Case Study – Modeling Cognitive Anxiety

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Abstract. The study of anxiety dynamics is an important goal with profound implications for understanding human emotions and actions. This study addresses the intricate interplay of psychological, cognitive, and external elements that collectively determine anxiety fluctuations. Deciphering these intricate dynamics provides a deeper understanding of decision making and emotional well-being. The study examines key variables such as anxiety-provoking events, beliefs related to worry, immediate and accumulated experiences, coping mechanisms, vulnerability, and more. This comprehensive investigation reveals the intricate web of emotional responses and their development.

Keywords: Anxiety States, Modelling and Simulation, Temporal Dynamics

1 Introduction

This study examines how cognitive biases influence anxiety, shedding light on how our thoughts impact our feelings and behaviors. It addresses the intricate interplay of psychological, cognitive, and environmental factors that collectively contribute to the fluctuation and flux of anxiety states. By unravelling these dynamics, deeper insights into decision making and psychological well-being emerge.

Anxiety dynamics encompass several fundamental concepts, each of which illuminates different facets of emotional states. Cognitive biases that influence how events are perceived affect emotional responses and contribute to anxiety fluctuations. In addition, emotional responses triggered by positive and negative experiences play a critical role in shaping the time course of anxiety. In addition, the study examines coping strategies and cognitive control mechanisms that individuals use to regulate emotions and sheds light on the delicate balance between internal processes and external influences.

Through a comprehensive exploration of these concepts, this study seeks to provide a comprehensive account of anxiety dynamics. By examining the interplay of cognitive biases, emotional responses, and coping mechanisms, a deeper understanding of how anxiety develops, and change is sought. This pursuit has implications not only for advancing psychological knowledge, but also for promoting emotional well-being and a better understanding of the human experience.

1.1 Variables

Variables:

Table 1. Variable definitions

Variable	Description	Symbol
Anxiety Provoking Event	An external event or situation that triggers anxiety in agents.	Ea
Belief About Worry	Agent's cognitive evaluation of worry's role in managing anxiety, influenced by experiences and coping strategies.	Bw
Short-Term Experience	Immediate emotional and cognitive response to an anxiety-provoking event.	Es

Long-term Experiences	Cumulative emotional and cognitive history of an agent's responses to anxiety over time.	El
Positive Coping Strategy	Agent's cognitive and behavioral mechanisms to effectively manage anxiety.	Cs
Sensitivity	Agent's susceptibility to experiencing anxiety, influenced by cognitive biases and other factors.	Sn
Short-Term Worry	Agent's immediate cognitive and emotional concern in response to anxiety.	Ws
Long-Term Worry	Persistent cognitive state of worry, influenced by cumulative short-term worry and experiences.	Wl
Personality	Enduring traits and characteristics influencing an agent's responses to anxiety-provoking events.	Ps
Traits	Specific attributes defining an agent's behavior, affecting anxiety responses.	Tr
Thought Control	Agent's cognitive ability to regulate and manage thoughts, influencing emotional and cognitive states.	Tc
Appraisal	Agent's cognitive assessment and interpretation of anxiety-provoking events, shaping coping strategies.	Ap

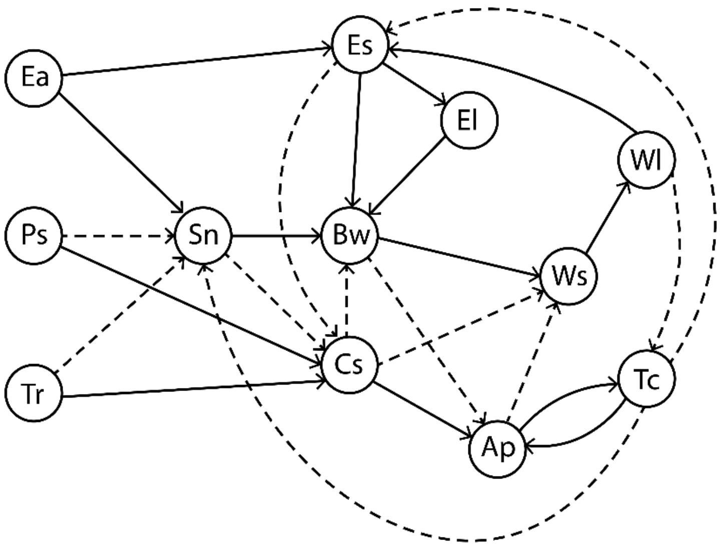
2 Background

By employing an agent-based model, a computerized tool that reflects individual behavior. Through the use of these virtual agents, the study aims to uncover the transformation of thoughts and emotions triggered by anxiety-provoking stimuli. By examining cognitive biases and coping mechanisms within this modeling framework, the research seeks to unravel the complex puzzle of emotional change and thereby shed light on the processes of decision making and emotional well-being. This interdisciplinary investigation has the potential to deepen the understanding of anxiety swings, provide valuable insights into psychology, and enhance the understanding of human emotional experiences.

Agent-based modeling is deeply rooted in the principles of complexity science. Each simulated agent replicates a person and their interactions with anxiety-provoking events. By integrating cognitive biases and coping strategies into this modeling approach, we aim to unravel the intricate interplay of factors that influence emotional change over time. Ultimately, this study should not only enrich psychological knowledge, but also contribute to an increased awareness of how emotions develop and influence overall well-being.

3 Formal Model

This section will explain the details of the model form a mathematical point of view. The relations implemented are based on earlier findings in literature on anxiety state and disorder. The model is fairly complex with a total of 12 nodes interconnecting to one another. The model in question can be seen in Figure 1 and Table 1.



*Solid line indicates a positive relationship, Dashed line indicates a negative relationship

Figure 1: Relation Diagram of the Model

	Ea	Bw	Es	El	Cs	Sn	Ws	Wl	Ps	Tr	Tc	Ap
Ea			+			+						
Bw							+					-
Es		+		+	-							
El		+										
Cs		-					-					+
Sn		+			-							
Ws								+				
Wl			+								-	
Ps					+	-						
Tr					+	-						
Tc			-			-						+
Ap							-				+	

Table 2: Relationship Matrix of the Model

Once the relationships between the nodes have been determined based on previous literature, the model is then formalized. This is where all nides are design to only accept input and produce outputs that range from 0 (low) to 1 (high) in an effort to reduce the model's complexity. The model can be split into two relation types; instantaneous and temporal relations.

3.1 Instantaneous Relationships

In this model there are 3 different inputs; Anxiety-Provoking Event (Ea), Personality (Ps), and Traits (Tr). For further explanation, both Ps and Tr are seen as positive where the higher the value of Ps and Tr of an individual, the better that individual is at controlling their anxiety. Thus, the giving a negative contribution towards the overall anxiety in the bigger picture.

Other than the three input nodes, there are a total of 6 other instantaneous relationships that are present. They are Belief of Worry (Bw), Short-Term Experience (Es), Short-Term Worry (Ws), Coping Strategy (Cs), Sensitivity (Sn), and Thought Control (Tc).

$$\boldsymbol{Bw(t) = \beta_{Bw}[\omega_{Bw}Es(t) + (1 - \omega_{Bw})El(t)] + (1 - \beta_{Bw})(Sn(t)(1 - Cs(t)))}$$

Belief of Worry (Bw) is positively influenced by Short-Term Experience (Es) and Long-Term Experience (El) while being negatively influenced by the product of Sensitivity (Sn) and Coping Strategy (Cs),

$$\boldsymbol{Es(t) = [\omega_{Es}Ea(t) + (1 - \omega_{Es})Wl(t)][1 - Tc(t)]}$$

Short-Term Experience (Es) however is proportionately influenced by a Anxiety-Provoking Event (Ea) and Long-Term Worry (Wl). It is also inversely influenced by Thought Control (Tc).

$$\boldsymbol{Cs(t) = \beta_{Cs}(\omega_{Cs_1}Ps(t) + (1 - \omega_{Cs_1})Tr(t)) + (1 - \beta_{Cs})(1 - (\omega_{Cs_2}Es(t) + (1 - \omega_{Cs_2})Sn(t)))}$$

Coping Strategy (Cs) can be seen as being influenced by Personality (Ps) and Traits (Tr) positively while being influenced by Short-Term Experience (Es) and Sensitivity (Sn) in a negative relationship. This means for an individual to possess a higher Cs value (better positive cooping strategies), they must first higher values of Ps and Tr. This can also be done by having lower levels of Es and an overall lower sensitivity level as well.

$$\boldsymbol{Sn(t) = \Psi_{Sn}(Sn_{norm} \cdot Ea(t)) + (1 - \Psi_{Sn})[1 - (\omega_{Sn_1}Ps(t) + \omega_{Sn_2}Tr(t) + \omega_{Sn_3}Tc(t))]}$$

Sensitivity is slightly different as it includes the Sensitivity Norm (Sn_{norm}). Sensitivity levels increase as Sn_{norm} and Ea values increase whilst values of Ps, Tr and Tc decrease.

$$\boldsymbol{Ws(t) = \beta_{Ws}Ea(t) + (1 - \beta_{Ws})[1 - (\omega_{Ws}Cs(t) + (1 - \omega_{Ws})Ap(t))]}$$

Levels of Short-Term Worry will increase with higher levels of Anxiety-Provoking Event (Ea) and lower levels of Coping Strategy (Cs) and Appraisal (Ap).

$$\boldsymbol{Tc(t) = \alpha_{Tc}Ap(t) + (1 - \alpha_{Tc})[1 - Wl(t)]}$$

For high levels of Thought Control (Tc), the positive contribution variable Appraisal (Ap) must be high in value while the opposite is true for Long-Term Worry (Wl). Thus, as the level of Appraisal (Ap) increase and the level of Long-Term Worry (Wl) decreases, the level of Thought Control (Tc) increases.

3.2 Temporal Relationships

$$\boldsymbol{Wl(t + \Delta t) = Wl(t) + \eta_{wl}[Ws(t) - Wl(t)](1 - Wl(t)) \cdot Wl(t) \cdot \Delta t}$$
$$\boldsymbol{El(t + \Delta t) = El(t) + \eta_{El}[Es(t) - El(t)](1 - El(t)) \cdot El(t) \cdot \Delta t}$$
$$\boldsymbol{Ap(t + \Delta t) = Ap(t) + \eta_{Ap}[\tau_{Ap}(t) - Ap(t)](1 - Ap(t)) \cdot Ap(t) \cdot \Delta t}$$
$$\text{where, } \boldsymbol{\tau_{Ap} = (\omega_{\tau 1}Cs(t) + \omega_{\tau 2}Tc(t)) + \omega_{\tau 3}(1 - Bw(t))}$$

Temporal relationships are relationships that change over time as the value is determined by the addition of variables onto its previous value. This can be seen with t and $(t + \Delta t)$ where it represents the time interval between each term. With that said, Long-Term Experience (El) is primarily contributed by Short-Term Experience (Es). Short-Term Experience (Es) however is then contributed by Anxiety-Provoking Event (Ea), Thought Control (Tc), and another temporal variable Long-Term Worry (Wl). Long-Term Worry (Wl) then is solely contributed by its short-term counterpart, Short-Term Worry (Ws) which is also contributed by the last temporal variable Appraisal (Ap). Appraisal (Ap) is then contributed by three variables which are Coping Strategy (Cs), Thought Control (Tc), and Belief About Worry (Bw).

Note that all three temporal variables are governed by a regulator to control the rate of change. The regulators are $\boldsymbol{\eta_{wl}}$, $\boldsymbol{\eta_{El}}$, and $\boldsymbol{\eta_{Ap}}$. Thus, with all of the formulas created, a model was developed and underwent simulations to understand and explore uncover patterns, insights and trends that could explains anxiety states.

4 SIMULATION RESULTS

A variety of simulations have been run in this section to show how the model works and to compare the effects of various variables on a fictitious person's anxiety related to their traits and personalities.

Agent	Anxiety-Provoking Event (Ea)	Personality (Ps)	Trait (Tr)	Sensitivity Norm (Sn_{norm})
1 (Low Risk)	1.0	1.0	1.0	0.1
2 (Medium Risk)	1.0	0.5	0.5	0.5
3 (High Risk)	1.0	0.0	0.0	0.9

Table 3: Initial Planning

Three situations were fabricated to mimic three different levels of risk, Low Risk, Medium Risk, and High Risk. These occurrences mimic a situation in which a person is dealing with a sudden change in their life. Only continuous stressful occurrences, though, will be described in this writing. In addition, several factors can be changed to imitate various qualities. In order to simulate a monitoring activity, we chose the following settings for this article: numStep = 500, numStepChange = 500, and Δt = 0.1. To find the best parameter values for the model, these settings were derived from several trials.

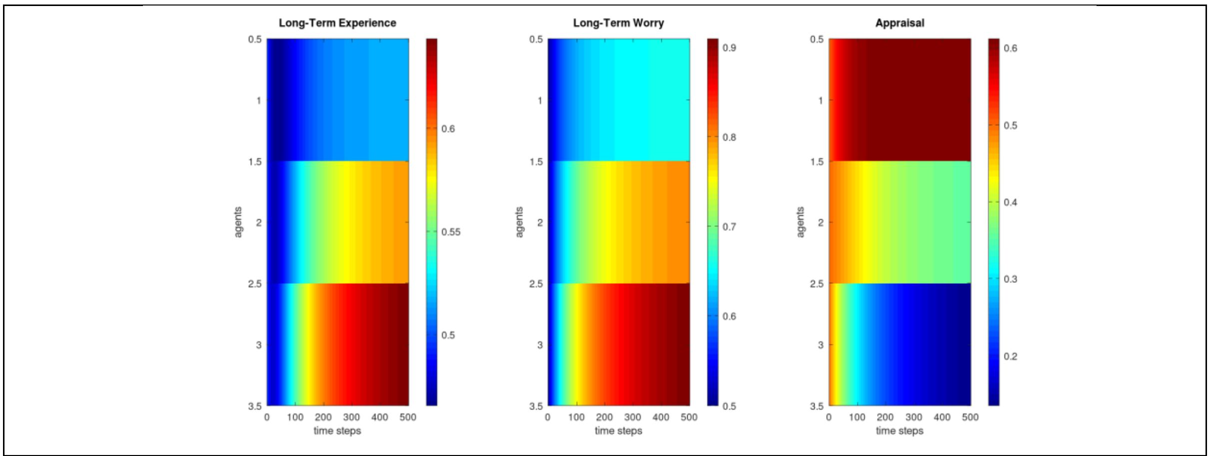


Figure 2: Heatmap

Figure 1 visualizes that Agent 1 who experienced low levels of Long-Term Experience (El) and Long-Term Worry (Wl) while having high levels of Appraisal (Ap). Agent 2 having a median score for all attributes (Ea = 1.0, Ps = 0.5, Tr = 0.5, Sn_{norm}=0.5). Agent 3 then to mimic a high risk, the parameters are set to very high values that would contribute to high levels of anxiety (Ea = 1.0, Ps = 0.0, Tr = 0.0, Sn_{norm}=0.9).

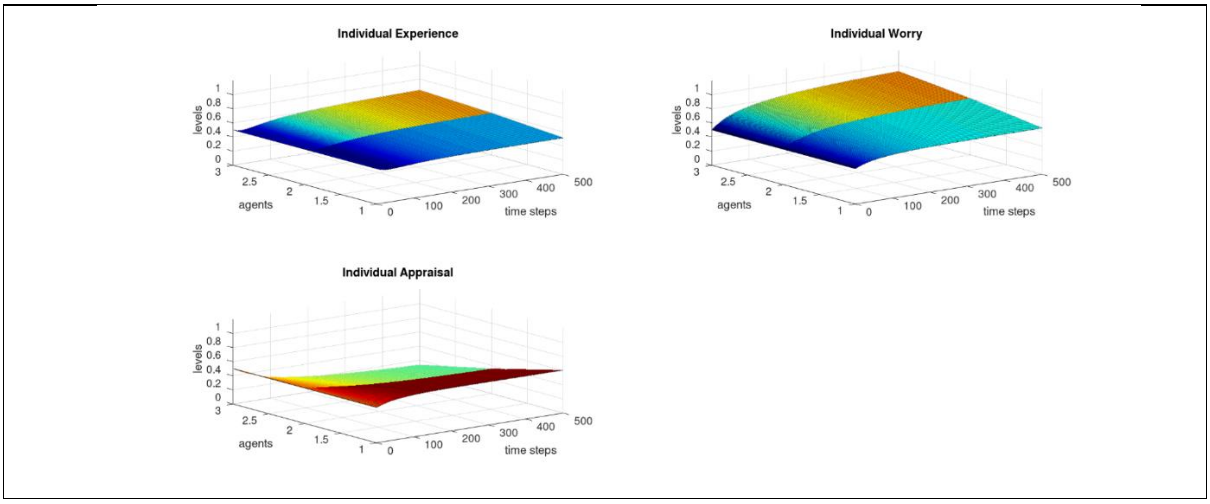


Figure 3: Temporal Specifications

Figure 2 shows the long-term of each agent's Individual experience, worry and appraisal.

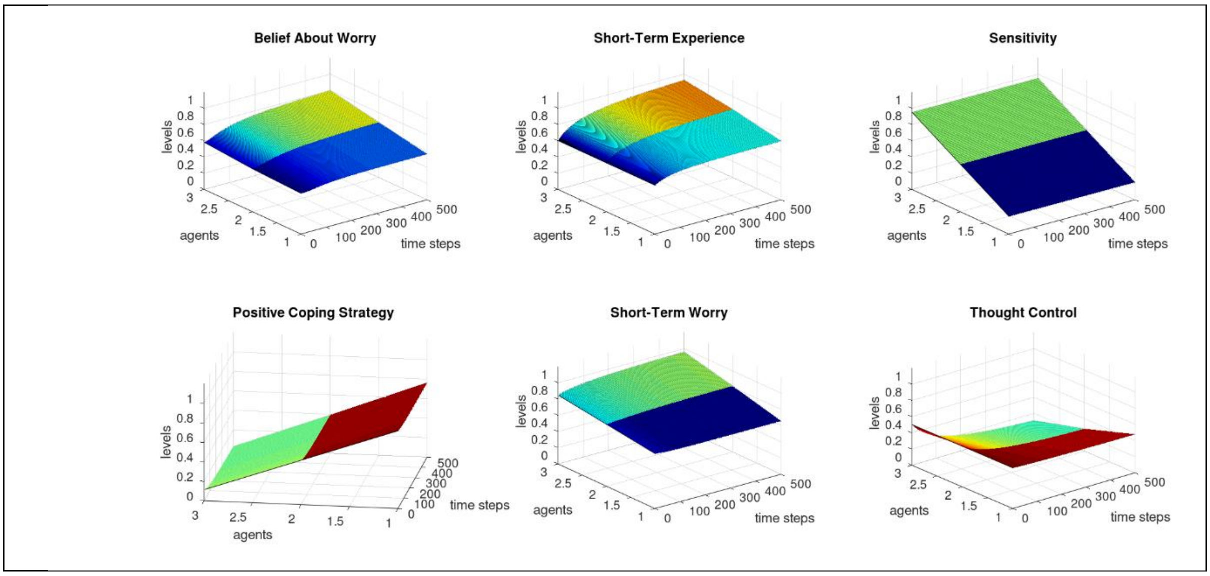


Figure 4: Instantaneous Specifications

Case#1 (Low Risk Person)

Agent 1, was able to manage their stress levels well without letting their levels of worry both short and long term to reach such high values when compared with other cases. As seen in Figure 4, Agent 1 was able to handle and regulate their anxiety even with high levels of Anxiety-Provoking Event (Ea) due to their high levels of Coping Strategy (Cs) and low levels of Sensitivity (Sn) after being exposed to the incoming stressor. This in turn allowed Agent 1 to experience low levels of Belief About Worry (Bw), Short-Term Worry (Ws), and moderately high levels of Appraisal. In the end, with the combination of these relationships, Agent 1 was able to manage their anxiety levels.

Case#2 (Medium Risk Person)

Agent 2 starts of with moderate traits and personality so we can assume that this individual is what we would call the norm or average person. As seen in Figure 4, after being exposed to the incoming stressor, their Coping Strategy (Cs), Sensitivity (Sn) and Thought Control (Tc) to have dipped much more than the previous agent (Agent 1). The lower levels of these three variables have caused a slight increase in Belief About Worry (Bw), Short-Term Worry (Ws) and Short-Term Experience (Es). This increase then contributed and resulted in Agent 2 experiencing relatively higher Long-Term Experience (El) and Worry (Wl) as well as lower levels of Appraisal (Ap). In short, due to the moderate levels of starting attributes, Agent 2 can manage their anxiety levels on a moderate level and not as well as Agent 1. However, this is to be expected as with moderate anxiety coping traits and personalities, the individual can only moderately control their anxiety levels in the end.

Case#3 (High Risk Person)

The simulation results have demonstrated that persons with low levels of Personality (Ps) and Traits (Tr) tend to experience a great increase of short-term experience when they are exposed to an incoming stressor. This is because Agent 3 lacks the ability to cope with stressful situations and positively appraise the events they have experienced, he or she are unable to manage their thoughts. As a result, there is a rise in anxiety and an added potential for sensitivity in the future. In the end, someone without a good personality or traits that can handle stress will experience much higher levels of anxiety due to their lack of positive coping strategies (Cs), high levels of sensitivity (Sn) and low thought control (Tc).

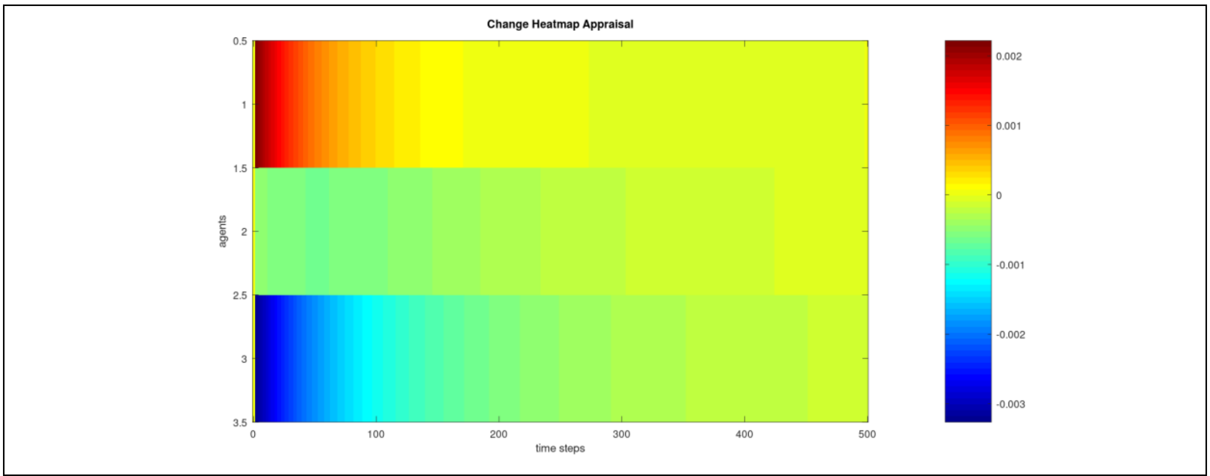


Figure 5: Change Heatmap Appraisal

5 Mathematical Analysis

For the mathematical verification, equilibria analysis is used to verify if there are situations where the model will become stable. The stability of a model means that the model reaches a state of equilibrium or in other words, does not change too much under small perturbations. This can be done by looking at the differential equations used in this model where the derivatives or a singular derivative equal to zero.

$$\frac{dy}{dx} = 0$$

The differential equation above denotes that the change of a variable is equal to zero. Thus, reaching a state of equilibrium as no (or very little) fluctuations will occur.

The importance of verifying the model is to ensure that it is stable enough to be used as an unstable model will become chaotic and be impossible to utilize. In addition, a stable model can indicate the correctness of the model as once a stable state is reached, information can be gained that could explain the theory or problem connected to the model that was made. To obtain any and all possible equilibriums, the values of variables that will create this situation must be discovered. To do this, the temporal equations are described in a differential equation form,

$$\frac{dWl}{dt} = \eta_{wl}[Ws(t) - Wl(t)]\big(1 - wl(t)\big) \cdot wl(t)$$
$$\frac{dEl}{dt} = \eta_{El}[Es(t) - El(t)]\big(1 - El(t)\big) \cdot El(t)$$
$$\frac{dAp}{dt} = \eta_{Ap}\big[\tau_{Ap}(t) - Ap(t)\big]\big(1 - Ap(t)\big) \cdot Ap(t)$$

In order to reach a state of equilibrium, as stated before, the differential equations must be equal to zero. Thus, in a stable situation, the equations above can then be described as:

$$\frac{dWl}{dt} = \frac{dEl}{dt} = \frac{dAp}{dt} = 0$$

Assuming all parameters are non-zero, this provides the following equilibrium equations.

$$[Ws(t) - Wl(t)]\big(1 - Wl(t)\big) \cdot Wl(t) = 0$$

$$[Es(t) - El(t)]\big(1 - El(t)\big) \cdot El(t) = 0$$

$$\big[\tau_{Ap}(t) - Ap(t)\big]\big(1 - Ap(t)\big) \cdot Ap(t) = 0$$

These equilibrium equations can then be broken down further to see the specific conditions where the state of equilibrium is reached. The conditions are as follows:

$$\frac{dWl}{dt} = 0 \;:\; Ws(t) = Wl(t) \vee Wl(t) = 1 \vee Wl(t) = 0$$

$$\frac{dEl}{dt} = 0 \;:\; Es(t) = El(t) \vee El(t) = 1 \vee El(t) = 0$$

$$\frac{dAp}{dt} = 0 \;:\; \tau_{Ap}(t) = Ap(t) \vee Ap(t) = 1 \vee Ap(t) = 0$$

a) **Case #1:** $Ws(t) = Wl(t)$

$$Es(t) = [\omega_{Es}Ea(t) + (1 - \omega_{Es})Ws(t)][1 - Tc(t)]$$
$$Tc(t) = \alpha_{Tc}Ap(t) + (1 - \alpha_{Tc})[1 - Ws(t)]$$

b) Case #2: $\boldsymbol{Es(t) = El(t)}$

$$Bw(t) = \beta_{Bw}[\omega_{Bw}Es(t) + (1 - \omega_{Bw})El(t)] + (1 - \beta_{Bw})(Sn(t)(1 - Cs(t)))$$
$$Cs(t) = \beta_{Cs}(\omega_{Cs_1}Ps(t) + (1 - \omega_{Cs_1})Tr(t)) + (1 - \beta_{Cs})(1 - (\omega_{Cs_2}El(t) + (1 - \omega_{Cs_2})Sn(t)))$$

c) Case #3: $\boldsymbol{\tau_{Ap}(t) = Ap(t)}$

$$Ws(t) = \beta_{Ws}Ea(t) + (1 - \beta_{Ws})[1 - (\omega_{Ws}Cs(t) + (1 - \omega_{Ws})\tau_{Ap}(t))]$$
$$Tc(t) = \alpha_{Tc}\tau_{Ap}(t) + (1 - \alpha_{Tc})[1 - Wl(t)]$$

With the cases stated above, the state of equilibrium for this model can be achieved if either one of these cases were to occur. Thus, verifying the model in a mathematical sense by equilibria analysis.

6 Conclusion

In summary, the exploration of anxiety dynamics using agent-based modeling has illuminated the intricate interplay of emotional responses shaped by cognitive biases, coping mechanisms, and fear triggers, providing a deeper understanding of the nuanced development of human emotions. Notable findings underscore the central role that cognitive biases and coping strategies play in shaping emotional responses, as well as the complicated dynamics between short-term experiences and long-term emotional states. An important entry point for the application of this research lies in its potential to provide essential support to people struggling with anxiety problems. By using the insights gained from the model, we can envision the development of interactive agents or therapeutic robots designed to help people manage their anxiety. By integrating the comprehensive results of the model into these technological advances, people can be provided with tailored strategies for real-time emotion regulation that effectively help them manage and regulate their emotional responses. The model's findings have the potential to be translated into pragmatic solutions that provide individuals with the tools to skillfully manage their anxiety and ultimately strengthen their emotional well-being and mental health.

7 Reflective

Participation in the cognitive anxiety modeling case study has revealed a wealth of insights and findings. At the outset of the project, integrating cognitive biases, coping strategies, and external triggers into an agent-based model presented challenges that required effective time management and collective collaboration. An early finding highlighted the importance of a solid baseline understanding and prompted a shift toward extensive research prior to model development. This adjustment underscored the value of sound decision making and strategic planning. The journey deepened understanding of cognitive anxiety dynamics and exposed the intricate connections between cognitive biases, coping mechanisms, and emotional responses. However, deeper exploration of cognitive biases and their nuanced effects is desired. Moreover, matching the results of the model with real-world applications could enrich the practical dimension. In consideration, it appears that spending more time on a comprehensive exploration and seeking mentors to integrate theory and application is an alternative. Future students can benefit from addressing cognitive biases, planning carefully, and seeking expert advice. This project highlights the importance of systematic research, strategic planning, and collaborative efforts in deciphering complicated psychological phenomena through computational modeling.