An emotion model for non-player characters inspired by neurotransmitters

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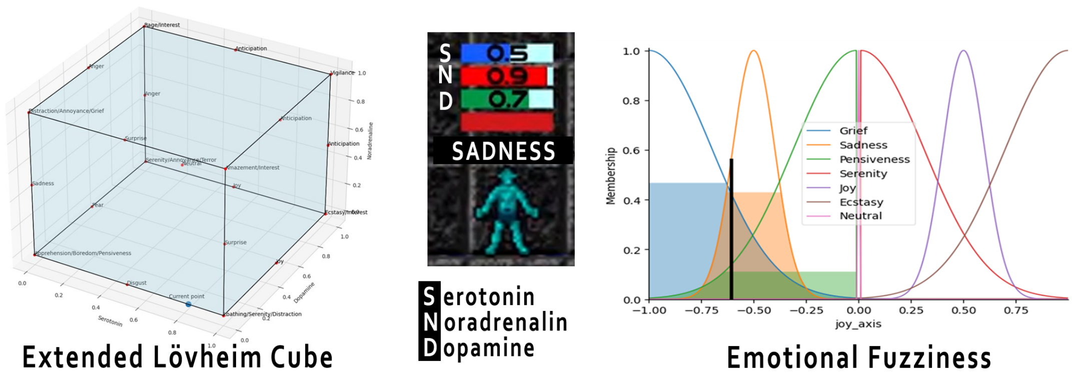

Figura 1. Illustrated depiction of a NPC with neurotransmitters and a result emotion, which is determined through the Extended Lövheim Cube model on the left and the Emotional Fuzziness on the right.

Abstract. *Many video games depend solely on pre-written scripts, limiting character interaction complexity to what the writers and developers can explicitly design and implement. Nevertheless, real-life decision-making involves various human elements, particularly emotional relationships, which evolve unpredictably. One way to overcome the restrictions of scripted actions is to have non-player characters capable of simulating human emotions. However, the emotion models found in the literature do not adequately represent the dynamic and complex emotions that arise when an NPC is affected by an action. The Lövheim model has the advantage of associating emotions with the effects of neurotransmitters, which are directly related to what actions provoke in people. However, that model is complicated to associate with the diversity of emotions an NPC should experience in a game. In this paper, we propose a new emotion model for NPCs that combines the dynamics of the Lövheim model with the richness of Plutchik's wheel of emotions, which we call the Extended Lövheim Cube. The combination of emotions caused by neurotransmitter variations must consider the emotional states' fuzziness, which we consider using fuzzy logic in our model. We validate our Extended Lövheim Cube model by imposing typical in-game actions on an NPC and comparing the resultant emotions with expected ones. Our results show that the fuzzy logic was to able to keep the desired features while having acceptable accuracy values.*

Keywords *Emotion, Neuroscience, Game AI, NPC, Fuzzy Logic, Neurotransmitters*

1. Introduction

When people play video games, they usually encounter non-player characters (NPCs) that behave in predictable ways, following programmed instructions and not reacting appropriately to unexpected actions. This behavior emerges because many games rely entirely on scripts, and character interactions are only as complex as the writers and developers design them. Typically, they use traditional, limited behavior models, such as a decision tree. However, real-life decision-making is much more complex than these simple approaches. Events and outcomes depend on many unpredictable human factors. One of the most promising strategies to overcome the limitations of scripted actions is to have the characters express emotions.

The simulation of emotions can be used for many purposes, even public safety. The work by Subagyo, Nugroho, and Sumpeno [Subagyo et al. 2016] is used to visualize how a crowd would behave when evacuating a building on fire. That allows safety procedures to be tested and improved, potentially saving lives. However, such representation of behaviors must be realistic enough for its results to become meaningful data. To achieve that, we need to incorporate emotion models into the NPCs' behavior. However, the emotion models found in the literature do not adequately represent the dynamic and complex emotions that arise when an NPC is affected by an action. They usually focus on basic or primary emotions (further explained in Section 3.1).

In the present paper, we propose a new emotion model for NPCs that combines the dynamics of the Lövheim model [Lövheim 2012] with the richness of Plutchik's wheel of emotions [Plutchik 1994], which we call the Extended Lövheim Cube (Figure 1). This paper is organized as follows. Section 2 presents the related works. Section 3 presents the three emotion models we considered in our work and our new emotion model. In Section 4, we first describe the implementation of the original Lövheim Cube of emotion, where we locate emotional states as Euclidean distances to an origin point. We present this implementation to compare it with our Extended Lövheim Cube, which incorporates fuzzy logic to represent emotions. Section 5 presents the tests and results of the implemented algorithms, which shows that the extended cube with fuzzy logic provides acceptable accuracy values, while the use of Euclidean distances with Lövheim's model doesn't. Finally, Section 6 concludes our work with final considerations and proposals for future work.

2. Related works

At the beginning of the investigation, it was necessary to define which notation models would be used to describe emotions (used in psychology and neuroscience). To help in this process, we counted on the help of undergraduate neuroscience students who helped in understanding the models used. We focused on using logic notations that could be implemented to help enrich the game AI in a game environment. For simulating emotions in digital characters, both Russell's Arousal-Valence model of affect [Russell 1980] (1980) and Plutchik's wheel of emotions (1980) [Plutchik 1994] were used in previous papers such as [Bicalho et al. 2020] and [Baffa 2017] and had good results according to the authors. However, the emotion model proposed by Hugo Lövheim [Lövheim 2012] in 2012, which is called the cube of emotions, seemingly had no significant references for this implementation context. Unlike the other models, which were created by psychologists, it is inspired by neuroscience. It proved to be an essential part of the research as we

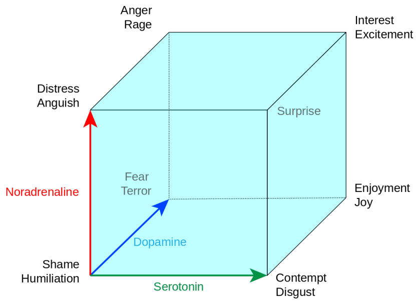

Figura 2. Lövheim's cube of emotions. Picture obtained from [Kolmogorova A. e A. 2021].

explored the associations it defines between emotions and neurotransmitters. Papers like [et al. 2021] detail their roles. It investigates the correlation between neuromodulators and social behaviors based on the current literature, which was very useful in learning about the hormone oxytocin. The understanding of these concepts informed the decisions taken for the proposal of a new extended cube of emotions.

There are very few works on emotion models for NPCs in the literature. One of the first collections of works is the proceedings of the Emotion in Games Workshop [Yannakakis 2011]. Bicalho et al. [Bicalho et al. 2020] present a model of emotion and culture from which we get the most inspiration. Li and Campbell [Li 2010] present a model based on psychological and sociological research that they claim is easy to use. Popescu et al. [Popescu 2014] propose an emotion engine called GAMYGDALA. However, none of those works represent complex combinations of emotional states.

Future Falls is a game proposed by Bicalho, Feijó and Baffa [Bicalho et al. 2020] for testing the influence of culture models in non-player characters decisions and behaviours. It was an inspiration for this project. The original intention was to explore interactions between characters of different cultures. The player can be spotted at a certain distance and as he gets closer to the characters, and that causes them to react. They all respond to events based on their particular culture, prejudice against humans and trust level. These variables have an impact on the calculation of their emotion, which is based on the wheel of emotions model. When an agent is attacked by the protagonist, it may run away in fear, or become a dangerous enemy due to anger. And if it's happy, it will follow the player and even push him. That is why there are both positive and negative actions as options for interactions, which increase or decrease trust. All of them visibly have an emotion, a health bar and a trust level bar. The game ends when the player is killed or when he earns a high level of trust by most.

3. Models of emotion

3.1. Existing models

An emotion model describes emotional states based on theories. It's used to help in visualize the spectrum of emotions and how they relate to each other [Plutchik 1994]. The present study focused on Hugo Lövheim's cube of emotions [Lövheim 2012] as the baseline model. However, some aspects of Robert Plutchik's wheel of emotions [Plutchik 1994] and W. Gerrod Parrott's emotion framework [Parrott 2001] were also important.

Lövheim's model (Figure 2) utilizes eight emotions spread across vertices (enjoyment/joy, interest/excitement, contempt/disgust, sha-me/humiliation, fear/terror, surprise, anger/rage, distress/anguish), and distributed by the values of three neurotransmitters: serotonin (dependent variable on X-axis), noradrenaline (also known as norepinephrine, dependent variable on Y-axis) and dopamine (dependent variable on Z-axis). For example, shame/humiliation, distress/anguish, contempt/disgust and surprise are emotions with low levels of dopamine, while fear/terror, anger/rage, enjoyment/joy and interest/excitement are on the higher side of the spectrum. Fear/terror is also low-serotonergic and low-noradrenalinergic, anger/rage and enjoyment/joy are combinations with maximum noradrenaline and serotonin levels, respectively, and interest/excitement is a blend of the three neurotransmitters.

Considering that dopamine is related to stimulation in the reward system [Berridge e Kringelbach 2015], the direct association of its pure intensity with fear/terror might be considered inconsistent at first. However, in the original paper (Lövheim, 2012) [Lövheim 2012], Lövheim justifies it by stating these two emotions also reinforce habits, but in this case it is to avoid situations considered to be dangerous or scary. He even mentions there is a rewarding effect related to them. It is important to note that the representation of the neurotransmitters as axes doesn't mean any of them are independent in real life. After all, the author admits they likely influence each other in more complex manners.

Neurotransmitters are molecules made up of a precursor molecule that is present in their cell. They are synthesized in a neuron and act as chemical messengers to affect another cell, transmitting electrical signals [Cuevas 2007]. Serotonin, noradrenaline and dopamine, particularly, belong to a class called monoamines because they are derived from a single amino acid. Another relevant trait they all share is being produced in small regions of the brain by relatively few neurons. The role of monoamine systems in emotions is given by their regulation of behaviours. That has become a known strategy for treating psychiatric disorders, since many medicinal drugs directly alter these systems. While dopamine is connected to reward and motivation, serotonin is related to self-confidence and noradrenaline to stress and anxiety. The reason for this model to group two emotions together as one, except surprise, has to do with Silvan Tomkins's theory of basic emotions [Tomkins e McCarter 1964]. According to it, only eight exist. Each comes with two names because the left one represents its weaker manifestation and the right one is its strongest form [Kolmogorova A. e A. 2021]. Originally, Tomkins labeled the emotion startle alongside surprise, but it was later proved they had no association [Ekman P. 1985].

The wheel of emotions (Figure 3) proposes there are eight primary emotions (anger, fear, sadness, disgust, surprise, anticipation, trust, and joy) and each has three intensity levels (for example, anger becomes annoyance and rage in, respectively, lower and higher intensity). The intensities provide more gradual transitions between the emotions. There are four axes, which contain two basic emotions considered to be opposites: joy vs. sadness, anticipation vs. surprise, anger vs. fear and trust vs. disgust. Then there are the dyads, the mixture of those feelings. For example, fear and surprise combined become awe. Thus, this model established associations between sentiments. These definitions were acquired through reading [Bicalho et al. 2020].

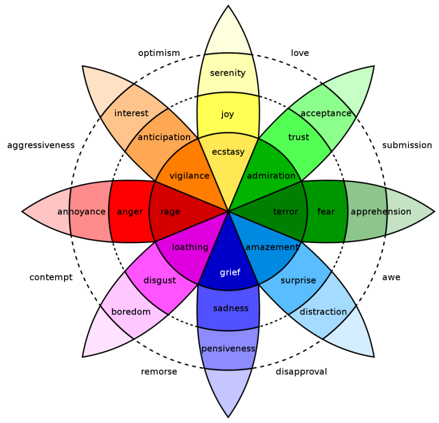

Figura 3. Plutchik's wheel of emotions. Picture obtained from [Bicalho et al. 2020].

Primary emotion	Secondary emotion	Tertiary emotion
Love	Affection	Adoration · Fondness · Liking · Attraction · Caring Tenderness · Compassion · Sentimentality
	Lust/Sexual desire	Desire · Passion · Infatuation
	Longing	Longing
Joy	Cheerfulness	Amusement · Bliss · Gaiety · Glee · Jolliness · Joviality · Joy · Delight · Enjoyment · Gladness · Happiness · Jubilation · Elation · Satisfaction · Ecstasy · Euphoria
	Zest	Enthusiasm · Zeal · Excitement · Thrill · Exhilaration
	Contentment	Pleasure
	Pride	Triumph
	Optimism	Eagerness · Hope
	Enthrallment	Enthrallment · Rapture
	Relief	Relief
Surprise	Surprise	Amazement · Astonishment
Anger	Irritability	Aggravation · Agitation · Annoyance · Grouchy · Grumpy · Crosspatch
	Exasperation	Frustration
	Rage	Anger · Outrage · Fury · Wrath · Hostility · Ferocity · Bitterness · Hatred · Scorn · Spite · Vengefulness · Dislike · Resentment
	Disgust	Revulsion · Contempt · Loathing
	Envy	Jealousy
	Torment	Torment
Sadness	Suffering	Agony · Anguish · Hurt
	Sadness	Depression · Despair · Gloom · Glumness · Unhappiness · Grief · Sorrow · Woe · Misery · Melancholy
	Disappointment	Dismay · Displeasure
	Shame	Guilt · Regret · Remorse
	Neglect	Alienation · Defeatism · Dejection · Embarrassment Homesickness · Humiliation · Insecurity · Insult · Isolation · Loneliness · Rejection
	Sympathy	Pity · Mono no aware · Sympathy
Fear	Horror	Alarm · Shock · Fear · Fright · Horror · Terror · Panic ·
	Nervousness	Anxiety · Suspense · Uneasiness · Apprehension (fear) · Worry · Distress · Dread

Figura 4. Parrott's emotion framework. [Murgia et al. 2014].

One other model that proved useful for the project was Parrott's emotion framework [Parrott 2001]. It is a classification of emotions based on a tree structure. Figure 4 shows its three levels: primary, secondary and tertiary emotions. Each one decomposes the previous level into multiple, less abstract feelings. It enabled the discovery of specific links between emotions that were absent in the other models.

3.2. A new extended cube of emotions

Based on the existing models, this work proposes a new extended cube of emotions (Figure 5), with 22 emotions distributed in 21 points. The relation between the indexed points and the emotions is detailed on Figure 6. In studying the wheel of emotions and the cube of emotions, it became apparent that there was potential for naturally blending some of their definitions. This model keeps the orthogonal coordinate relationships between the monoamine systems, but represents the emotions using the descriptions of Plutchik's wheel [Plutchik 1994].

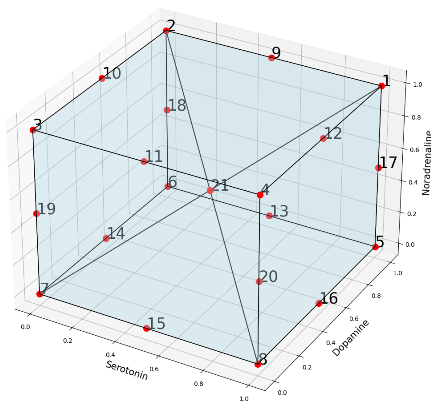

Figura 5. Proposed extended cube of emotions.

Since both original models consider the intensity of mostly the same feelings, but each adds different informations, they could complement each other. Instead of

Serotonin	Noradrenaline	Dopamine	Result
Low	Low	Low	7. Apprehension/Boredom/Pensiveness
Low	Low	Medium	14. Fear
Low	Low	High	6. Terror/Annoyance/Serenity
Low	Medium	Low	19. Sadness
Low	High	Low	3. Distraction/Annoyance/Grief
Low	Medium	High	18. Anger
Low	High	Medium	10. Anger
Low	High	High	2. Rage/Interest
Medium	Low	Low	15. Disgust
Medium	Low	High	13. Joy
Medium	High	Low	11. Surprise
Medium	High	High	9. Anticipation
High	Low	Low	8. Loathing/Serenity/Distraction
High	Low	Medium	16. Joy
High	Low	High	5. Interest/Ecstasy
High	Medium	Low	20. Surprise
High	Medium	High	17. Anticipation
High	High	Low	4. Amazement/Interest
High	High	Medium	12. Anticipation
High	High	High	1. Vigilance
Medium	Medium	Medium	21. Neutral

Figura 6. Table with all the model's points.

only considering extreme low or high levels of the monoamines, there could be points between the corners, thus including more sentiments. Lövheim stated that there could be "..supposedly, an infinite number of intermediate states, located inside the cube mode"[Lövheim 2012]. Many points have more than one emotion because they are placed in the beginning and/or ending of more than one axis. For example, the point apprehension/boredom/pensiveness is the origin of all three neurotransmitter axes and the increase in any of them can lead to either fear, disgust or sadness. That is why it represents all of their low intensities simultaneously. Firstly, all the original emotions from the cube were swapped. Most of them have a direct correspondent in the four axes of the other model.

- Contempt/Disgust → Boredom, Disgust and Loathing
- Fear/Terror → Apprehension, Fear and Terror
- Enjoyment/Joy → Serenity, Joy and Ecstasy
- Anger/Rage → Annoyance, Anger and Rage
- Surprise → Distraction, Surprise and Amazement
- Interest/Excitement → Interest, Anticipation and Vigilance

Nonetheless, there are exceptions. Shame/humiliation is not a basic emotion in Plutchik's model and neither is sadness in Lövheim's. Shame is considered to be a tertiary dyad between fear and disgust [et al 2015]. Such combination is not compatible with the cube, since shame is linked to low levels of dopamine and serotonin, while fear and disgust happen at their extreme concentration. That was the first major inconsistency encountered. Looking at another model, Parrott's emotion framework (Figure 4) managed to fill that gap, defining shame as a secondary derivation of sadness and humiliation as a tertiary derivation. Of course, the nomenclatures of each model are not necessarily based on the same sources and the exact meaning of each emotion can vary. Even so, Lövheim's cube is not a linguistic classification, it is dependent on the relationship between neurotransmitters and sentiments. Any given emotion's placement in it is validated by the monoamine that causes it (or lack thereof). The dyads were entirely discarded for the new model because of that. Studies investigating the association between humiliation and sadness demonstrated that humiliating events can cause significant depression [McCarley 2009]. Lövheim even mentions in his article that people suffering from depression appear to have low serotonin levels, which is why common antidepressants act to increase them [Coleman J. e E. 2016]. Serotonin has been more the subject for depression treatment than the other two neurotransmitters [Moret e Briley 2011], but they have also been used for therapy. The antidepressant drug ketamine increases release of dopamine [et al. 2022], desipramine and nortriptyline do the same for noradrenaline. There are also experiments showing that noradrenaline depletion in the brain causes depressive symptoms to return after a recovery [Moret e Briley 2011]. These facts all indicate low function of all three monoamine systems causing depression, just like shame/humiliation.

Distress often denotes stress more than the idea of sadness itself. Anguish also might give the impression of pain. Despite being one of the most basic and visually recognizable emotions, sadness is an umbrella for many different terms. In the paper [et al. 2020], this linguistic complexity is explored. Both distress and anguish are used to express intense, extreme forms of sadness. Additionally, in the wheel of emotions, grief is considered the highest level of sadness, and distress is a commonly described reaction to grief [Pop-Jordanova 2021]. Given that sadness seems to be connected in some ways to both shame/humiliation and distress/anguish, the first being low-noradrenalinergic and the other being high, there could be a scale between them. That is the reason why shame/humiliation and distress/anguish were replaced with pensiveness (lowest intensity of sadness in the wheel of emotions) and grief, respectively. However, they are definitely not the same. Keeping these names unchanged in the new model and just adding sadness as a point in the middle of their edge was considered, but all other emotions were already using Plutchik's terms.

The remaining basic feeling in the wheel of emotions, trust, is too distinct from the ones in Lövheim's model, so it couldn't be represented. The justification for this omission is the role of a hormone called oxytocin in stimulating trust. This hormone also acts as a neurotransmitter, but it does not belong to the same type as serotonin, noradrenaline and dopamine. As was explained in the previous section that monoamines come from a single amino acid, oxytocin is derived from peptides. Several studies have shown it affects social bonding activities, such as cooperation, generosity and naturally trust [et al. 2021]. Many attempts were made to include this neuropeptide in the extended model. The first option was establishing a completely independent axis for it. In the paper [et al. 2021], it also mentions a possible connection between dopamine and trust behaviour, so merging both or just including the emotion in the z-axis somehow were also contemplated. Upon further consideration, it became apparent that would be outside the scope of the model due to some factors: the relationship between the hormone and the monoamines is not clearly established; some recent studies about the oxytocin association with trust had conflicting results; more research is needed to understand how dopamine is involved, as there could simply be overlap with the reward system [et al. 2021].

Another relevant difference between the sentiment models is the presence of the previously mentioned opposites. According to the wheel of emotions, it is impossible to feel, for example, fear and anger at the same time. Lövheim himself even points it out: "Plutchik also developed a sort of three-dimensional model of emotion, in which the emotions are basically ordered in a circle based on similarity. An intensity dimension is added to this polar, similarity-based model. Here Plutchik might have been misled by the fact that the model originated from a two-dimensional representation, a so-called circumplex model, which then might have led to the possibly false conclusion that the emotions could be ordered in opposing pairs. Therefore, Plutchik's model is not three-dimensional in the same sense as the model presented in this article"[Lövheim 2012]. Interestingly, his own interpretation of sadness in the cube is "the inability to reach the basic emotions of enjoyment/joy", which feels quite similar to the idea of there being opposite feelings. One other possibly minor inconsistency is the fact one model names excitement as the higher level of interest and for the other its vigilance. Although vigilance is not shown in the cube, it is mentioned as being part of the noradrenaline axis.

Finally, a point for the neutral state was included, located at the exact centre of the cube. That is also alluded to in the original paper [Lövheim 2012]. This decision came from the need of having to calculate some emotion in this position for the coding experiments, regardless of the actual debate around it existing or not [Gasper K. 2019]. In conclusion, this proposed model keeps all the same limitations presented by Lövheim. The exact properties of each monoamine, its associations with emotions and the impact of other factors such as cognitive processes must all be better elucidated.

4. Proposed Approach

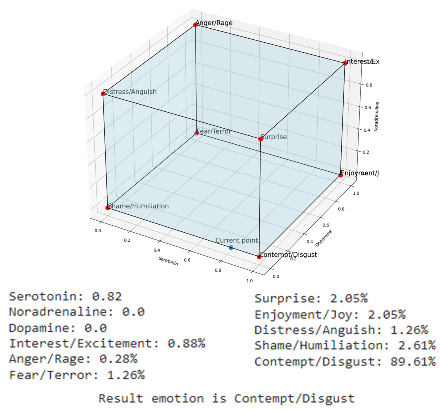

Figura 7. Results from the Euclidean distance score implemented.

4.1. Cube of emotions and Euclidean distance

The first approach was trying to interpret the cube mathematically in a way that emotions could be extracted from the levels of monoamine concentrations. Upon learning about the cube of emotions model and its Cartesian coordinate system, an idea emerged that emotions could be expressed as points located inside it. Despite not having to do with AI techniques, making calculations based on the distance between points, also known as the Euclidean distance, felt like a particularly interesting approach to consider with this 3D model. Lövheim provided no particular interval for the neurotransmitter axes, but considering each corner of the cube as an extreme, the choice was made to have them span from zero to one. The following steps were developed: given three input values in the range of zero to one for serotonin, noradrenaline and dopamine levels, we consider these values to be the coordinates of a point and calculate its distance to one of the cube's vertices. Then, we take the result and turn it into a score, using the formula seen below. The division by the square root of three is to ensure the maximum possible distance is between the origin of the coordinate system, (0,0,0), and the farthest vertex in the cube, (1,1,1). By subtracting the division from one, we invert its positioning, so the larger the distances, the lower the score will be. At last, we multiply it by a hundred to have a percentage, as presented in Equation 1, where ser stands for serotonin, nor means noradrenaline, and dop is dopamine.

$$score = (1 - \frac{\sqrt{(ser-x)^2 + (nor-y)^2 + (dop-z)^2}}{\sqrt{3}}) \times 100 \tag{1}$$

This mathematical operation is done to all eight vertices. After that, the scores need to be scaled so they all together add up to a hundred. However, a point that is significantly closer to the input than the others should not undergo that process. To preserve the relative difference between the points, if there is one maximum score, it stays the same and the factor applied to the others takes it into consideration.

i in range(len(score)) score.count(max_score) $>$ 1 final_score[i] = score[i] $\times \frac{100}{\sum score}$

score[i] $\neq$ max_score final_score[i] = score[i] $\times \left(\frac{100-\text{max\_score}}{\sum score-\text{max\_score}}\right)$

Consequently, the maximum final score, which is the closest point to the neurotransmitters' coordinates, determines the result emotion. It is the emotion represented by the closest vertex (Figure 7). There are still the situations where the input coordinates are equally distant from two or more points. To provide characters with a single feeling, a random one is picked between the ones with maximum score.

4.2. Extended cube of emotions

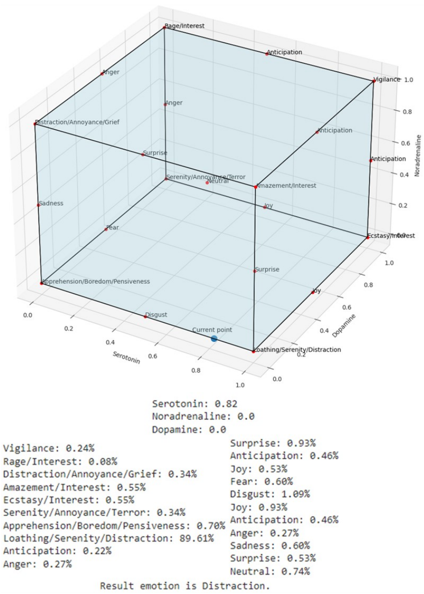

Figura 8. The Euclidean distance score implemented for the extended cube.

The exact same procedures described in the previous section were also applied to the proposed extended cube of emotions, which means more scores had to be calculated and compared, as seen in Figure 8.

4.3. Fuzzy logic

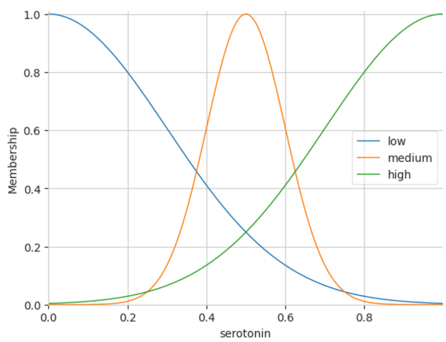

Figura 9. Membership function for serotonin as antecedent.

Our understanding of emotions is heavily impacted by language, so their very own definition can be filled with ambiguity. The use of fuzzy logic stood out for being exactly designed to tackle such problem. Unlike the deterministic Euclidean distance score, fuzzy logic provided the opportunity for NPCs to have partial and less predictable sentiments.

In order to start coding, it was necessary to determine what should be the crisp inputs and outputs, the fuzzy sets and the fuzzy rules. Those became clear quite early, due to the linguistic nature of fuzzy logic.

With the tools provided by the SciKit-Fuzzy library[1], it was possible to define the three monoamines as the antecedents, fuzzified into sets of low, medium and high. With values that range from 0 to 1, numeric intervals define the size of each set (Figure 9). The emotions are the consequents. To find a membership function that could represent them, it was necessary to find a sequential order for the distribution of emotions, which is not what happens in the 3D cube. That is exactly why the extended cube model is used since it provides an actual order to place the emotions. Inheriting the concept of four axes from the wheel of emotions, despite Lövheim's model not having four concurrent feelings nor opposites, leads to four consequents. Each one has pairings of opposite emotions (each with their intensities) with the addition of a neutral sentiment in range of values from -1 to 1. Figure 10 shows the plot of the joy vs. sadness membership function. Joy intensifies from left to right. Conversely, sadness is stronger from right to left. Between -0.01 and 0.01, there is a small neutral classification which is meant to be declared for situations where a combination of monoamine levels doesn't result in any of the emotions particular to the axis. Following this example, we represent the other axes similarly using the same pairings as Plutchik's. Since trust is not part of the model, the disgust axis consequent exceptionally had half of the fuzzy sets, so its neutral range varies from -0.01 to 1.

The fuzzy rules are simply the associations seen in the cube of emotions. For example, if serotonin and dopamine are high, but noradrenaline is low, the result emotion is enjoyment/joy. During the initial implementation of said rules, there were some completely wrong associations. As such, a few rules had to be removed, which means some of the points proposed in the extended cube could not exist. Yet, they were all repetitions, so no unique emotion was lost.

Many tests were made to ensure the representation of the variables were correct. Specifically, the numeric intervals and membership functions of all the antecedents and consequents were constantly changed. Initially, triangular functions were used, but compared to Gaussian membership function, the latter provided a bit more subtle gradual transition between the monoamine levels and the results.

5. Tests and Results

Besides shooting the NPCs with a weapon, we consider that a player could have six other interactions: giving or stealing their items, talking politely or not, giving or stealing their money (shown in Table 1). Given the dynamic capability of the monoamine systems to deal with sudden changes [Lövheim 2012], they are significantly impacted by each situation. As referenced in Section 3.2, [et al. 2021] suggests a possible link between generosity and dopamine, also mentions serotonin influence. For that reason, giving an item in the game noticeably increases a character's dopamine levels and in a lesser capacity, serotonin. These informations are consistent with the fact neurons often produce more than one neurotransmitter [Purves 2001]. All of the effects of the player actions can be seen in Table 2.

[1] https://pythonhosted.org/scikit-fuzzy/https://pythonhosted.org/scikit-fuzzy/

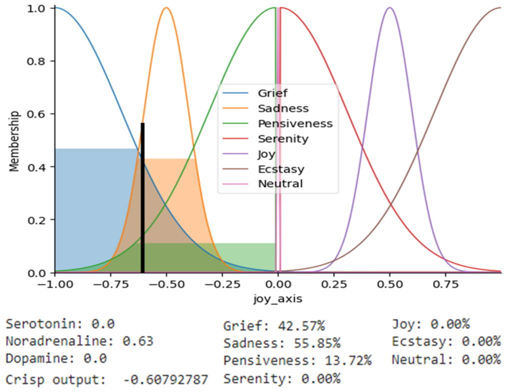

Figura 10. Results from the fuzzy joy vs. sadness consequent membership function

Action	Expected Emotions
is_attacking	Anger/Rage, Fear/Terror, Distress/Anguish
is_giving_item	Enjoyment/Joy
is_stealing_item	Shame/Humiliation, Contempt/Disgust, Anger/Rage
is_talking_politely	Enjoyment/Joy, Distress/Anguish, Surprise
is_not_talking_politely	Shame/Humiliation, Interest/Excitement
is_giving_money	Enjoyment/Joy
is_stealing_money	Distress/Anguish, Contempt/Disgust, Anger/Rage, Surprise, Fear/Terror, Shame/Humiliation

Tabela 1. Lövheim emotions based on player actions

In order to be able to relate the expected emotions as an implication of the actions performed by the player, we defined a list of the expected emotions that the model should calculate to the NPCs. Table 1 presents the list of emotions based on the Lövheim cube. Furthermore, for the extended Lövheim cube model proposed in Section 3.2, we define the list of expected emotions that is presented in Table 3.

Table 4 was acquired by simulating the expected impact each player action would have on the NPC's neurotransmitters. For all emotions, given an initial one, we looked at the emotions they would become after a player's action. The criteria for the accuracy was whether actions resulted in the expected emotions or not (Table 3). Analyzing the results, we see that the Euclidean algorithm for Lövheim's cube had the worst results overall. Despite using the same Euclidean distance approach as the extended cube in the next column, it is not as precise because it has fewer emotions to consider. Comparing the results from the fuzzy algorithm (that is also using the extended cube) with the others, there is an improvement for three actions and a decrease in the rest. However, the fuzzy results are all close to the ones in the previous column. As such, the Euclidean method for Lövheim's cube presents substantially different values.

Action	Serotonin Level Change	Noradrenaline Level Change	Dopamine Level Change
is_attacking	Decrease by 0.3	Increase by 0.3	None
is_giving_item	Increase by 0.1	None	Increase by 0.3
is_stealing_item	None	None	Decrease by 0.3
is_giving_money	None	Increase by 0.3	None
is_stealing_money	Increase by 0.1	Decrease by 0.3	Increase by 0.1
is_talking_politely	Increase by 0.3	None	Increase by 0.1
is_not_talking_politely	Decrease by 0.3	None	None

Tabela 2. Effects of player actions on neurotransmitter levels

Action	Expected Emotions
is_attacking	Anger, Rage/Interest, Serenity/Annoyance/Terror, Distraction/Annoyance/Grief, Fear
is_giving_item	Joy, Ecstasy/Interest, Amazement/Interest
is_stealing_item	Sadness, Apprehension/Boredom/Pensiveness, Disgust, Annoyance, Loathing/Serenity/Distraction
is_talking_politely	Apprehension/Boredom/Pensiveness, Serenity, Surprise, Distraction/Annoyance/Grief
is_not_talking_politely	Pensiveness, Anticipation, Vigilance Apprehension/Boredom/Pensiveness,
is_giving_money	Amazement/Interest, Joy, Ecstasy/Interest
is_stealing_money	Distraction/Annoyance/Grief, Loathing/Serenity/Distraction, Rage/Interest, Disgust, Surprise, Fear, Anger

Tabela 3. Extended Lövheim emotions based on player actions

6. Conclusion

The work presented in this paper includes proposing a new emotion model based on Lövheim's cube of emotions and Plutchik's wheel of emotion, combining the first's dynamics with the latter's richness of details. A prototype was also developed to implement the models. The first is based on Lövheim's model and applying Euclidean distance formula, the second uses the same formula for the extended cube and the last one uses fuzzy logic in the extended cube to consider the emotional states' fuzziness, which is caused by neurotransmitter variations. Without the extended cube, there is no implied distribu-

Action	Lövheim	Extented	Fuzzy
is_attacking	96.9%	78.31%	67.15%
is_giving_item	44.9%	82.48%	70.29%
is_stealing_item	53.1%	96.97%	100.00%
is_talking_politely	51.7%	72.28%	64.08%
is_not_talking_politely	30.0%	96.14%	100.00%
is_giving_money	22.9%	95.87%	100.00%
is_stealing_money	36.2%	71.00%	62.34%

Tabela 4. Results based on expected emotions presented in Table 1 and Table 3

tion order for the emotions in their consequent membership function, which means it is essential for the application of fuzzy logic.

The results presented in Table 4 show that the Euclidean implementation for Lövheim's cube was less accurate than the other two algorithms. Despite having the same method, the extended cube displays values closer to the fuzzy implementation. We are, therefore, confident in using the extended cube with fuzzy logic, which can give us a better and more in-depth representation of the emotional variation while keeping acceptable accuracy values.

This project's contributions include exploring the links between emotion models, showcasing the barriers that can arise when implementing fuzzy logic for emotion simulations and demonstrating the potential of integrating more neuroscience knowledge with game AI, which also has implications for other areas, such as evacuation training simulations.

A real-time simulation environment could be implemented to allow users to interact with emotional NPCs. It could also help visualize and analyze the results. Allowing the NPCs to interact with each other is another possible future work. At last, during the research process for the project, many different neuroscience theories demonstrated potential to control agent behaviour, such as Abraham Maslow's hierarchy of needs [Maslow 1943]. The integration between artificial intelligence and neuroscience has a lot of potential to give each other valuable insights.

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