Models of Anxiety for Agent Deliberation: The Benefits of Anxiety-Sensitive Agents

Blue Sky Ideas Track

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ABSTRACT

Anxiety is one of the most critical sources of harm to psychological wellbeing, tied to an array of issues, from discomfort and maladaptive coping to severe pathological disorders –making of anxiety one of the largest economic and social healthcare expenses. AI systems are not neutral to the exposure of individuals and societies to anxiety, and the current emphasis on performance-optimization of current AI systems arguably sets a pathway for a systemic rise of anxiety. As a response to this trend, towards further increasing the human-centeredness of existing applications, this paper is dedicated to depicting the landscape of open challenges, high-impact applications, and promising solutions for designing anxiety-sensitive agents. This paper first circumvents the key components of anxiety through a summary of the extensive psychology literature on anxiety; then shows the feasibility of building agent-based models by putting forward an example of a logical model of anxiety; and last, examines current research fields through the lens of anxiety, highlighting categories of prospective applications and techniques which stand to benefit from anxiety-sensitive agents.

KEYWORDS

Anxiety; Emotion-Sensitive AI; Human Wellbeing; Agent Model Of Emotion; AI For Social Good; Reasoning Under Uncertainty

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1 INTRODUCTION

Anxiety is a fundamental emotion characterized by the belief, usually raised by observing cues of threats, of encountering possible dangers in the future and raises reactions directed to either dealing with this danger or knowing whether this danger will come true; and diminishing the salience of the triggering belief [74]. The experience of anxiety is linked to numerous negative side effects which can be detrimental to wellbeing, including worry, irritability, tension, concentration problems, and sleep issues, indirectly a cause of greater professional failure and social isolation [12, 20, 23, 88]. Moreover, extended periods of anxiety increase the risk of developing physiological disorders such as heart disease [91], and significantly increases the risk of developing severe mental health disorders, including depression and panic disorders [8].

The importance of anxiety is well-recognized and has been explicitly framed as a component of the wellbeing Sustainable Development Goal [37, 83]. Anxiety is the largest source of mental health problems, as demonstrated by a global surge in anxiety disorders from 11.6% to 25% during the COVID-19 pandemic [1, 9, 86, 93, 98]. Anxiety also comes at a great economic cost to society, with negative effects on performance and expensive treatments [45, 109, 113], totalling up to a cost of US$ 1 trillion each year [1, 2, 6, 46].

However, despite anxiety being a high-impact social concern and AI research turning towards promoting wellbeing and social good [29, 95], the landscape of anxiety-sensitive AI solutions remains extremely narrow. Whereas extensive interest has been displayed in emotion-sensitive AI since the dawn of the field [18, 39, 76], the range of concrete solutions remains relatively limited. Most solutions focus on user mental modelling [55], such as emotion-aware teaching [53], emotion-adaptive robots and man-machine interactions [102], and emotions as affordances for adjusting pre-written plans [25, 40, 71]. From a more fundamental standpoint, the current near-ubiquitous paradigm for designing AI systems is actually highly anxiety-inducing, as the race for performance maximization pushes systems (and people operating them) to the limit and constant exposition to maximally efficient risks. Google Itinerary plans for the shortest route, no matter if it involves very tight connections between irregular buses. Is the prospect of saving 5 minutes of travel time worth 30 minutes of anxiety questioning whether the current bus will arrive on time?

This status-quo can be escaped and this paper is dedicated to demonstrating that anxiety-sensitive agents[1] can replicate, mitigate, and alleviate human anxiety, and that an array of scientific challenges, concrete solutions, and high-impact applications are within reach. Specifically, this paper first introduces a comprehensive overview of core theories of anxiety from psychology, providing foundations for further modellers to get started with anxiety; then the paper demonstrates the feasibility of building anxiety-sensitive agents through a formalization of anxiety theories in a classic model of emotions; last the paper highlights the significance of anxiety-sensitive agents by casting the research fields of Agent and Multi-Agent Systems research within the spectrum of anxiety.

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[1] By anxiety-sensitive agents, we consider any agent with a model of anxiety, which encompasses both agents with human-like anxiety-sensitive behaviours and agents with social-intelligence abilities that can account for the anxiety that their decisions can cause to people impacted by the system.

2 PSYCHOLOGICAL FOUNDATIONS

2.1 The roots of anxiety

While there is no agreed upon definition of what triggers anxiety within psychology, it is widely accepted that anxiety is triggered by the perception of uncertain threats that imply a possible danger to one's own motives, such as goals or needs [11, 74, 100]. In contrast to fear, which concerns more certain and imminent threats [100].

To explain what triggers anxiety further, a threat may be defined as a future danger raised by the observation of a cue that is interpreted as a predictor of an aversive event, often based on learned associations and heuristics [70]. Further, how aversive or dangerous one perceives a threat to be is dependent on the motivation which is threatened, and one's perceived ability to cope with it [8, 11]. Uncertainty may be organized into sensory uncertainty, state uncertainty, rule uncertainty, and outcome uncertainty; each having distinct neurological representations [5]. But as for anxiety, sources of uncertainty primarily concern: Uncertain cues that may predict many potential threats with varying likelihood and danger [70]; Uncertainty in how capable one believes they are in dealing with threats [7]; Uncertainty in what actions are available and effective in dealing with the threat [84]; And uncertainty in whether one's goals will be thwarted or not [74]. Moreover, uncertainty on its own may be threatening and trigger anxiety, as it can indicate the presence of possible unknown threats [19].

How sensitive one is to uncertainty and threats largely depends on individual differences, with greater sensitivity associated with: Biased learning and stronger reactions to threats [4, 63]; Greater intolerance of uncertainty and avoidance of it [44, 79]; And hypervigilance, with greater attention paid to threat-related cues [33];

2.2 The state of anxiety

Mental processes The mental process of anxiety begins when an uncertain threat is detected, triggering a state of vigilance where attentional resources are allocated to potential threats, as well as increasing the salience of threat-related memories [10, 35]. At this stage, the nature of the threat is appraised, including an estimation of its uncertainty and potential danger [67, 94]. Followed by a secondary appraisal of the self and how capable one is in dealing with the threat, including an estimation of available resources and ability to have control [87, 101].

Anxiety is then experienced as a negative affective state characterized by feelings of tension and helplessness in response to a perceived inability to control or predict one's goals [7, 31]. Worry can be thought of as a method of dealing with this feeling of uncertainty and uncontrollability, imagining future possible dangers and considering strategies to increase control over them [103]. In addition to updating held beliefs to reduce anxiety, such as reconsidering the value of a threatened goal with the purpose of reducing the anxiety it triggers [104].

Neurological processes The Behavioural Inhibition System (BIS) is identified as responsible for anxiety, with key structures and functions being: the amygdala, performing emotional evaluations of input and mediating the increase in arousal (e.g. reward or punishment) [66, 68]; the septo-hippocampal system responsible for goal regulation, reacting to discrepancies, conflicts, and uncertainty coinciding with goals [43]; and the prefrontal cortex, involved in controlling attention and more complex functions such as those expressed in social anxiety [13, 73]. In response to triggers of anxiety, these systems are known to be responsible for behavioural inhibition, feelings of distress and increased sensitivity to threat-related information [43, 58]. At lower levels of information processing, anxiety has a greater overlap with other negative emotions such as fear, sharing subcortical systems responsible for an increase in arousal (e.g. increased heart-rate, skin-conductance) via a release of neurochemicals including nor-adrenaline and cortisol [43, 68].

Behavioural characteristics Anxious behaviour is generally characterized by an increase in avoidance, favouring behaviours that minimize anticipated risk as well as uncertainty [44, 65]. In addition to increased vigilance and search for threat-related information, such as scanning the environment, and information-seeking [34, 54]. How humans behave to reduce anxiety is commonly studied in psychology as forms of coping, with two popular categories being problem-focused coping aiming to resolve the source of the anxiety, and emotion-focused coping that targets the experience of anxiety such as distraction or revising held beliefs [67].

Maladaptive processes While anxiety is an adaptive emotion which helps us identify risks and motivate us to take control, it can also spiral out of control and become debilitating to everyday life, as demonstrated by crippling effects of anxiety disorders. These disorders are often characterized by maladaptive behaviours, which often turns anxiety into a self-reinforcing spiral. Examples of maladaptive behaviour include overly conservative and avoidant responses to threats, which are only effective in reducing uncertainty and anxiety in the short-term [44], and reinforce false beliefs about threats [70], and further increasing future sensitivity [19].

Function of anxiety Anxiety has been investigated for millennia [26], and there are theories from many perspectives and disciplines that attempt to explain the mechanism and function of anxiety. Notable examples include philosophical and theological theories which tend to emphasize existential sources of anxiety, such as meaninglessness or death [96, 111], and those that seek to explain anxiety in a given context, such as the workplace [23].

However, psychological theories typically place uncertainty at the centre of anxiety [100], exemplified by Miceli & Castelfranchi's theory of anxiety as an epistemic emotion which argues that the object of anxiety is the uncertainty with which an event implies a danger threatening to thwart a goal [74, 75]. Anxiety then functions as a motivation to reduce this uncertainty, through behaviours which increase epistemic control (e.g. worry or searching) and pragmatic control (e.g. preparation or avoidance) in response to triggers of anxiety [74, 75].

3 MODELLING ANXIETY

This section demonstrates the feasibility of building sound models of anxiety by putting forward a model directly derived from the theories presented in the previous section and showing how such a model can be applied for explaining and dealing with some classic anxiety disorders. As a basis, we use the *Dynamic Logic of Graded Attitudes* (DL-GA) framework [28], designed to represent beliefs, goals, and intentions as dynamic components of an agent's mental state. Agents experience emotions as a result of appraising available

actions according to their current mental state, including the believed plausibility that a state of affairs will be true after performing the action, and with what strength they wish to achieve or avoid it. What emotion the agent experiences is determined by rules derived from the "OCC" model of emotions [81], and act as a heuristic in selecting an action to execute.

As a theoretical basis, we use the definition of anxiety about an event provided by Miceli & Castelfranchi [75, p.133]: *"To be anxious about an event e implies: (a) some goal p (for instance, to pass an exam); (b) the belief that e may imply a danger d, that is, the thwarting of p; for instance, the exam e may imply failure d; (c) the belief that d is possible or likely (but possible is enough), together with the belief that the information available about d's likelihood is insufficient to establish whether p will be thwarted or not; (d) the epistemic goal p_1 to know whether d will come true (that is whether p will be thwarted or not); because of the preceding beliefs, goal p_1 is perceived as hardly satisfiable; and (e) the goal or wish q that d does not come true, which is different from the wish that e does not occur."* Integrating this definition within the DL-GA logical formalism crossed with epistemic goals defined by [72], anxiety can be expressed as:

(a) The agent wishes to achieve the goal p with the strength k
(b) The agent believes with plausibility h that after executing the intended action a, the danger d will be true. And, the agent believes with plausibility h that the goal p will be thwarted if d occurs.
(c) The agent does not have the strong belief (i.e. believed plausibility at max) that after executing the intended action a, d will be true. And, the agent does not have the strong belief that after executing the intended action a, d will be false.
(d) The agent has the epistemic goal with strength i to know whether d will come true or will not come true.
(e) The agent wishes to avoid d with the strength j.

where i represents the relative importance for epistemic control, j for pragmatic control, and k for goal achievement .
As a starting point, this model can explain in what situation an agent will experience anxiety, and how anxiety will influence the following action-function, with the help of the two intensities corresponding to the two primary coping mechanisms of anxiety as described in section 2 (e.g. epistemic and pragmatic control).

As an example demonstrating an interesting property of anxiety, consider Alice, who is anxious about an upcoming exam. Alice is experiencing a high degree of anxiety despite having studied diligently and believing that unexpected questions in the exam (i.e., a possible danger) are unlikely –because to Alice the goal of passing the exam is of critical importance, and she believes unexpected questions imply almost certain failure. To cope with this anxiety, Alice tries to reassure herself that there won't be any unexpected questions on the exam, by revisiting her course-book and past exams once more (achieving an epistemic goal), and in the process she identifies a topic for the exam she can study a bit more (achieving a pragmatic goal). Alternatively, Alice might find the uncertainty to be unbearable (as is often the case in anxiety disorders), and make the drastic decision to avoid the exam entirely, abandoning her goal, but successfully avoiding uncertainty.

4 THE RELEVANCE OF MODELLING ANXIETY

Integrating anxiety in models provides numerous potentialities for pushing forward the envelope of a broad spectrum of existing and future agent techniques. Anxiety provides complementary perspectives to **general questions** on the agent paradigm, providing a new paradigm to push past the current reward-centric approaches within AI, which this section demonstrates by reconsidering existing research fields along the spectrum of anxiety.
Deliberation models: most classic agent deliberation mechanisms (e.g. belief revision, goal formation, planning, norms, teamwork [27, 30, 47]) are known from psychology to be tightly related to anxiety, thus making of anxiety a unifying framework for supporting the coherent integration of these different aspects within agent deliberation (e.g. anxiety for aligning goals, their importance, what can harm them, what beliefs are to be maintained, and how to adapt plans to such factors).
Coordination and interaction, as an intrinsic drive for individual agents to coordinate and spontaneously engage in conventions (in addition to extrinsic formal organization) [21]. Anxiety is known to be valuable in human societies for facilitating smooth coordination between agents, in particular through equipping agents with a motivation to uphold a sufficient degree of social control; promoting pro-organizational behaviour and the creation of explicitly organized activities [41]; creating shared agreements on dealing with uncertainty [50]; and regulating the perception and sensitivity to trust between agents [112]. In hybrid societies & MAS for humans, anxiety-sensitive agents can benefit trust and wellbeing in interactions with(in) humans, as an example consider anxiety in healthcare: Agents need to account for anxiety in deciding what information to disclose to patients as to not cause unnecessary anxiety, and need to communicate information about anxiety to other agents as to coordinate treatment and interventions.
Game theory, auctions, and social interactions grounded in psychology, with anxiety being critical to understanding the influence of uncertainty on human decision-making [44, 115]. Beyond models that assume rationality, anxiety models allows for incorporating more realistic models of bias towards risk and uncertainty [33], and bounded-rationality where anxiety is tied to impaired decision-making and risk-aversion [14, 77]. As an example, consider an agent deciding when it is time to leave as to catch the bus in time for an appointment. If the decision to leave raises anxiety (e.g. due to tight connections, appointment importance), the agent will likely choose to leave early and wait for longer over the possibility of missing it.
Knowledge representation and planning, as anxiety typically arises out of knowing how much you don't know about the future and the mind "filling in the gaps" with representations of possible future threats [44]. As such, anxiety-sensitive agents foster the development of new forms of planning and modelling uncertainty and danger, by providing an insight into how anxiety helps humans deal with uncertain dangers: as a motivation to increase epistemic control as shown by the model of anxiety presented in 3; in how humans update and utilize beliefs about danger [70]; as a signal of insufficient epistemic certainty, i.e. knowing that you don't know enough to determine if a plan safe [74]; Markovian models [97] appear to be highly suited for anxiety-sensitive agents, with recent

work demonstrating that classic MDPs may be used to generate anxiety-sensitive plans [106].

Learning and adaptation in response to threats, as an evolutionarily adaptive emotion driving both avoidance and approach behaviours, striking a balance between exploration and exploitation as to maintain a degree of safety. Equipping agents with models of anxiety can facilitate safe learning under uncertainty, as anxiety drives humans to learn about potential threats and how to avoid them in the future [78, 85]; while staying within the boundaries of safety by signalling when it's time to be cautious [58]; For autonomous agents navigating an unfamiliar environment, anxiety can augment uncertainty-aware reinforcement learning techniques concerned with safety [16, 59], by providing a psychological basis for modelling threats and mastery to overcome them.

Modelling and social simulation: anxiety is a societal driving force as well as a harmful societal challenge to be better understood, often stemming out of social vulnerability, crisis-management, and policymaking. Moreover, anxiety is known to be an important factor in many central topics within social simulation, such as in-group trust [15], social identity and norms [61], and opinion formation [49]. Anxiety-sensitive agents have already been implemented as scale-based models driving anxious behaviour in response to threats (e.g. [60]), or as a constant variable representing uncertainty avoidance (e.g. [105]). However, anxiety still poses an open challenge to social simulation, with current models failing to capture many critical aspects and social phenomena tied to anxiety [51].

Human-agent interaction which the role of anxiety in human interactions and relationships demonstrate: as an intrinsic drive for social control in tension with trust [22, 38]; increasing sensitivity in making and perceiving social judgements [63]; and the importance of interpersonal regulation of anxiety to performance and wellbeing in human teams [42, 107]; Moreover, models of anxiety serve to benefit many challenges central to human-centred design. For example, a mental model of anxiety can benefit trust and explainability in hybrid teams by pointing to the potential threats a human perceives (e.g. anxiety about algorithmic evaluations [56] or automated decision-making [82]).

5 APPLICATION AREAS & IMPACT

Anxiety-sensitive agents serve to benefit numerous application areas and challenges in society. This section investigates the potential impact of anxiety-sensitive agents in four different application areas, including an assessment of societal benefits.

Supporting wellbeing A wide array of agent-based applications already exist to support wellbeing and mental health such as virtual characters providing a controlled environment for exposure-based therapies [114], and cognitive agents facilitating behaviour change [64]. These agents can be augmented with anxiety-sensitive capabilities for adapting to the dynamics raised by the disorder and patient's features and recognizing patient's anxiety level (e.g. through natural language-based anxiety assessment [62, 80]), which act as an enabler for more personalized medicine that is also anticipates and adapts to the evolving condition of the patient, while sustaining the potential for wide-spread use, thus helping overcoming current bottlenecks on mental health access [110]; as well as better assessing wellbeing at an organizational level [69]; and training mental health professionals [57]. Impact-wise, anxiety-sensitive agents could benefit hundred millions of people on matters from temporary disorders to life-and-death impact –anxiety being the most prevalent form of psychiatric disorder today [116].

Human-centred agents Emotions are critical to human life, and human-human and human-agent interaction (e.g. empathy, intentions) [24]. However, anxiety remains relatively unexplored despite its known impact on human-agent interaction [32] (e.g. trust, in-time support) in the many existing models of human-agent interaction featuring emotions [52, 92]. For example, an agent that can recognize anxious behavior patterns of students in a classroom or online (e.g. avoidance, aggression, impatience) can provide key insights on whether students are striving or struggling as well as indications on the root of the issue and possible repair (e.g. a missing notion causing distress in practical exercises, negative group dynamics) –the very same approach can be set for numerous information technology systems, which tend to exist (if not create) a context where anxiety is an important factor, beyond pedagogy [36]. As such, anxiety-sensitive agents can alleviate unnecessary anxiety for millions (if not billions as illustrated in [106]) of users.

Empathic societies Multi-agent systems are increasingly used to support social development and coordination (e.g. city development, crisis response, environment management) [108], influencing decisions that can have a significant impact on many stakeholders. Despite this importance, current systems do not account for the anxiety that such applications can produce, with city development possibly exposing a million of inhabitants to daily commuting anxiety [3, 99], and coordination in healthcare blind to the anxiety it possibly causes both patients and practitioners [48, 89]. For example, social simulations featuring anxiety-sensitive agents can help capture psychological consequences on various populations of various policies. Impact-wise, such anxiety-sensitive agents may alleviate a moderate degree of anxiety for the millions of people affected by their application in policy-development and coordination.

Human-inspired solutions: anxiety sensitivity is suited for accounting for real-world uncertainties and seeking to sustain a form of pragmatic and epistemic control, beyond reward-maximization. Such cognitive ability is particularly suited for autonomous robot navigation [59], predictive maintenance [90], and medical diagnosis [17]. For example, anxiety-sensitive features can be used in robots to decide on a degree of conservativeness in regards to battery, localization, and potential harms in the environment.

6 CONCLUSION

Anxiety is one of the most extensively researched fields of psychology, being at once a critical factor in human wellbeing while also being an intrinsic drive to seek control through pragmatic, social and epistemic means. While opening new scientific and engineering challenges (e.g. modelling frameworks, development methodologies, validation, quality control) This paper has demonstrated that agent-based models of anxiety are within reach, and that the AAMAS community stands to benefit from modelling anxiety. Specifically, (1) anxiety provides a complementary perspective to many application areas of multi-agent systems, and (2) anxiety is a fundamental part of human cognition for researchers to draw inspiration from and push the envelope of agent-based applications.

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