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Complex Adaptive Behavior of Hybrid Teams

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Abstract

The challenges in uncertain, dynamic and complex military operation environments exceed the problem-solving capabilities of individuals. Problem-solving has become a team task. These [hybrid] teams, which typically include machine and human elements, utilize autonomy and artificial intelligence to enhance the quality of actionable information and decision-making capabilities in solving complex problems. For this to be effective, shared mental models must be developed by teams. This demands adaptive behavior of team members to establish a common understanding, and its members to respond to the changes in complex dynamic environments.

In this paper, we introduce a mathematical formalization of an interaction platform designed to support individuals working in heterogeneous, hybrid teams. The purpose of the platform is to facilitate convergent adaptive behavior and interoperability. Hilbert space is used to provide a mathematical foundation and coherent axiomatic structure. Individual and shared mental models are represented in the form of superposition of vector states in a conceptual space. Hilbert Space allows for the inclusion of phenomena, such as spooky activation, entanglement, or emergence that are representative of complex social dynamics.

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Keywords: Complex Adaptive Behavior; Hybrid Teams; Agile Teams; Human-Machine Interaction

1. Introduction

The Greek word “aporia” literally means a dead-end where it is impossible to proceed with a solution. In the context of reasoning, it characterizes any cognitive situation in which a threat of inconsistency confronts the interlocutors. An aporia occurs when a set of perspectives comes in conflict with each other, but are deemed individually plausible. An aporia can emerge in a hybrid team, which is composed of Artificial Intelligent (AI) agents and human agents. A hybrid team acts together to accomplish a given intent. To do so, team members may

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need to generate new plans, and develop new course of actions to accomplish the given objective. This requires an adaptive behavior of the team members so that problem solving becomes a team task. The perplexities in this type of situation require higher order theories that support the information processing and a self-initiated behavior of the intelligent agents in their interaction with the environment. This means that the interacting agents' actions are constrained to match with the intentions of the members of the hybrid team. The ensuing limitations can impede the adaptive behavior of the actors in the teams.

The self-initiated behavior in AI is constrained with the intent. The intent sets the initial state of the agent and proceeding steps require adaptive behavior to attain the objective. Every attempt to understand the environment is an interaction. In the social paradigm, the interaction of a human between environment and other agents is a generative process, which includes but is not limited to thinking, reasoning, and acquiring knowledge[1-4]. The generative process takes place as a continuous interaction with the environment. Due to the uniqueness of every individual, each generative process is unique, and an aporia can emerge[3, 5, 6]. An attempt to overcome the inconsistencies will result in adaptive behavior taking place as individuals work to shift the meaning ascribed to a phenomenon[6]. The adaptation will either result in a shared phenomenon or continued incongruence. Present approaches oversimplify the nature of the aporia, and as a result, solutions are also oversimplified, or more likely, prone to being wrong or ineffective[7]. For example, a method to reduce conflict that is based on the classical prediction of rational choices, will not account for the complexities of the problem. A method built on the assumption that humans behave as classical rational agents will fail to capture the order effects in agent information interaction. Contrary to classical approaches, it has been demonstrated that quantum cognition provides axiomatically coherent answers to demonstrated deviations. The scholarly work in quantum cognition[8-11] and Gärdenfor's conceptual space[12-14] rendered the Hilbert space geometrical formalism applicable to the known semantic analysis. This formalism and subsequent theoretical developments[15] revealed the quantum structure in latent semantic analysis and distributed representation of cognitive structures developed for the purpose of neural networks[16]. The effectiveness Hilbert space in information retrieval is recognized by K. Van Rijsbergen[17]. The subsequent studies recognized the effects of superposition, uncertainty, and entanglement in the information retrieval[18]. D. Widdows demonstrated the effectiveness of quantum logic for connective negation in exploring and analyzing word and meaning[19, 20]. Following this development, P. Bruza and his collaborators proved the implication of quantum structures to model semantics space and cognitive structure. They introduced the formalization of context effect about concepts and scrutinized quantum structures of language which include, but are not limited to entanglement, and words in semantic space[9].

A major challenge in modeling the reasoning of a decision-making entity is contextuality. J. Busemeyer introduced the quantum dynamic model of prediction in decision-making[21]. In quantum theory, the act of measurement as a contextual action, is known as the observation of a micro level entity. At the macro level, measurement is the act of a decision-making entity. The action alters the state of the agent and the agents' understanding of the environment. This important characteristic improves the complex adaptive behavior of decision-making entities[11]. At the same time, A. Khrennikov introduced an advanced quantum decision model[22, 23], which supports the results of Busemeyer's work. The model introduced a complex probability amplitude and demonstrated its efficiency in the algorithm of Prisoners Dilemma and the disjunction effect[24]. This research introduced the use of quantum theory outside of the micro world and ameliorated the misconception about the notion of decoherence at the macroscopic level.

The Hilbert space provides a framework to implement the tensor vector algebra. The discussed quantum cognition is not about quantum computing. Rather, it is a method to study the constructs of semantic analysis, conceptual space, and contextuality by using quantum cognitive structures. This can have profound implication in the advancement of AI in adaptive autonomous systems. One main contribution of these developments to AI paradigm is to advance formalization and structuring of artificial knowledge by enhancing it with the introduced quantum mathematical formalism.

The structure of the paper as follows. Section 2 provides a summary of the theoretical foundation of the quantum decision theory such as representing a phenomenon in Hilbert space. In section 2, compatible and incompatible events and the ensuing interference effect in complex situation is discussed with the mathematical formalism of quantum decision theory. Section 3 provides the representation of adaptive behavior of a hybrid system in decision support tool platform. Following this in section 3, a geometric representation of understanding of a shared