency more intuitively.

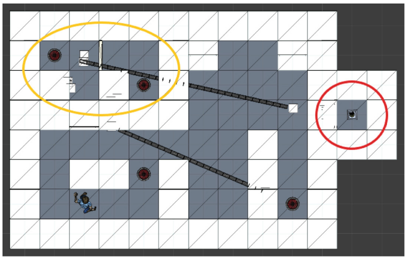
5 Proof of Concept

We conducted our experiment on a game called Lab Recruits[5] which we subject to the combination of aplib and our implemented model of appraisal[6] to provide the proof of concept and show our early results in PX testing. Lab Recruits is a 3D game developed in Unity which has different replayable levels. Each level is a laboratory building with a number of rooms containing interactable objects, such as button and non-interactable objects, such as desk and fire hazards.

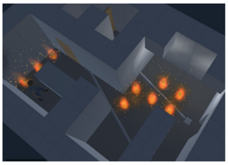
Figure 4a shows the floor plan of the level exposed to PX testing using our approach. It consists of four buttons, three doors, and some fire hazards. The goal is for the player to escape the level by reaching the exit room circled in red. Access to this room is guarded by a closed 'final door'. The level contains some rooms with a puzzle (yellow circle) that involves finding the buttons to open the final door and reopen the doors that in the process become closed to entrap the agent. Figure 4b and 4c show two provided setups with the different amount and locations of fire hazards. The agent will lose health points by passing each fire hazard. These setups are examples of choices considered by designers, although being currently simple, as to which one would lead to better PX. There is also a baseline setup, in which no fire hazard exists in the game level, to compare its emotional outcomes with the result of two mentioned setups.

As mentioned in Sect. 4, a developer sets needed inputs of the model such as the goal set, initial likelihood of each goal, the desirability of events for each goal, the threshold and decay rate of emotions in *Player Characterization*. A test agent is deployed, set with multiple goals, though here we will only discuss the most significant one, namely completing the level. Initially, the agent is assumed to believe that the likelihood of achieving this goal is 0.5. The agent is given a program so that it can automatically

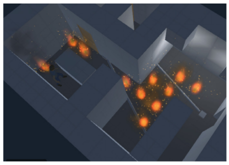
[5] https://github.com/iv4xr-project/iv4xrDemo/tree/occDemoPrototype.
[6] https://github.com/iv4xr-project/jocc.



(a) The floor plan of the level.



(b) Setup 1.



(c) Setup 2.

Fig. 4. The level under the PX test in Lab Recruits.

explore the level. As the agent progresses, its belief on the likelihood of completing the level changes, depending on the number of opened door as well as remained closed doors. Opening each door is assumed to have a desirable consequence for the agent because it increases the chance of the agent to complete the level.

The timeline of triggered emotions at the baseline setup in the agent with respect to the goal "completing the level" is shown in Fig. 5, along with their intensity levels at each time. The agent initially experience some hope and fear due to the assumed initial belief that completing the game is possible, with the likelihood 0.5. This depends on the agent's mood which influences the degree of hope and fear the agent initially has. When the agent pushes the button that opens the first door (time = 60)[7], the agent's hope regarding completing the game starts to increase. It decays or gets re-stimulated according to the events until time 110 when it is replaced by joy. The agent feels a level of satisfaction, when completing the game.

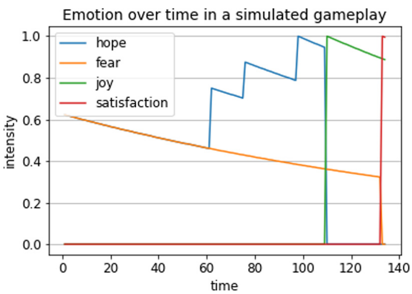
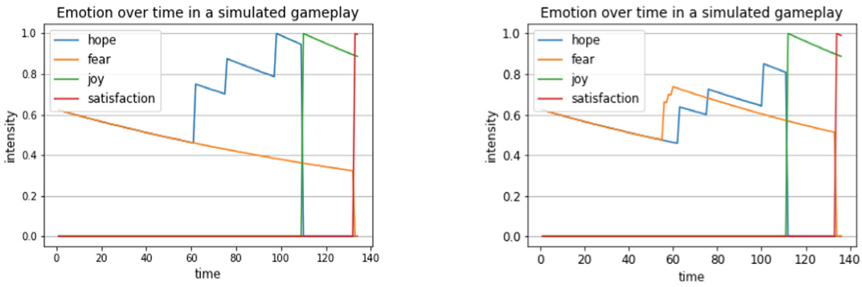


Fig. 5. The emotions' timeline in the baseline setup (no fire hazard).

The timeline of emotions in setup 1 and setup 2 in Fig. 6 shows that the trend of positive emotions is actually quite similar to that of the baseline, although with a smaller level of hope in the setup 2. However, comparing the result of setup 2 with setup 1

[7] The system is event driven, so only events can change the likelihoods. All emotions decay until an event is perceived. However, we can add an event type to the system to decay the likelihoods when there is no event for some period of time to update the emotional state.

and the baseline reveals something interesting. Fear shows a quite different trend in setup 2 (Fig. 6b). It is stimulated multiple times during the execution, whereas the same emotion, despite having numbers of fire hazards, has been never stimulated in setup 1 (Fig. 6a). In other words, having some fire hazards may not necessarily trigger fears in the agent unless the agent passes the certain numbers of fire hazards. Such a comparison can be useful for designers e.g. to determine the amount, and placement, of hazards to induce certain degree of fear along with keeping the chance for satisfactory experience of accomplishing the goal. In our case, setup 1 is less likely to thrill the player, whereas setup 2 has a better balance of the quantity and placement of the fire, by generating fear and even in relatively close time interval with a rise in hope, while still keeping the level survivable.

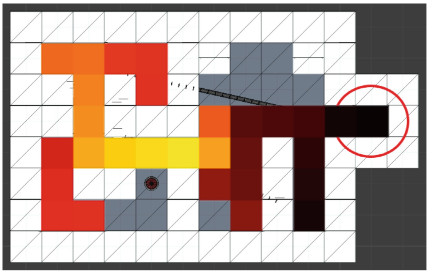


(a) Setup 1 (b) Setup 2

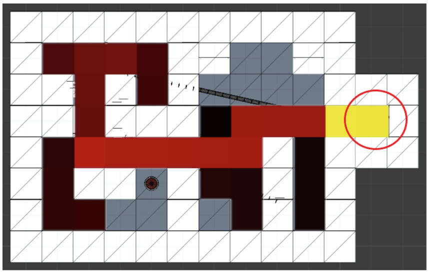
Fig. 6. The emotions' timelines correspond two setups of the game level in Figure. 4. (threshold = 0, decay rate = 0.005)

Figure 7 shows some heat maps, providing spatial information of the agent's emotions in setup 2. Comparing the outcomes of Figs. 6b and 7a illustrates that the highest level of fear is experienced when the agent is in a particular fire covered corridor (yellow in Fig. 7a). Fire intensifies the agent's fear of failure, and moreover the agent has to walk this corridor several times. The most drastic decline in fear is when the agent is about to finish the level.

As can be seen in Fig. 7b, the agent feels a higher level of hope when progressing in solving the buttons-doors puzzle in the puzzle rooms. After pushing the button that corresponds to the final door and reopening the door of puzzle room to escape it, the agent becomes certain that passing the final door is achievable now. Thus, the hope suddenly is replaced by the joy for reaching the final door to complete the game. At the end, the agent feels satisfied when the achievement is confirmed. Having such information would help Lab Recruits designers to adjust the puzzles and fire hazards in such a way to induce certain emotions, at the right moments and the right places, which ultimately affect a certain aspect of player experience like enjoyment. It is worth mentioning that depending on the player profile designed in the player characterization such as the initial player mood and type of player (experienced or new player), the result might differ to some degree. However, assessing the influence of these factors on PX is a future work.



(a) Negative emotions: yellow= high fear, dark red=low fear.



(b) Positive emotions: Mahogany red=hope, Ruby red= joy, yellow= satisfaction.

Fig. 7. The heat maps of triggered emotions in setup 2. Black = very low intensity (or no emotion), white = walls, gray = unexplored area. (Color figure online)

6 Related Work

PX researchers aim to understand the gaming experience to ultimately induce certain experience. Fernandez [9] outlines the influence of players' emotional reactions and their profile in enjoyment by extending the usability methods to uncover relationships between game components and the degree of fun in players. Sanchez et.al [24] explained that usability of games can be defined in the term of *playablity*. They present a framework guided by attributes and properties of playability to characterise experience for PX evaluation and observing the relation between the experience and the developed elements of a commercial video game. Psycho-physiological methods is among techniques to measure aspects of PX like flow and immersion. Jennett's et al. [13] tries to develop a subjective and objective measure for immersion using questionnaires and eye movement tracking respectively. Drachen et al. [7] report a significant the correlation between heart rate, electrodermal activity and the self-reported experience of players in first-person shooter games. Zook and Riedl [30] introduce a temporal data-driven model to predict the impact of game difficulty to player experience. Results of their empirical study on a role-player combat game show the game, that tailors its difficulty to fit a player abilities, improves the player experience.

Zhao et al. [29] create agents with human-like behavior to assist game designers to evaluate their games. The study focuses on training agents based on style of in-game play and skill. A variety of techniques are utilized in the provided case studies to train play-testing agents to test logic of the game under development as well as game-playing agents which interact with human players to mimic the game play experience for different play style. Stahlke et al. [25] also aim to use play-testing agents to test games by following humans' navigational behavior. They investigate the impact of play-style, the experience level and cognitive process on modeling humans behavior. Most of PX prediction techniques are data-driven which involve human players in the process and as a result, they demand a high level of human labor. This led researchers to investigate model-driven approaches. A computational model of motivation is presented in [11] to predict PX without the need of human player using empowerment, the degree of control an agent has over the game. The study measures empowerment by intelligent agents to create levels with defined empowerment to induce different PX. This would help to produce desired content characteristics during the procedural content generation.

Despite existing research on modeling the OCC theory, the theory has not been employed in the context of PX testing. Having a proper formalization of emotion would act as a bridge from psychological description of emotions to computational models of emotions which are translatable to codes. Formalization of emotions has been mostly done in the form of BDI logic. Steunebrink [26] deployed a formal model inspired by the OCC theory to specify the influence of emotions, specifically hope and fear, on a BDI agent's decisions. Later, a full version of the model with all 22 emotions is explained in [27]. Dias et al. [6] presents an OCC-based appraisal engine called FAtiMA (**F**earnot **A**ffec**TI**ve **M**ind **A**rchitecture) for creating autonomous agent characters that can appraise events and behave based on socio-emotional skills. Its main use case is to automate virtual characters in conversing with humans. FAtiMA is claimed to be inspired by the OCC theory to simulate emotional skills in autonomous agents. However, so far, no formal model has been introduced to evaluate the toolkit regarding the OCC theory. A BDI-like probabilistic formalization is described in [10] for OCC event-based emotions during the appraisal. The study evaluates the desirability of consequences of an event based on the agent's goal and the degree that the consequence can improve the possibility of the goal achievement. Unlike other formalisations that give a high level function for appraisal variables, it proposes a more refined logic-base calculation for these variables and also tries to formalize 'effort' and 'realization' that are involved in appraising some event-base emotions.

7 Conclusion and Future Work

This paper presented an automated PX testing approach using an emotional model. An event-based transition system is introduced to model the appraisal for event-based emotions according to the OCC theory which is then combined to a Java library for tactical agent programming called aplib to create an agent-based PX testing framework. Early results of our experiment with the prototype show that such a framework that can emulate players' emotions would let developers to investigate how emotions of players would evolve in the game during the development stage. By providing e.g. heat-map visualisations of triggered emotions and their timelines, designers gain insight on how to alter parameters of their systems to evoke certain emotions.

We are currently doing more advanced experiments using the case study, Lab Recruits, to investigate initial moods, emotions and their effect on certain aspects of PX as a future work. There are also some concepts like emotional intensity after a recurrence that are described with high level functions in the literature which need a calculation mechanism. In particular, we want to do further research on how exactly an emotion should regain its intensity level after a re-stimulation. Furthermore, the proposed framework, if enhanced by the coping process, would be able to simulate the effect of emotions on players' behavior for further PX evaluations. However, this needs extension in our event-based transition system to support the coping process formally respecting the OCC theory. We ultimately plan to conduct research on validation of our model by comparing our results with the data of human players.

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