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The Collective Intelligence Concept: A Literature Review fromThe Behavioral and Cognitive Perspective

[Saraswathy Shamini Gunasekaran, Mohd. Sharifuddin Ahmad, Alicia Tang, Salama A. Mostafa]

Abstract— **Over the years, the idea of group effectiveness to individual performance in problem solving has fascinated the many minds of researchers, essentially in the field of software agent technology. Group effectiveness focuses on the overall group contribution rather than the individual effort. Some terms which are often associated with the above includes collective effort, global brain and self-organization while there are many more which inter-relates. While group behaviour espouses the main ingredient of such effort, other studies do suggest the potential of a communal cognition is as essential. In this paper, our intention is to provide a systematic review of the influences of behaviour and cognition to the concept of collectiveness in Collective Intelligence.**

Keywords—*artificial intelligence, collective intelligence, behaviour, cognition, agent*

I. Introduction

Research in the field of CI has led to many interesting discoveries in fields ranging from psychology [1–3], complexity sciences [4], cognitive studies [5–9], biology [10–12], computer sciences and semantics [13–15] and social media [16, 17]. The motivation that intrigues the interest of many in their field of expertise over such a perplexed term is focally inspired by the dynamics of its compound characteristics. Early investigations in CI suggest a repository of terms which is associated with either the communal behavior of humans [18–21], insects [22], animals [23], bacteria [24] and microorganisms [25] or the communal cognition of humans. As such, the terms:

Swarm Intelligence, Group Intelligence, Distributed Intelligence, Social Intelligence, Collaborative Intelligence, Collaborative Computing, Collaborative Knowledge, Cultural Intelligence, Global Brain and Universal Intelligence

are widely expressed to support the openness, peering, sharing and global [26] aspects of a group-based behavior in comparison to the individual ability in optimizing solutions to complex problems [27–41].

Consequently, earlier intervention of CI in technology focuses more on the behavioral aspects, particularly the swarm and flocking behavior of insects and birds. Beni and Wang [42] introduce the expression of Swarm Intelligence (SI) in the context of cellular robotics systems. Their inspiration on SI comes from nature, especially biological systems. The collective behavior which is visible in nature can be a reference for a group of agents or biods by trailing simple rules which leads to the emergence of an intelligent global behavior that is unknown to the individual agents.

The swarm behavior of ants is further experimented by Dorigo [43] when the potential of CI becomes more pertinent in the field of artificial intelligence. He believes that the stigmergic behavior amongst a swarm of ants is able to conceptualize the simplest form of intelligence into spectacular working algorithm. Stigmergy is a mechanism of communication used by ants. During this process, each ant exerts pheromones as it wanders in search of food. The route which has the strongest pheromone helps create a trail with which other ants follow suit.

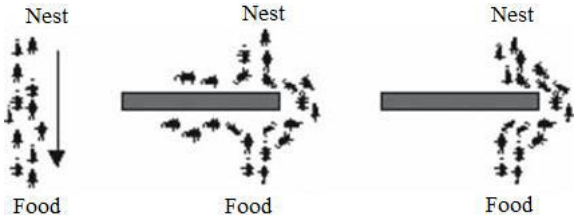

Figure A: Ants‘ stigmergic behaviour in finding the shortest route between food and nest [44]

Dorigo [43] and Bonobeau and Meyer [45] suggest that the CI concept in SI focuses on the collection of largely self-organized behavior which emerges from swarms of social insects. This concept is widely conceptualized in numerous optimization problems which ranges from combinatorial problems, such as sequential ordering problems, assignment problems, scheduling problems, the maximum clique problem, graph coloring, assembly line balancing and vehicle routing problems, to more recent continuous, multi-objective or dynamic problems in machine learning, data mining, telecommunication networks and bioinformatics [45].

Kennedy and Eberhart [46] focus on the flocking birds social behavior. Their concept of CI reflects on a population of interacting elements that are able to optimize some global objective through collaborative search of a space [46]. Birds have extraordinary abilities in flocking synchronously for food searching and long-distance migration as well as efficient social interaction that enables them to fly without collisions even while often abruptly changing directions, scattering and quickly regrouping when reacting to external threats, and avoiding predators [47]. The simplicity, efficiency and fast convergence nature of the flocking birds social behavior are utilized in many neural network applications. Their usage expanded in the field of combinatorial optimization problems to computational intelligence applications, from electrical and electro-magnetic applications to signal processing and graphics, from image analysis and robotics to bioinformatics and medical applications.

While the concept of CI gains recognition in the field of AI from a behavioral perspective, its influence on the field of open innovation [48], decision support [49], crowd-sourcing [50] and social collaboration [51] are increasing at a rapid rate from a cognitive perspectives. The emergence of Web 2.0 in 2004 and other social media technologies facilitates many social computing applications such as THREADLESS, WIKIPEDIA, GOOGLE and many more as gateways of media through which vast amount of data is globally shared and discussed. These new internet technology platforms enable multiple broadcasts in which problems are shared and discussed, thus globally leveraging patrons to contribute collective synergy solutions. The influence of collectiveness in terms of cognition is becoming a vital aspect as the internet becomes a global pandemic where people from various geographical areas are connected and knowledge and information sharing become accessible by a click of the mouse.

Consequently, collectiveness in behavior and cognition and its influence on the technological domain remains separate. A collective behavior is described as the budding of actions through the simplest form of lingual and non-lingual interaction that occurs amongst people, animal, insects and even microorganisms [52]. For example, an alarmed crowd would collectively flee from a dangerous situation. Similarly, ants exert pheromones to avoid a precarious trail. Other social phenomena include rumors, linguistic convention, the emergence of a standard currency, transportation systems, the world wide web, resource harvesting, crowding and scientific establishments [53, 54]. Collectiveness from the cognitive perspectives is described as the communal inkling that involves various degrees of thinking and analytical awareness.

The next section of the paper provides a detailed review on the influence of behavior and cognition on the concept of CI from two domains: sociological and psychological. The subsequent section discusses the importance of behavior and cognition as a communal property in CI. The conclusion section is inclusive of both summary and future work.

II. Background

A. *Sociological Domain*

Wheeler [55], an entomologist, is the first researcher to observe group behavior, particularly in insects. He looks at the potential of a swarm of ants working together forming a huge collaborative process [55]. The group behavior in insects is the sole cause for the swarm to survive and that defines these six-legged creatures as super organism.

The concept of CI concerns more towards the human behavior when Durkheim [56] identifies the role of societal behavior as the sole source of human logical thought [56]. He argues that a society constitutes a higher intelligence because it transcends the individual over space and time [57]. This higher intelligence represents the culture with which a society follows and is emotionally bound to it. For example, we queue up to pay at the cashier in any shopping complex because we recognize that it is the responsible, moral way to act. As such, the individuals working in a group naturally intensifies their sense of ownership towards the task that they are working on.

Szuba [58] examines the human aspects of collective behavior when he suggests that a specific property of a social structure is initialized when individuals organize and collaborate. This social behavior infuses the ability to solve more complex problems than any single individual can. This property amplifies if the social structure improves its synergy. He highlights the importance of the interaction processes that occur in all group-oriented tasks and believes that the efficiency in the interaction process often results in better outcomes.

Por [59] agrees that the capacity of communities is to evolve towards higher order integration and performance through collaboration. The collective behavior in these communities encourages the innovation process. In group-oriented task, the interaction process manifests a pool of ideas from the participating contributors which may gradually cross-fertilized thus contributing to an innovative output. He believes that the notion of "US" produces better outcomes than the notion of "I" when solving any organizational issues.

Atlee [60] suggests that the concept of CI is closely related to the capacity of families, groups, organizations, communities and entire societies to act intelligently as whole, living systems. An increase in numbers of contributors in a given group may improve the interaction process thus encourages the level of its societal intelligence. Societal intelligence is extremely powerful such that it has the ability to determine the political power in a given city.

B. *The Psychological Domain*

Wechsler [61] suggests that CI occurs only when there is an interaction or cross-fertilization of knowledge between those participating in any group-oriented task. He argues that CI should produce more innovative solutions or suggestions than individual-oriented task. He supports this by highlighting that each individual is unique in their thoughts and knowledge. Their capacity and this diversity acts as an enabler for information harvesting thus is used at its best. Levy [62] further suggests that CI is the form of universal, distributed intelligence, which arises from the collaboration and competition of many individuals. He believes that a single human entity may not be able to know everything of the world but all human knows at least an inch of knowledge of the whole as all knowledge resides in humanity. Thus, he suggests two vital points to the concept of cognitive collectiveness in CI:

- The ideals of CI imply the technical, economic, legal, and human enhancement of a universally distributed intelligence that could unleash a positive dynamic recognition and skills mobilization.
- The greater the number of collective intellects with whom an individual is involved, the more opportunities he/she has to diversify his/her knowledge and desire.

Brown and Lauder [63] explain the concept of CI as an empowerment through the development and pooling of intelligence to attain common goals or resolve common problems. They highlight two points: Firstly, they claim that successful, high-skill knowledge economies and education systems depend on the society's ability to create and pool the collection of knowledge [63]. They suggest that all humans are intelligent in their own unique way and when

they collaborate or compete with each other, they are able to produce something rather magnificent [64]. Secondly, the contribution of individuals' knowledge in a group intensifies when a group-oriented goal is visible. This notion of a common goal creates a precise scope in which these individuals are able to channel their knowledge at its best.

Engelbart [65] believes that people of different backgrounds or talents working together should do so as it helps to optimize the meshing of the various talents in organizations [65]. The differing talents and background results in a variance of knowledge in each individual. He coins the term "collective IQ" on which he stresses that it is the best form to leverage our group brain [66]. This can be achieved by sharing ideas and solutions through appropriate tools and methods with which individuals can work together to capture, manage, access and learn from the shared knowledge, reusing it in an effort to become more effective at addressing the many challenges in any form of businesses and societies [67].

Krause [68] reflects on the concept of CI from a cognitive perspective when he claims that each participating individual in a group is influenced by a functional diversity (differences in the approach used for problem solving) and an identity diversity (differences in race, gender, religion or ethnic background). These two facades of diversity reflect on their knowledge intensity and ultimately allow the contribution of a pool of legit information. When these different packages of information are combined and processed through social interaction, they provide a solution to a cognitive problem in a way that cannot be implemented by isolated individuals [68]. Thus, the benefits of CI increase with increasing group size. CI is a mechanism that individuals can use to overcome some of their own cognitive limitations, as these individuals are able to gain new knowledge through that social interaction [69].

III. Discussion

From the sociological domain, these investigations suggest that the behavioral aspects of living being influences the concept of CI [70, 71]. As the many researchers suggest, group behavior is an essential ingredient of CI. It not only improves the performance of a group in terms of decision-making and problem-solving, it also creates an illusion of power. The group behavior particularly focuses on the social capabilities of living beings. Socializing involves the process of conversing and interacting between two or more parties. It may be in various environments that incorporates different purposes. Subsequently, humans are living beings with exquisite social capabilities [71]. Their ability to communicate through formal and informal mechanism places them at the highest level of the social pyramid. They exert effectiveness when working in groups.

The concept of CI from the psychological perspective focuses on the collective cognition of the human agent. Researchers suggest that collective cognition is equally essential in CI. They highlight that every individual is unique, especially in the way they think simply because they have experienced life in a way which is dissimilar from one another. This experience, upon practice, becomes knowledge, which when used correctly to solve any given problem, manifests the level of intelligence of any individual. The uniqueness in intelligence diversifies the pool of knowledge and ultimately influences the collection of information in any group-oriented task. Subsequently, the best solutions are produced when this pool of information is cross-fertilized.

In conclusion, collective behavior and cognition have to bind themselves together to cause a chain of continuous reaction in which, the perception, ideas, thoughts or even emotions (cognition) [72, 73] that one agent exerts are characterized through various actions (behavior) [74] to the other agents in the group. The combination of cognition and behavior prompts the alleviation of the AI research towards augmenting [51] the intelligent capabilities of the living entities, particularly humans.

Intelligent augmentation involves the process of increasing the intelligent capabilities of a living entity to approach a complex problem situation, to gain comprehension to suit its particular needs, and to derive solutions to that problem. Engelbart [75] discusses the key aspects of "increasing capabilities" as having a more rapid comprehension, better comprehension, the possibility of gaining a useful degree of comprehension in a situation that previously was too complex, speedier solutions, better solutions, and the possibility of finding solutions to problems that before seemed insolvable. Complex situations refer to the professional problems of diplomats, executives, social scientists, life scientists, physical scientists, attorneys, designers, etc., whether the problem situation exists for twenty minutes or twenty years.

Wheeler [76], Levy [71], and Szuba [21] suggest that intelligent augmentation is highly achievable when groups of living entities work together in solving a given problem. Malone [77] proves this by introducing the Climate Co Lab project which engages millions of registered web users to propose solutions to curb climate change issues. Similarly, technologies that support Web 2.0 and the social media actively engage group level discussions, chats and information sharing resulting in various useful solutions and abundant information flow on multiple topics, issues and concerns. Subsequently, this is due to the evolving, unique and powerful characteristics within each living entity that can either be shared or competed at the cognition and behavioral level. Consequently, Meyer [78] describes this ability as Personal Intelligence (PI).

Personal Intelligence sanctions each living entity to redeem or customize past experience in sorting future tasks in a more structured and planned manner noticeably reducing the chances of errors and accomplishing a higher success rate in achieving ones goal [52]. In a group, the PI level differs between living entities. The PI level is strongly influenced by the experience and knowledge each living entity retains. The diffusion, composition, competition and collaboration of various PI levels contribute to a highly valuable intelligence coined as Collective Intelligence, CI.

Collective Intelligence (CI) is an area of research that focuses on group-based intelligence [49, 79–82]. Yang [83] explains CI as having many multiple sources of intelligent behaviors, thoughts or patterns communally analyzed for solving real world optimization problems. In the same way, Kapetanios [84] extends the notion by stressing that there should be a true source of collaboration among the diverse participants consisting of experts from different domains in

creating solutions and strategies for problems. Malone [85] elaborates on the validity of CI as intelligent sources of cross-fertilized thoughts. These findings supports that communication is prevalent in any group related task and the form of communication that exists may be lingual or non-lingual depending on the dynamics of the group.

The communication pattern presents a valid reference in establishing many CI-based algorithms. Some common CI-based algorithms include the Particle Swarm Optimization (PSO) algorithm and the Ant Colony Optimization (ACO) algorithm. Others include the Wolf Search, Cuckoo Search, Firefly, Krill Herd, Monkey Search, Eagle Strategy algorithms [83]. These nature-inspired algorithms conceptualize the communication patterns that exist amongst bacteria, insects and animals which embody low level intelligence as being compared to humans. Thus, a CI-based algorithm inspired by the dynamics of a group of human interaction may exhibit a more augmented-based intelligence.

IV. Conclusion

In conclusion, our investigation suggests that conceptualizing a CI algorithm that augments the intelligent social interaction between humans may contribute significantly to many domains. This intelligent social interaction includes the behavioral as well as the cognition perspectives of collectiveness. This is highly achievable since, firstly, humans possess the highest level of intelligence in the social hierarchy [86, 87]. Secondly, humans are accustomed to group-oriented goals, and thirdly, they materialize better execution of task and problem solving skills when in group compared to them working separately [88]. Our future work shall explore the various CI models which are available.

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