The Relationship Between Collective Intelligence and One Model of General Collective Intelligence

Andy E. Williams(✉)

Nobeah Foundation, Nairobi, Kenya
awilliams@nobeahfoundation.org

Abstract. A recently developed model of collective intelligence (CI) has been proposed to have the capacity for general collective intelligence (GCI), that is, the capacity for general problem-solving ability that can be reapplied across any domain. This paper explores the relationship between this model of GCI and a model proposed to describe existing CI solutions that are conventional in the sense of accomplishing a single function. The properties required for GCI in this model, and how they make this model unique from other approaches to CI, as well as the implications of these differences, are also explored. In addition, the implications of GCI are explored in terms of the capacity to drive societal impact at transformative scale, where that impact is suggested not to be reliably possible with other approaches to CI.

Keywords: General collective intelligence · Collective intelligence · Functional model · Functional decomposition · Functional fitness

1 A Model for Collective Intelligence as a Component of Collective Consciousness

A functional model of human consciousness has recently been proposed [1]. Where other approaches attempt to define the physical implementation of consciousness according to theories that are as yet incomplete, this new approach borrows the concept of functional modeling from software and systems engineering, and borrows aspects of functionalism [11] from the philosophy of consciousness, to define what is suggested to be the most complete model of the functions of consciousness to date. This approach focuses on modeling the functions consciousness is observed to have, including conscious self-awareness, where consistency with these observations can be validated. This functional model is proposed to be applicable to different physical implementations including not only human, but also to artificial, and Nth order collective consciousness [2]. In practice this flexibility has enabled this model to be used to design collective intelligence based social impact programs with the potential to vastly increase capacity for collective social impact [4]. This model of collective consciousness consists of four functional systems, the collective body, the collective emotions, the collective mind, and the collective consciousness. The collective body obeys principles enabling functionality to be decomposed into objectively defined

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building blocks so the collective can self-assemble physical or virtual (software) products to interact with the world without centralized control. The collective emotions focus on the motivations most highly prioritized by the group. The collective mind (the collective intelligence of the collective consciousness) creates a single cognitive model of the world and identifies interventions that maximize a given collective outcome. And the collective consciousness switches attention between these systems to maximize collective well-being.

2 A Model for General Collective Intelligence

Though groups have been suggested to have some degree of general collective intelligence [12] inherently, and despite the existence of general CI algorithms [13] to enhance that intelligence, the complexity of applying such algorithms may encourage each CI solution to target a specific problem. While Salminen and others point out a number of properties of CI [3] in addition to decision-making, from the functional modeling perspective CI solutions in general are represented here as systems of decision-making that function to maximize some outcome for the group. Considering the initial state and desired final state to be points in a "conceptual space", any solution can potentially be modeled as a function providing a path between those two points. A single conventional CI solution is represented in Fig. 1 as a function tracing a path through this "problem space".

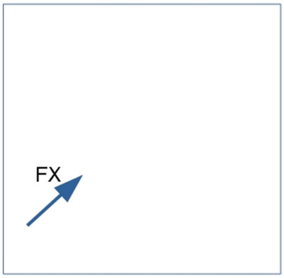

Fig. 1. Conventional CI solutions are represented as achieving a single function.

GCI is defined here as a system of decision-making that functions in any way required to continually maximize collective well-being for the group. To do so this model of GCI aims to model all other CI solutions as functions, and add those functions to a library so it becomes possible to select the intervention with the greatest projected fitness in mapping from the initial state to the final state. The resulting sequence of functions is represented in Fig. 2 as a sequence of lines tracing a path through the problem space. In this model the choice of function, results in its dynamics being locally chaotic and therefore non-deterministic, but globally stable in terms of keeping the collective's state of well-being within a bounded region [1]. This well-being function is defined with the assistance of a Universal Impact Metrics Framework [7] that enables all interventions to be objectively compared according to their capacity to achieve any targeted outcome, and a Semantic Metrics Framework [6] that enables the outcomes to be compared in terms of their impact on the well-being function, which is defined in terms of the collective's capacity to execute all its capabilities (capacity to execute all available functions). Setting aside the issue of validating these frameworks (to be addressed elsewhere [6, 7]), defining them as functional components in the model enables these approaches to assessing fitness to be continually honed across all problems.

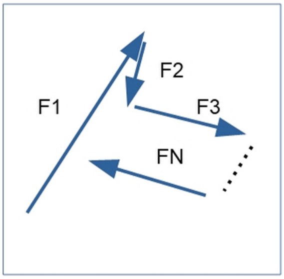

Fig. 2. GCI executes whatever sequence of functions is available to navigate problems.

In psychology individual intelligence is accepted to be defined as general problem-solving ability. The fact that this problem solving is fundamentally aligned with the well-being of the individual distinguishes the intelligence of one individual from that of another. By analogy, in this model, GCI is problem solving ability fundamentally aligned with achieving collective well-being, as opposed to the intelligence of individual members of the group, which is problem solving ability fundamentally aligned with their own individual well-being.

From this point of view GCI requires collectively navigating the problem space (collectively reasoning) according to collective well-being. In addition to modeling each CI solution so that it can potentially be used in a library, gaining the capacity to navigate the problem space in a globally stable way requires the problem space itself, that is the problems to be solved, to be modeled as well. In this approach problems are modeled in a consistent way using a semantic modeling framework (the eXtensible Domain Modeling Framework or XDMF [9]), so that the models of each problem can over time be combined into a single functional model of the world the collective can navigate. Again setting aside validation (to be addressed elsewhere [9]), defining the framework as a functional components in the model enables the modeling approach to be continually honed across all problems.

The ability to maximize collective outcomes per unit of resources increases the capacity of the collective to maintain well-being until the problem of making more resources available can be solved, so that well-being becomes self-sustaining. If a problem is the lack of a path from an initial state to a final state, the ability to sustainably construct a path of interventions to get from any initial state to any final state enables a decision-making system to potentially compose a series of interventions (a solution) to solve any problem. In other words, it potentially creates general problem-solving ability that can be transferred to any domain, that is, true GCI.

From the functional modeling perspective, a reasoning process is a potential solution to a reasoning problem. As a functional system, the GCI (collective mind) is a set of processes that "chooses" one reasoning process over another targeting the same outcome. To do so it must model the function the reasoning process is trying to achieve and must assign a metric of "fitness" according to the degree the function successfully achieves the targeted output. To have the capacity to be consciously chosen, all conscious reasoning processes must have some fitness metric.

In this model the collective mind being globally stable in terms of being constrained to a bounded region in the property "well-being" means that the projected impact of the reasoning process on well-being is assessed and continually compared to the actual impact achieved with the resources invested, so that projections can be updated. Conclusions (the output of reasoning) that decrease well-being sufficiently in this model direct investment of more mental resources to solving the current problem. And conclusions that increase well-being sufficiently direct reasoning elsewhere to shift investment of mental resources to the next problem. This flow between focus on the current problem and focus on the next problem moves with a convection that follows a pattern of dynamical stability in which the key metric is well-being. The model represents this convection using the Lorenz equations governing atmospheric convection, so that the dynamics follow a strange attractor providing the locally chaotic (and therefore non-deterministic) and globally stable behavior predicted as being required [1] (Fig. 3).

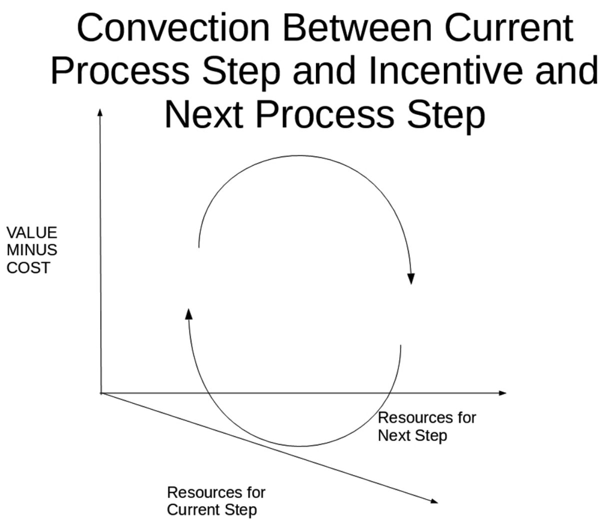

Fig. 3. Convection in the GCI

Since this GCI also contains "basic life processes" providing functional adaptation (the capacity to evolve and otherwise adapt any functional component to become more fit [3]), the initial choice to base global stability on the Lorenz model of convection is less important than the fact that global stability is the targeted outcome, that all functional components can be decomposed into their most basic building blocks, and that these processes can adapt each functional building block independently to achieve this targeted outcome through replacement by one that is more fit. Having a mechanism to measure actual results of implementing the selected solution and having a mechanism to use those results to continuously improve the predictions enables every aspect of the system to gain the capabilities required for GCI even if the initial proposed implementation lacks those capabilities.

Another goal of having a mechanism to objectively project the effectiveness of any solution in mapping from the initial state to the final state is to enable the collective to reliably converge on a choice between any set of proposed solutions.

3 Validation of the Model

If GCI is general problem solving ability then a GCI must have the ability to target any outcome. If problems can be defined as a lack of a path between an initial point and a final point in a problem space, then problem solving ability is related to the volume of problem space that can be navigated in a given time. Using impact on the volume of collective outcomes as a measure of this ability, ways to increase this impact are increasing the probability of achieving targeted outcomes, increasing the magnitude of targeted outcomes, and increasing the duration of the outcome by making it self-sustaining. As validation of the potential for the functional modeling, functional decomposition, and functional fitness aspects of this approach to significantly increase collective impact, these aspects of the approach were used to design an Agricultural Livelihoods Program. Using only a few of the many patterns of collectively intelligent cooperation available, the increase in impact on agricultural livelihoods was projected to be up to seven hundred and fifty times per dollar spent. This program was designed to be phase I of a proposed ten phase Collective Intelligence based Program to Accelerate Achievement of the Sustainable Development Goals (CIPAA-SDGs) [4] targeting a wide variety of SDGs, thereby validating the ability of this approach to be used to target a range of outcomes. This agricultural livelihoods program leverages CI to increase projected impact per program dollar to the point that the program is projected to become essentially self-funding so deployment at massive scale is reliably possible, thereby validating the potential to become self-sustaining. The pilot of this program is of sufficiently small scale that it can reliably be deployed, while the scale of cooperation targeted long-term is large enough to create sufficient value that it is projected to create sufficient competitive advantage for local businesses to ensure their participation. A functional model for a collective intelligence platform called the Social Impact Marketplace has been defined to orchestrate this cooperation between the pilot governments, donors, impact investors, entrepreneurs, and services providers leveraging patterns of cooperation that use this competitive advantage to incentivize participation by significantly increasing projected benefits for all participants, thereby validating the potential to increase the probability of achieving targeted outcomes.

In this Agricultural Livelihoods program a number of agricultural value chains have been proposed, each with a functional model allowing the fitness of that value chain in achieving outcomes for each role to be projected, so the value chain can be added to a library of functions the GCI can use to achieve collective impact. This enables the value chain with the best collective outcomes to be selected. For example, for governments and donors the projected fitness in increasing agricultural livelihoods of farmers per unit of program dollar is assessed. While for impact investors the fitness in increasing returns and decreasing risk is assessed. The volume of outcomes for all participants is measured on a universal scale so the total combined volume of outcomes for all participants (collective outcomes) can be maximized.

4 Differences with Other Models of Collective Intelligence

Though they might not be explicitly named, many perspectives on collective intelligence currently exist, and single purpose CI solutions have been defined from a number of those different perspectives [3]. In this GCI each of those CI solutions might be added to a library used to increase problem solving ability. Since multiple different functions in this library might serve the same purpose, in order to use the library effectively there must be some mechanism for the GCI to select the best one for a given purpose and a given set of conditions (a given context). This mechanism must be general enough to enable the choice of function to be optimized for any purpose and context.

From the perspective of whether the decision or the decision-maker is the focus, there are two approaches to using collective intelligence. One is optimizing selection of the decision, the other is optimizing selection of the decision-maker itself (any entity that makes decisions, whether an individual, or an algorithm or other process) [10]. Each of these approaches is suggested [10] to have a tendency to be used in certain domains, with selection of the decision-maker suggested to predominate in the structured problems often the focus of computer science approaches to CI, and with selection of the optimal decision proposed to predominate in the unstructured problems often the focus of social science approaches to CI. Assigning a weight that stores the projected or actual measured fitness of each function for each of the two domains enables both sets of solutions to be used so intelligence grows.

This approach can be generalized to use such weights to bridge larger sets of solutions, each of which is optimal in one or more of an arbitrary and potentially much larger number of domains (functional domain bridging).

In summary, a unique set of elements combine to steadily increase CI so it can converge on GCI. Functional modeling of any problem in terms of reusable building blocks (functional decomposition) is used to collaboratively find the best solution according to functional fitness. Functional domain bridging connects different problem domains into a single larger one. The GCI navigates through the problem space (functional stability) with a path that imitates human intelligence in its global stability. The GCI continually improves each functional component (functional adaptation). Of course using this GCI in any domain requires building up a library of collective reasoning processes and a set of functional models representing that domain.

5 The Principles of Collectively Intelligent Cooperation and Functional Modeling of Problems and Solutions

If collective decomposition of the world into functional models is to be achieved in a way that maximizes outcomes for all, it must be achieved through several layers of decentralization at the physical, virtual, and other levels. This decentralization requires adherence to principles of collectively intelligent cooperation [5]. If functional decomposition is essential for GCI in this model, and these principles are critical to functional decomposition, then these principles in this model are also required to have the capacity for GCI, which again is maximizing collective outcomes.

The "Operation" principles of collectively intelligent cooperation are that activities operate in a way that is:

- Decentralized in that activities don't belong to any given entity and instead are executed by the best candidate. The interaction can't be co-opted by any centralized interests.
- Peer to Peer in that all roles interact directly so no middle-man can insert their interests. A process may consist of many steps involving many participants, but each step can be considered as a direct interaction between two participants.
- Node-centric in that other than the input, no other role defines the information required for the interaction, so no third party can insert their interests. All the definitions required for interactions are stored by each participant. In groups this can be interpreted as the need to retrieve definitions from any third party can't be used to insert that third party's subjective judgment about what those definitions are, and in doing so enable them to co-opt the interaction to serve their interests.
- Massively collaborative in removing the limits to which collaboration can be scaled. In groups this can be interpreted as the interaction removing any subjectivity that makes a single decision-maker a bottleneck, removing any monopolization of roles that would make a single role a bottleneck, and removing any other factors that introduce bottlenecks limiting massive collaboration.

The "Ownership" principles of collectively intelligent cooperation are that entities are owned in a way that permits:

- Open exchange of information (open but not necessarily free). Such sharing is also important to increasing the scope and scale of cooperation.

The "Participation" principles of collectively intelligent cooperation are that each activity has their own metric of performance that permits:

- Each activity (and each solution consisting of chains of activities) to be replaced by better ones, and enables new modes of cooperation to be introduced over time through the hierarchy of processes of life (homeostasis, autopoiesis, etc.) represented within this model.

Leveraging these principles to open participation in collaborative processes to all prospects, functional modeling can be used to define a semantic model of each user's data, identities, and applications, to "open" them as well, so they are available for use in those processes. Functional decomposition breaks those models into objectively defined functions that any participant with the required role can potentially cooperate to execute. And semantic modeling enables outcomes of interactions within those collaborative processes to be stored in a common way. This functional decomposition and semantic modeling enable parts of processes to run in parallel, so a GCI can orchestrate execution of those functions collaboratively at far greater speed and scale. By creating a private intelligent agent for each user that provides access to the user's data on the user's behalf according to policies they specify, where interactions follow processes that can be modeled, if an individual's responses follow policies that can be implemented by a trusted intelligent agent that responds far more quickly on the individual's behalf, then the number of those agents can be multiplied, and the rate of interactions can be further scaled. Most or all of the required components for such agents already exist. By defining a metric for fitness in implementing each component GCI can enable vendors to collectively self-assemble them. In a model in which each entity owns their own data, GCI can coordinate massive decentralized queries to provide access to large datasets. By enabling users or intelligent user-agents to spontaneously self-assemble into communities GCI can potentially enable collaboration with this data to achieve any outcome. Without scaling collective reasoning through the assistance of intelligent agents in this way, there is a limit to the scale and speed at which a group can cooperate to find and evaluate solutions, e.g. resulting in the capacity to evaluate perhaps tens or hundreds of options where a GCI might evaluate trillions. Without the capacity to consider sufficient solutions to do so, maximizing impact on collective outcomes (such as the sustainable development goals) cannot be reliably achievable.

6 The Collective Body in Practice

Since the principles of collectively intelligent cooperation [5] must govern all interactions, whether human-human or human-machine in order to achieve the capacity to maximize collective outcomes, then they also must govern all design of all products or services in this model of GCI. Therefore, unlike any other model of CI, this model defines principles of collectively intelligent cooperation [5] that must be applied to the design and use of physical products, software, processes, or anything else, in order to gain the ability to reliably achieve massive increases in impact by decoupling elements into discrete units of functionality that can be manipulated at computational rather than human scales.

A functional model of all the components of a physical or software solution and a metric for projecting the fitness of each prospective solution provider's component in achieving that function, combined with applying the principles of decentralized cooperation required for functional decomposition, together allows providers to self-assemble into solutions, even where providers don't understand or know about each other's offerings.

Phase III of the CIPAA-SDGs program is intended to deploy a collective intelligence platform (a Collaborative Design Platform) with the goal of providing competitive advantage for groups of businesses that cooperate to increase the re-use of materials through sustainable circular business practices. This planned Collaborative

Design Platform is intended to enable businesses to algorithmically search for opportunities to share designs of components and materials to lower costs and increase reuse, to algorithmically search for opportunities for consumers and users to share use, and other opportunities for cooperation that create value for the end user. Then to combine businesses into value chains that cooperate to share that benefit.

For example, an auto manufacturer could create value for the consumer if they designed their vehicles in a more modular way that enabled greater reuse, and if they created programs that facilitated reutilization of parts and materials after first use, so that parts were cheaper and cars lasted much longer. But currently this isn't feasible because a business can't compete by making cars last longer and therefore reducing revenue. However by finding a great many of these opportunities, a GCI could increase the value until it creates unbeatable competitive advantage for the group, and could spread the cost of this "subsidy" (i.e. the loss in revenue due to reducing use) across a larger and larger chain of cooperating businesses so that the portion of the subsidy paid by the auto manufacturer alone decreases until the increase in competitive advantage due to this subsidy outweighs their cost in offering the subsidy.

Finding these potentially thousands or even millions of opportunities to cooperate, and therefore achieving this increased material reutilization, is too complex without computational CI. And though increasing the size of the chain of cooperating businesses can potentially increase competitive advantage until it's sufficient for the group to dominate any market, this cooperation is unstable without GCI [5]. Furthermore, this cooperation must follow the previously mentioned well-defined principles for algorithmic searches for opportunities to cooperate to be possible. But where the dollar value of cooperation is greater than zero such algorithmic approaches enable cooperation to reliably be scaled until it can subsidize or pay for achieving the targeted social, economic, environmental or other collective impact.

The collective emotions and other features have not been implemented in the current design of the Agricultural Livelihoods Program that is phase I of the CIPAA-SDGs program. However, eventually it is required to ensure a decentralized process for deciding which goals the collective will target.

7 Algorithmically Maximizing Collective Outcomes

Optimizing processes through use of a fitness function to select optimal components, enables processes to be redesigned algorithmically to follow a more optimal path through this state space that minimizes cost of execution while maximizing value of the outcome achieved (Fig. 4).

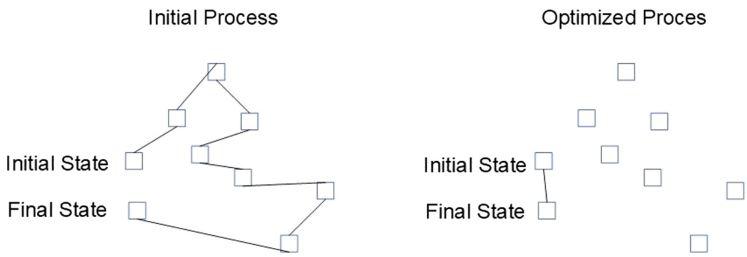

Fig. 4. Optimizing processes.

This GCI approach firstly optimizes processes through "functional fitness". A solution is modeled as a process consisting of a series of activities. Optimization theory, a large area of applied mathematics, concerns finding best available values of some objective function given a defined domain (or input) [8]. In the case of maximizing collective outcomes, this requirement of optimization can be satisfied by assigning a metric of an entity's "performance" in terms of its impact on collective well-being (the collective's capacity to execute its capabilities [6]).

The approach then optimizes processes through "functional decomposition". Algorithms can increase the rate of outcomes by finding opportunities to execute functions in parallel. Functions can be executed in parallel when they are decomposed into building blocks according to the previously mentioned principles so that execution of one instance can be decoupled from that of another. Algorithms can increase the magnitude of outcomes, or can transform outcomes to more optimal ones, by executing additional functions in series. Functions can be executed in series when inputs and outputs are modeled so one function can be set to act on the outputs of another, in this way execution of functions can be coupled together. The resources available to execute functions can be increased by cooperating through sharing functionality. That is, by finding all other processes where the same function is used, and creating value through cooperating to save costs in creating and using these functions.

Functional modeling of both problems and solutions enables reuse and sharing of both. Each individual in the collective is a piece of the jigsaw puzzle that may have the capacity to execute some unique function, that is, may have some functionality others don't have. Each individual also may have some unique information others don't have. Each individual has a finite capacity for information. That is, there are limits to the volume of information an individual can navigate. And each individual has a finite capacity to learn and execute processes. That is, there are limits to the volume of processes that an individual can navigate. It's also important to have the ability to navigate all the domains of expertise of the group rather than being limited to the domains of expertise of a few decision-makers. Furthermore, its important to have the ability to harness the resources of the group, rather than being limited to the resources controlled by a limited sub-set of decision-makers. A GCI platform however might orchestrate cooperation according to functional models of problems and solutions to address these challenges (Fig. 5).

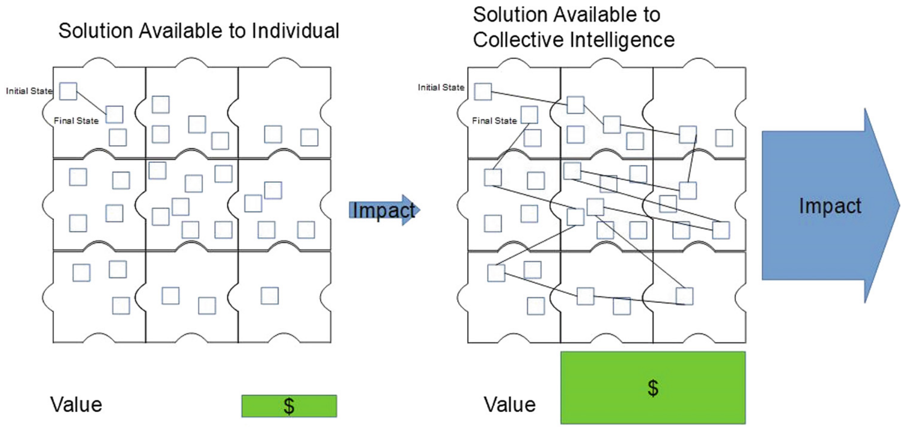

Fig. 5. Far more solutions (more paths) are available to the collective with a GCI.

Without GCI (including with conventional CI) outcomes can become aligned with individual interests, and individuals who don't compete to further their own interests rather than serving the collective well-being gradually lose access to resources and therefore gradually lose decision-making power [5]. With GCI outcomes are aligned with collective interests, and individuals who don't cooperate to further collective interests are the ones who gradually lose decision-making power [5].

8 Conclusion

Existing conventional CI solutions have be modeled here as single functions. An approach to GCI has been modeled as using a library of such functions to potentially gain vastly greater general problem solving ability. This creates opportunity for each other CI project to become a function in a much larger and much more powerful GCI. Reusable functional building blocks in turn create the potential to enable construction of far more powerful and comprehensive CI functionality far more quickly.

By combining individuals into a single potentially vastly greater intelligence, this model of GCI creates the potential to reliably address collective challenges where they are not reliably solvable with existing approaches to CI that don't adhere to the required principles [5]. This includes the SDGs [5]. With the United Nations estimating a $23 trillion USD gap in funding to achieve the SDGs, the potential to reliably address such issues is of profound global importance. This potential importance provides motivation to take next steps, such as conducting a survey of domain experts to validate claims regarding some of the required functional components.

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