Defining Functional Models of Collective Intelligence Solutions to Create a Library a General Collective Intelligence can use to Increase General Problem Solving Ability

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Abstract
With the great and growing number of collective intelligence models and algorithms to implement those models, the task of developing a single understanding of which model is optimal may steadily become more and more untractable. However, rather than competing to determine which model is best, a more productive approach might be cooperating to create a collective repository to store information about how each model performs in each context. This paper proposes a methodology for defining functional models of CI solutions, so those CI solutions might be added as functions to a library that a General Collective Intelligence might use to increase its general problem solving ability. Utilizing such a library might require information to be stored about which inputs, targeted outputs, and contexts of execution in which each solution or given category of solution might be optimal. Functional modeling of collective intelligence solutions and the context in which they operate facilitates this.

Introduction

A Functional Modeling Framework (FMF) has recently been developed for representing models of collective cognition. Using this framework, a model for Collective Intelligence (CI) with general problem solving ability (a General Collective Intelligence or GCI) has recently been defined [13]. This framework aims to provide the ability to represent and compare all systems of collective cognition (collective intelligence) in terms of a set of basic cognitive functions, a set of basic adaptive processes, and a set of principles of cooperation. Because this is a functional framework independent of implementation, it has also been used to define models of individual and artificial cognition [10].

In complex systems design, functional modeling provides a number of important benefits, such as permitting multidisciplinary cooperation to implement large systems by defining functional components with well defined interfaces that remove the need to understand other disciplines [1] – [8]. Because this functional modeling approach facilitates large scale collaboration, and because the same functional components is proposed to be valid for representing individual, artificial, and collective cognition, this approach can potentially be used to align cooperation between initiatives aiming to develop systems of cognition in these areas, creating the potential to significantly increase their impact by each implementing a different subset of the same set of components.

The Validity of a Functional Modeling Approach towards Representing CI Algorithms

Parts of the FMF, such as it's semantic modeling capability, are still under development. The FMF is of great potential importance to the study of CI even without representing CI algorithms semantically in terms of a set of basic cognitive functions. Firstly, the principles of decentralization defined by this model are proposed to be required in all processes within CI algorithms, in order for those algorithms to have the capacity to reliably maximize collective outcomes, rather than allowing any processes within them to become centralized in a way that forces decision-making to align with the interests of a subset of decision-makers [13]. Secondly, the adaptation ability defined by this model are proposed to be required to enable a CI to choose the optimal problem to solve[13].

A library of CI algorithms can also be very useful without semantic modeling of the processes within the algorithms themselves. In the same way that early semantic modeling efforts may have used manually defined ontologies for categorization, a useful library of CI algorithms might be constructed by creating functional models that simply define input, outputs, and context, essentially treating the CI algorithms themselves as black boxes that can be manually labeled (categorized) as different.

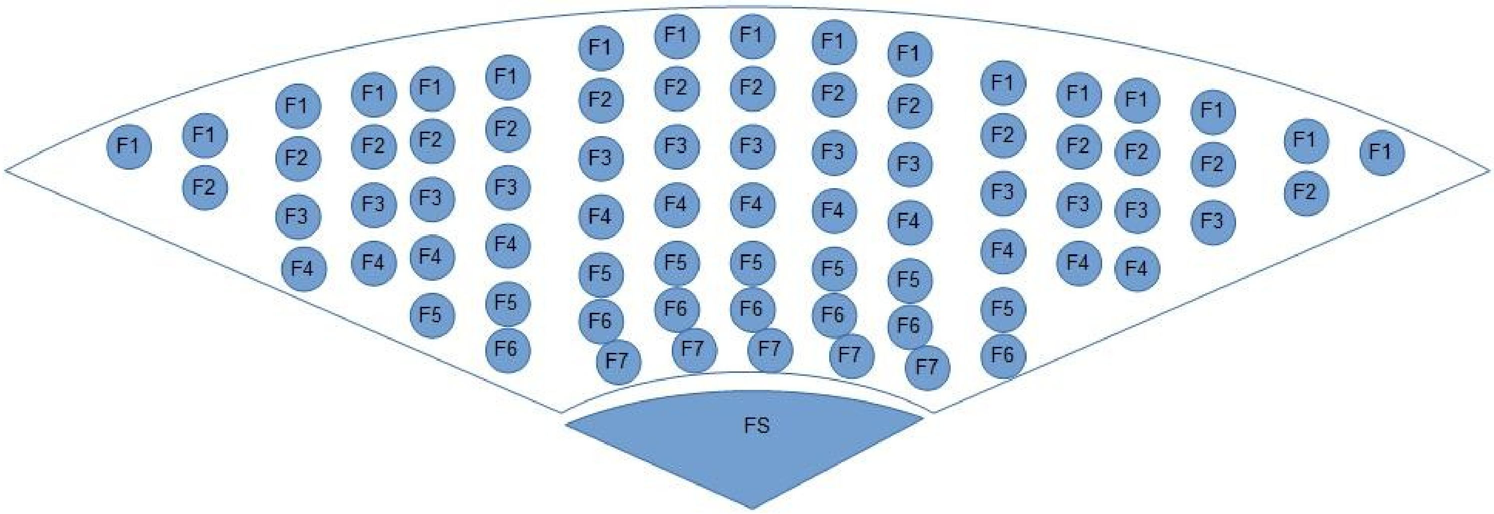
Of course, in order to develop the capacity to automatically categorize CI algorithms in such a library, the capacity to represent any process in terms of the cognitive functions defined in a common framework like the FMF must be developed.

To gain the capacity to represent any process in terms of a common set of cognitive functions, this modeling approach proposes that cognition or collective cognition can be represented in terms of a discrete set of functions (functional units F1 to F7, and FS). On the input path (cognitive or other input), the set of functional components implementing these cognitive functions are proposed to act to receive understanding in terms of concepts (understanding meaning the process that enables comprehension of the sentence "the quick brown fox jumped over the lazy dog"). On the output path (using cognition to drive action or conclusions) these functional components are proposed to direct understanding through reasoning (reasoning meaning the process that enables answering the question "what fox jumped over what dog?").

Functional Units in Systems of Collective Cognition

Functional Unit	**Input Function**	**Output Function**
F1 to F3	Create Concept	Create Signals from Concept
F4	STORE (Store Concept)	UNSTORE (Recall Concept)
F5	RECALL (Recall Concept)	UNRECALL (Store Concept)
F6	PATTERN (Detect Pattern in Concept)	UNPATTERN (Detect Concept in Pattern)
F7	SEQUENCE (Detect Sequence of Operations in Concept)	UNSEQUENCE (Detect Concept in Sequence of Operations)
FS	COGNITIVE AWARENESS (Choose Problem to Solve and Reasoning Process to Solve it)	COGNITIVE AWARENESS (Choose Problem to Solve and Reasoning Process to Solve it)

Multiple instances of each of these functions in a conceptual model of the brain that connects these functional units into paths, is proposed to have the capacity to represent any intuitive or rational methodical reasoning process.



This paper proposes that representation of reasoning processes in this way is possible because any intuitive reasoning can be represented in a functional model as a form of pattern detection. And since the set of functions AND, OR, as well as NOT can represent all logic and is therefore Turing complete, this paper proposes that any logic, and therefore the logic in any rational methodical reasoning process, can be represented in a functional model in terms of a function to detect patterns, and in terms of patterns representing a Turing complete set of logic functions, whether or not they are the functions AND, OR, and NOT.

As with all other components of this framework, the goal is not to design a static set of components that “solves” GCI, but to define a methodology for orchestrating cooperation that reliably converges on GCI. That is, to provide a methodology to improve or replace any component with ones that have greater fitness in achieving the targeted objective. For this reason, whether these are the correct cognitive functions into which reasoning can be decomposed, or whether the definitions of these functions are correct, are not critical.

Of course, reasoning requires semantic representation of both processes and information. Such representations define a multitude of relationships connecting any entity to other entities that define its potentially many properties. Each perspective defines a set of relevant relationships. For example, from the perspective of a comparison with a "mouse" a fox is "large". From the perspective of a comparison with a "horse" a fox is "small". In this framework the semantic representation (concept) of each entity are assumed together to form a space of concepts (a conceptual space).

In order to have the capacity to represent all the constructs used in reasoning, and therefore that are used in all artifacts of reasoning such as any natural language text or speech, the requirements of the model for the conceptual space, and the requirements for other components of the FMF, must be elaborated and used to define implementations of those components that are validated through experimentation.

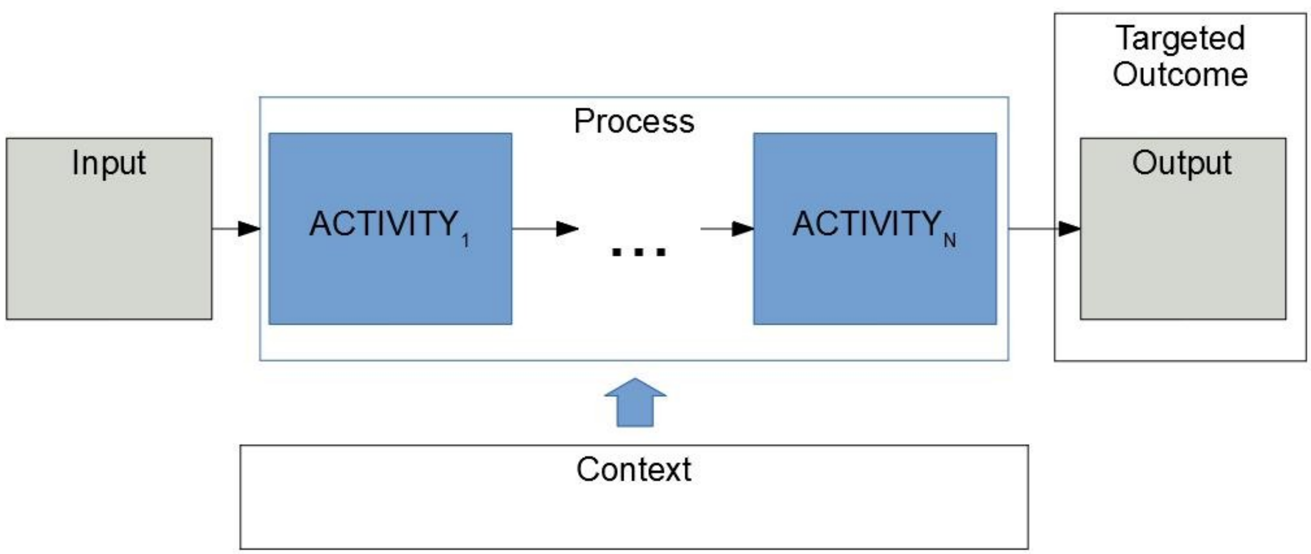
A set of Large Scale international Collaborative REsearch (LSCORE) initiatives are currently being conceptualized to leverage this human-centric functional modeling approach to permit large scale collaboration to reliably converge on working models of human, artificial, and collective cognition (general collective intelligence), where such collaboration has not proved possible before. This framework is intended to enable each LSCORE initiative to implement part of the total required set of components and to use them in either modeling the solutions (LSCORE-CI, and LSCORE-HACC),or modeling the problems (LSCORE-CI4SI&SD), so that together they form a semantic model of the problem space, and library of reasoning functions in a cognitive system capable of using general problem solving ability to navigate that problem space. Aligning cooperation between initiatives in this way may help ensure the research of any individual participant is relevant to a much larger set of problems, and therefore stakeholders.

- LSCORE-CI (Collective Intelligence)
- LSCORE-HACC (Human and Artificial Consciousness and Cognition)
- LSCORE-CI4SI&SD (Collective Intelligence for Social Impact and Sustainable Development)

The pre-planning phases of these proposed initiatives are intended to validate the framework and other assumptions on which the project is based. The planning phases of the proposed LSCORE initiatives are intended to elaborate those requirements. The implementation phases are intended to orchestrate large scale collaboration between the initiatives to implement them.

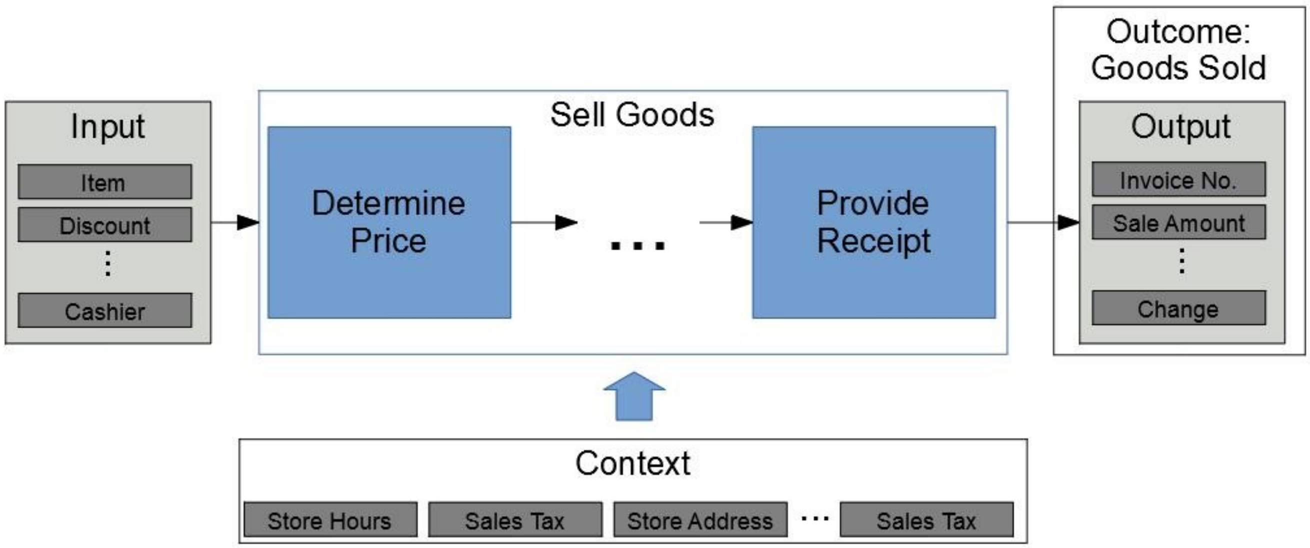
Defining Functional Models of Collective Intelligence Solutions
As described in the case of cognitive functions for an individual system of cognition such as an AGI [14], reasoning (cognitive functions) representing the functions of a given AI solution, may be modeled and those models combined into a library that an AGI might use to increase its general problem solving ability. The basic functional modeling approach is to:

In summary, each CI solution can be conceptually represented in terms of a function with an input, an output, a context of execution, and an outcome related to that output. The context of execution represents all the information that the output is dependent on that is not part of the input, such as configuration parameters.



Processes are defined here as functions that can receive input multiple times within the same instance of execution. By this definition a CI that plays chess is a process (Process: Play Chess) because each move of the opponent is a separate input within the instance of the game. However, the CI taking all the positions on the board as input and generating the next move is a function (Function: Move Chess Piece).

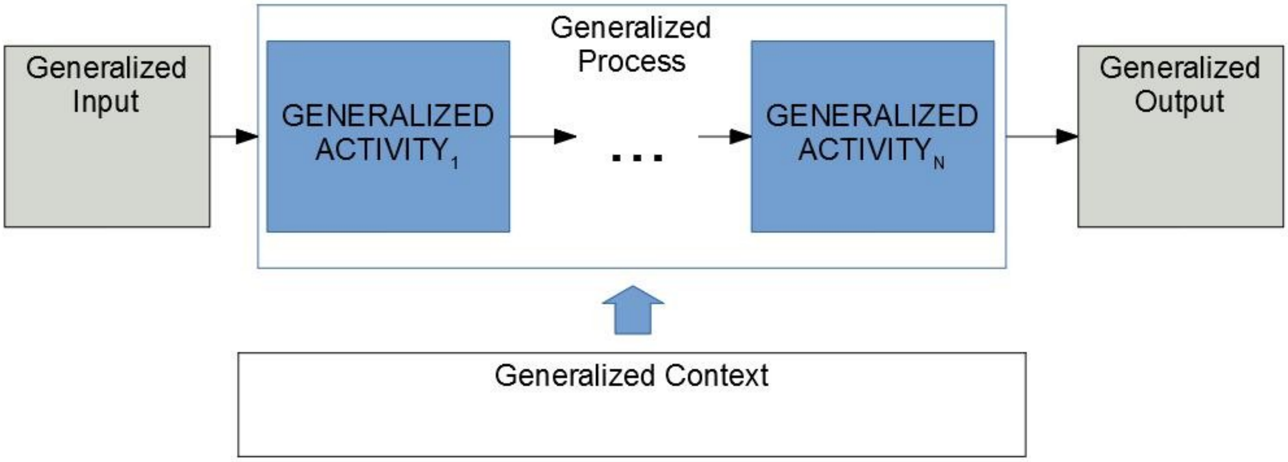
An example is the function "Sell Goods" that is involved in retail sales operations. In terms of its external interactions this function is described in terms of the concepts that form its inputs, its outputs, and the context in which it is executed. In terms of its implementation this function is executed through a number of specific activities.



Functional modeling of each collective reasoning process or function within a CI algorithm requires semantic modeling of the concepts input to and output from those processes or functions. Therefore in order to create a functional model of a CI solution a semantic definition of input and output concepts is required. This is intended to be provided by the implementation of the eXtensible Domain Modeling Framework (XDMF) [12]. Since that is not yet available, a database of synonyms for each concepptual entity in the input, output, or context may allow that library of functions to be searched.

Generalizing Solutions to Apply to a Greater Range of Problems

Functional models can be generalized by modifying the activities so they apply to more general categories of inputs and outputs. This generalization itself is not a uniform, one-dimensional process. All the inputs, outputs, and context are separate dimensions along which generalization might be performed. Some inputs, some outputs, some aspects of the context, or even some activities may be generalized in any given instance of a generalized process. Generalization along one of these dimensions may result in the function being more general in that more instances of that function are contained within that generalization group. Generalization is then from this perspective a multi-dimensional function with a specific input and a specific output that maps to a specific generalization group.

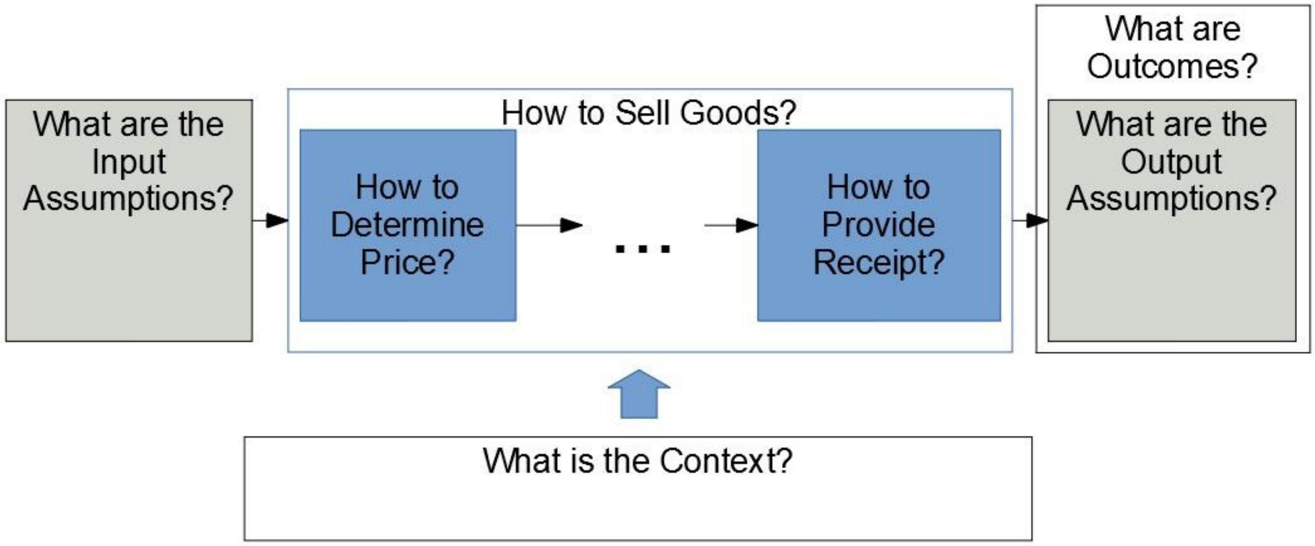


Defining Functional Models of Problems

Functional models of problems must be defined in order a library of functional models of solutions to be useful. In this approach a solution is a path in conceptual space, and a problem is the lack of such a path, so a functional model of a problem of a problem is very similar to that of its solution. A problem is then similarly defined in terms of a number of assumed inputs (inputs assumptions), a number of assumed outputs, and an assumed context in which the problem is being solved.

One key difference between the functional model of the problem and that of a given solution is that the set of inputs provided to the problem as assumptions might not align with the set of inputs required by any solutions. Assuming again that individual and collective cognitive processes, are composed of the same basic set of functions, psychologists have identified two types of reasoning that all human reasoning is confined to. These are rational methodical reasoning, and intuitive reasoning. Rational methodical reasoning essentially attempts to use an "equation" to come to a decision. Intuitive reasoning essentially comes to a decision through estimation from past patterns.

In the case of partial information the set of inputs provided by a given definition of the problem might align with the requirements of some pattern-based (intuitive) collective reasoning (i.e. might align with some CI algorithm). In the case of more complete information the set of input assumptions might align with the requirements of some rational methodical reasoning. But additional inputs and additional information in the context might be present that don't map to any reasoning process at all. For example, the fact that someone has decided that the current date is their lucky day may have nothing to do with retail pricing processes of any actual CI algorithm (e.g. the price of fish).



Defining the Projected Fitness of a Solution in Solving a Problem
The FMF distinguishes GCI from the intelligence of members of the group in that individual intelligence targets the problem of maximizing individual well-being. Collective intelligence is separated from the individual intelligence of members of the group in that it targets the problem of maximizing collective well-being. In order to maximize collective well-being in all circumstances there must be a way of measuring it. Approaches to CI that lack a methodology for incorporating measurement of collective well-being in determining fitness at performing tasks fail in this respect. This shortcoming proposed in this paper to restrict any group to having a collective intelligence factor that is potentially a deterministic function of the intelligence of its members, rather than having a general collective intelligence that is truly an emergent property.

The ability to compare outcomes, and a system of decision-making which ensures that comparison, is key to maximizing them. The functional components provided by the FMF for the purpose of these comparisons are a Universal Impact Metrics Framework (UIMF) [15] for comparing impact in common terms, and a Semantic Metrics Framework (SMF) [16] for comparing impact on well-being so that all interventions can be reliably compared in those terms. Impact and well-being in the UIMF and SMF are defined using the same human-centric functional modeling approach to represent the way human beings intuitively measure impact and well-being respectively, in the attempt to create representations that can be intuitively understood in natural language. For example, well-being is defined in each of the functional systems (body, emotions, mind, and consciousness) as being the capacity of the system to execute all of its functions. These functions in turn are defined by the functional state space of each system [17]. Collective well-being in the collective body, emotions, mind, and consciousness is the aggregate of this individual well-being.

Defining the Relative Importance of Problems
Traditional models of CI ignore the need for decentralization to balance the forces of centralization that constrain solutions so they solve the wrong problems (problems aligned with the interests of the most powerful decision-makers). The current model of GCI balances centralized prioritization of specific functions, and decentralized cooperation between functional components to achieve those functions, so that functional components to tend towards a natural balance of collective fitness, and so that the

collective tends towards well-being, so that the cooperation between individuals is stable and therefore sustainable [11].

Searching the Library for the Solution with the Greatest Projected Fitness in Solving Each Problem

Creating the ability to search the library for the solution with the greatest projected fitness in solving each problem is a matter of determining the domains which define the different contexts in which a given CI process or function might be optimal, and then defining a system of weights that determine which domain should be used in which context, so that the information about which process or function is optimal is stored in those weights. A methodology for defining and using these domains is explored elsewhere [18].

Searching the Library of Problems for the Optimal Problem to Solve

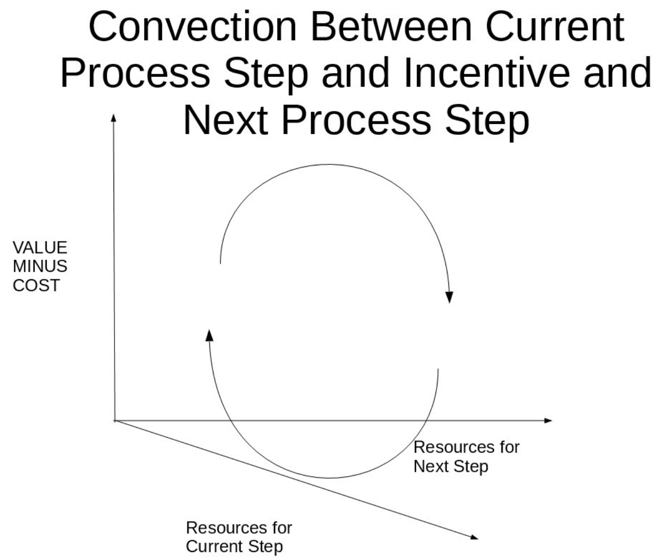
Where a CI solution uses the intelligence of crowds to find an optimal solution, a GCI must also have the capacity to choose the optimum problem to solve. In order to do so, a GCI must keep track of its fitness, and it must keep track of information such as whether the current CI process is projected to reach a conclusion within the resources available before collective well-being falls too low.

The model of GCI developed within the FMF (the so-called "change engine") is proposed to have the potential to significantly increase impact on collective challenges that might prove intractable otherwise due to perverse incentives to key decision-makers. A GCI is proposed to have the capacity to reliably impact such collective challenges, including poverty and environmental degradation, where solving those challenges globally has not proved reliably achievable by any existing methods.

The system of collective cognition is modeled as projecting the value minus cost of each activity being executed (its "fitness" in achieving its targeted outcome) and either investing resources into the current collective reasoning activity (current CI algorithm) until complete, or discontinuing the current reasoning activity to invest resources into the next (choosing to solve another problem). The targeted outcome in the case of collective cognition is maintaining the cumulative value of outcomes minus cost within a stable range. The projected value minus cost of the current activity is one axis of the cognitive fitness space in this model. The actual value of the resources invested into the current activity is the second axis of this space. And the value of the resources available to be invested into the next activity is the third axis of this space. Again, it's important to note that the definition of the fitness space and the definition of any other element of the model may or may not prove correct. But that still does not invalidate the framework's approach of enabling every component to be replaced with one that is more fit.

The collective cognitive process keeps resources invested in a stable range between the boundaries of being insufficient for any current reasoning activity to occur, and being too great for any subsequent reasoning activities to occur. The sequence of reasoning activities selected to be executed by the collective cognitive process functions to maximize stability in terms of keeping the cognitive well-being as close as possible to the center of a stable range, and not allowing that stable range to be exited. By executing reasoning activities in a sequence that keeps the state of cognitive well-being within a stable range, the collective cognitive process navigates the collective conceptual space (cognitive state space) as well as the state space of the environment.

The forces in this model create a convection between investing more resources in the current reasoning activity, or searching for a new one.



These forces are represented in this model by the Lorenz equations for convection. The parameters of the Lorenz equations can be chosen to form a globally stable dynamics (a strange attractor) in the well-being space, despite a chaotic path through the conceptual space. The same Lorenz equations are used to implement all the other functional components in the model so that their dynamics within their fitness spaces and state spaces obeys the same global stability despite local instability. More detail regarding the application of these equations is provided elsewhere [19], [20].

Using Collectively Intelligent Cooperation to Scale the Project to Build the Library
The proposed implementation project identifies a wide range of projects in human consciousness or cognition, AI, or collective intelligence, and aims to represent the functionality of those projects in terms of this single framework so that the functionality can be generalized and added to a library of functionality that might be reused in other domains where it applies. This library of functionality can then forms valuable research infrastructure with the potential radically increase the impact and accelerate the progress of any group working on defining such models.

The plans being developed for the prospective LSCORE initiative use the proposed ontologies of collective cognitive functions, adaptive processes, and principles of decentralized cooperation to organize cooperation between a wide range of projects so that they form this infrastructure. To do so LSCORE uses this ontology to provide the ability to represent and compare models of individual and collective consciousness or cognition, and to provide the ability to reliably find the most fit components of each model so the whole reliably converges on the functionality observed for consciousness and cognition. With this framework massive collaboration may become possible. This initiative aims to leverage that cooperation to become the CERN of consciousness and cognition research.

Because of this common framework, research within this project can span a wide variety of fields while still contributing to the common goal of defining working models for individual or collective consciousness or cognition. Some applications currently being developed include modeling the impact of clinical interventions on individual human consciousness and cognition [21], modeling artificial consciousness and cognition in relation to Artificial General Intelligence (AGI), and modeling software platforms that combine individuals into a single system of collective consciousness and cognition with vastly greater ability to solve collective social, economic, environmental, and other challenges [22], [23]. Creating a single framework to represent mathematical models for consciousness and cognition also means these models can be applied towards maximizing impacts on these collective challenges, where game theory models suggest impact isn't reliably achievable otherwise. The potential value of all of these impacts justifies a significant investment in this research by a much wider range of stakeholders.

Modeling the Sustainable Development Goals as Problems for Collective Intelligence to Solve
A practical application of this approach is currently being developed. The pre-planning phase of the proposed Collective Intelligence for Social Impact and Sustainable Development Program as currently defined aims to use a functional modeling approach to define functional models of specific social challenges so that models of collective intelligence can be applied to solve them. This Social Impact and Sustainable Development Program aims to also identify candidate collective intelligence approaches to solving some of the most pressing of these social challenges, so that the fitness of one solution can be compared with others, where fitness is defined in terms of its increase in volume of outcomes per unit of input, and the increase in impact on collective well-being due to that increased volume of output.

Conclusions

There are a great and growing number of approaches to collective intelligence, or collective intelligence algorithms. Amid this increasing flood of information, trying to find a single optimal model may be an unmanageably large and complex task. However, because doing so may permit the emergence of a GCI that is separate from the intentions of each individual intelligence forming the group, there may be great potential in the approach of combining all problem definitions into a single semantic model of the collective problem space, and combining all collective intelligence functions into a single library a General Collective Intelligence can use to coordinate the group's activities in navigating that problem space.

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