

# Defining and Quantifying an Exponential Increase in General Problem-Solving Ability Within Groups

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## Abstract

The concept of collective super-intelligence has been described by various authors in the field of collective intelligence, some of whom have estimated the qualitative properties of a collective super-intelligence and have attempted to determine the types of problems that a collective super-intelligence might excel at. This work departs from those opinions in leveraging a Human-Centric Functional Modeling approach able to represent the behaviour of complex human-observable systems like individual or collective cognition. With this approach, for the first time models have been developed that allow the impacts of collective intelligence to potentially be predicted or even simulated with far greater accuracy and understood more reliably. This article explores how a collective super-intelligence might be defined and quantified in terms of the general collective intelligence factor ( $c$ ), and also explores how such a collective super-intelligence might be expected to differentiate itself from current forms of collective intelligence.

## Keywords

General Collective Intelligence; general problem-solving ability; general collective intelligence factor; super-intelligence

## 1. Background

Two key elements are proposed here to create the capacity to significantly increase the general problem-solving ability of groups. One is Human-Centric Functional Modeling, which represents systems in terms of all functions that are observable within innate human awareness, so that the states accessible through such functions form a functional state space which the system moves through. Functional state spaces allow complex systems to be represented in terms of a finite number of functional components so that the problem of understanding how those systems are implemented can be reliably solved in an incremental way, as opposed to other approaches to implementing complex systems like artificial cognition, for which the time required to succeed is unknowable and might just as easily be one hundred years as it is to be one month. Since functional state spaces have been defined to represent a wide variety of systems from artificial cognition, to homeostasis and other basic life processes, to the physical universe, then functional modeling has the potential to increase understanding of how these systems are implemented. In the case of artificial cognition this implies understanding how an Artificial General Intelligence might be implemented. In the case of the physical universe, this implies understanding how the fundamental forces might be unified.

The second element proposed to create the capacity to significantly increase the general problem-solving ability of groups is the ability to reliably compose and execute any problem-solving processes leveraging any information or any reasoning from any individual in the group, and the ability to reliably explore all possible solutions that might be composed that way and to reliably select the best. For any process  $P_i$  in a given domain by which a group might solve the problem of achieving any outcome  $I_k$ , the capacity to potentially execute any such problem-solving processes is by definition general problem-solving ability in that domain. In the set of all processes  $P_i$  targeting an outcome  $I_k$  for a given set of inputs and a given context of execution, that outcome will reach a maximum for some 'i'. Furthermore, as hypothesized in a game theory based analysis [7], implementing one or more instances of any chains of cooperation required to reliably maximize outcomes achieved through that problem-solving process by the group, or required to make outcomes achieved through that process

reliably self-sustaining for the group, is only achievable through a system of collective optimization that prevents optimizing outcomes for some subset of individuals from being the stable strategy as opposed to optimizing collective outcomes for the group being the stable strategy. Therefore, for any group solving the problem of achieving a given magnitude of any outcome  $I_k$  that cannot be achieved by any optimization serving the interests of a subset of the group, the capacity to reliably achieve that outcome requires a sufficiently powerful system of collective optimization with general problem-solving ability.

## **2. Introduction**

The pioneering work of Woolley et al. [1] extracted a general collective intelligence factor ( $c$ ) characteristic of groups by giving a groups a number of tasks from all quadrants of the McGrath Task Circumplex [2], a well established taxonomy of group tasks based on the coordination processes they require. Human-Centric Functional Modeling has been used to represent the collective cognition as moving through a collective space of concepts (a “collective conceptual space”) in which the volume of that space that can be navigated by that cognition per unit time is representative of the general collective intelligence factor [4].

Use of a Human-Centric Functional Modeling Approach to define a functional state space representing the behavior of complex systems as paths through their functional state space, such as defining the collective conceptual space the collective cognition is represented as moving through, clarifies the problem being solved and clarifies the nature of any solution being considered. As an example, defining the general collective intelligence factor as representative of the volume of the collective conceptual space that can be navigated by a collective cognition per unit time clarifies the meaning of an intelligence “vastly qualitatively smarter” than a human mind, which without this functional modeling approach has been called a “difficult notion to comprehend” [9]. Without a functional modeling approach many similar problems might be poorly defined, and different solutions might not be readily comparable or distinguishable.

## **3. Related Work**

Other work has estimated the qualitative properties of a collective super-intelligence. Following singularity thinking and “extrapolating current technological capabilities as far possible within physical limitations, such as the law of energy conservation, the second law of thermodynamics, and certain theoretical limits on computability”, at the theoretical limits to the general intelligence factor of groups the potential abilities of a collective intelligence have been hypothesized to go from being widely accessible, so that it can be used whenever needed to being omnipresent, to go from being intelligent and knowledgeable, so that it can deal with more complex and diverse problems to being omniscient, and to go from being powerful and efficient in realizing its solutions to being omnipotent [8].

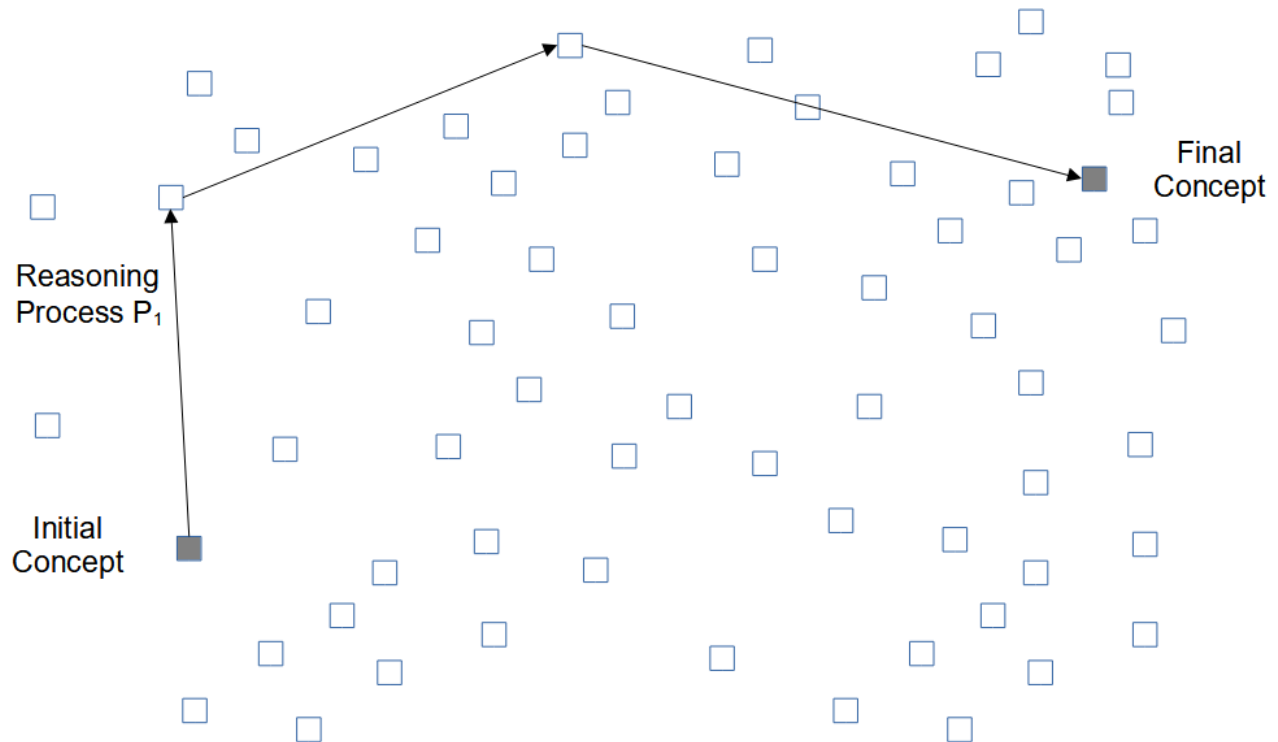
Others have estimated that a collective super-intelligence would “excel at problems that can be readily subdivided into independent sub-problems”, and that if that collective super-intelligence was also vastly qualitatively smarter, it might “have an advantage on problems that require new conceptual insights or complexly coordinated deliberation” [9]. No known research however other than the current work has quantified the term collective super-intelligence however.

## **4. Model**

Assuming it is possible to define a complete semantic representation of meaning, in which concepts are nodes in a network graph, and in which reasoning and understanding processes are the edges connecting those nodes in a three dimensional space, then the cognitive system can be seen as navigating a space of concepts or a “conceptual space”. In this conceptual space concepts might be

unevenly distributed. In this representation each reasoning or understanding process used by the cognition to navigate this conceptual space takes an initial concept as input and produces a final concept as output. Since each group of concepts is also a concept, the final or initial concepts might be a group of concepts.

# Conceptual Space



*Fig 1. The individual cognition navigates the conceptual space with reasoning or understanding processes. The collective cognition navigates the collective conceptual space with collective reasoning or understanding processes.*

Assume that in this conceptual space general problem-solving ability (intelligence) is represented by the volume of conceptual space that can be navigated per unit time. Assume the average IQ test has the capacity to detect a range of IQ from one to two hundred, and has the capacity to resolve IQs within that range at a precision of one (i.e. with an accuracy of less than plus or minus one half). This is equivalent to the capacity to detect the ability of the cognitive system to navigate a region of anywhere from 1 to 200 units of volume in conceptual space.

# VOLUME OF INTELLIGENCE

*Fig 2. The volume in conceptual space that can be navigated per unit time represented by one unit of intelligence (i.e. an IQ of 1).*

Representing this volume of conceptual space that can be navigated per unit time as a cube for simplicity, it is a total volume having three sides each with length L, where L measures some distance in conceptual space. If the distance between two concepts in conceptual space is related to the length of reasoning required to solve the problem of navigating from one concept to the other, and if there are two hundred questions that are asked in this test, L might intuitively be interpreted as the combined difficulty of the questions (the combined distance) along any given axis. For a volume of 200 the length L is equal to the cubed root of this number or approximately 5.9. Rounding to a number of questions given by the next lower integer (five), the number of questions used to test an IQ of 200 is equivalent to a length of five cubes along each of the three axes (x, y, z), or a total of 125 questions, with each cube having a length L equal to 5.9/5 or a question difficulty of 1.18, where the ability of that test to resolve IQ is potentially:

$$\delta IQ = \pm \frac{1.18}{2} = \pm 0.59$$

In this case the capacity of the test to resolve IQ does not fall within the stated target of plus or minus one half. Alternatively, choosing the number of questions used to test an IQ of 200 to be the next highest integer (six) the number of questions is equivalent to a length of six cubes along each of the three axes (x, y, z), or a total of 216 questions, with each cube having a length L equal to 5.9/6 or question difficulty 0.98, where the ability of that test to resolve IQ is potentially:

$$\delta IQ = \pm \frac{0.98}{2} = \pm 0.48$$

In this interpretation, in order to determine an IQ of up to 200 with a precision of less than plus or minus one half, an IQ test must contain at least two hundred questions, the average difficulty of each of which is 1. The question then becomes how to use this conceptual picture to understand how it might be possible to detect an IQ that is exponentially higher than 200. Firstly, if a single question tests the individual's ability to navigate a specific one unit volume of IQ in conceptual space, then in order to determine the capacity to navigate to other unit volumes of IQ, the other questions must access those different volumes. For example, assume that the level of difficulty of the test was limited to asking questions that each add two single digit integers together. Any question that adds two single digit integers together can be generalized so that it can be answered with the same technique, and is therefore the same general question. Asking the same general question repeatedly does not test the capacity of the cognitive system navigate to any other region of conceptual space.

To have the capacity to test for a given level of IQ, it is hypothesized that each question must have a level of difficulty D given by:

$$D = \frac{IQ}{N^3}$$

Here N is the number of questions. According to this hypothesis, the total volume of IQ that a single question of difficulty "one" might be able to detect is a single unit of IQ. With an IQ test containing a

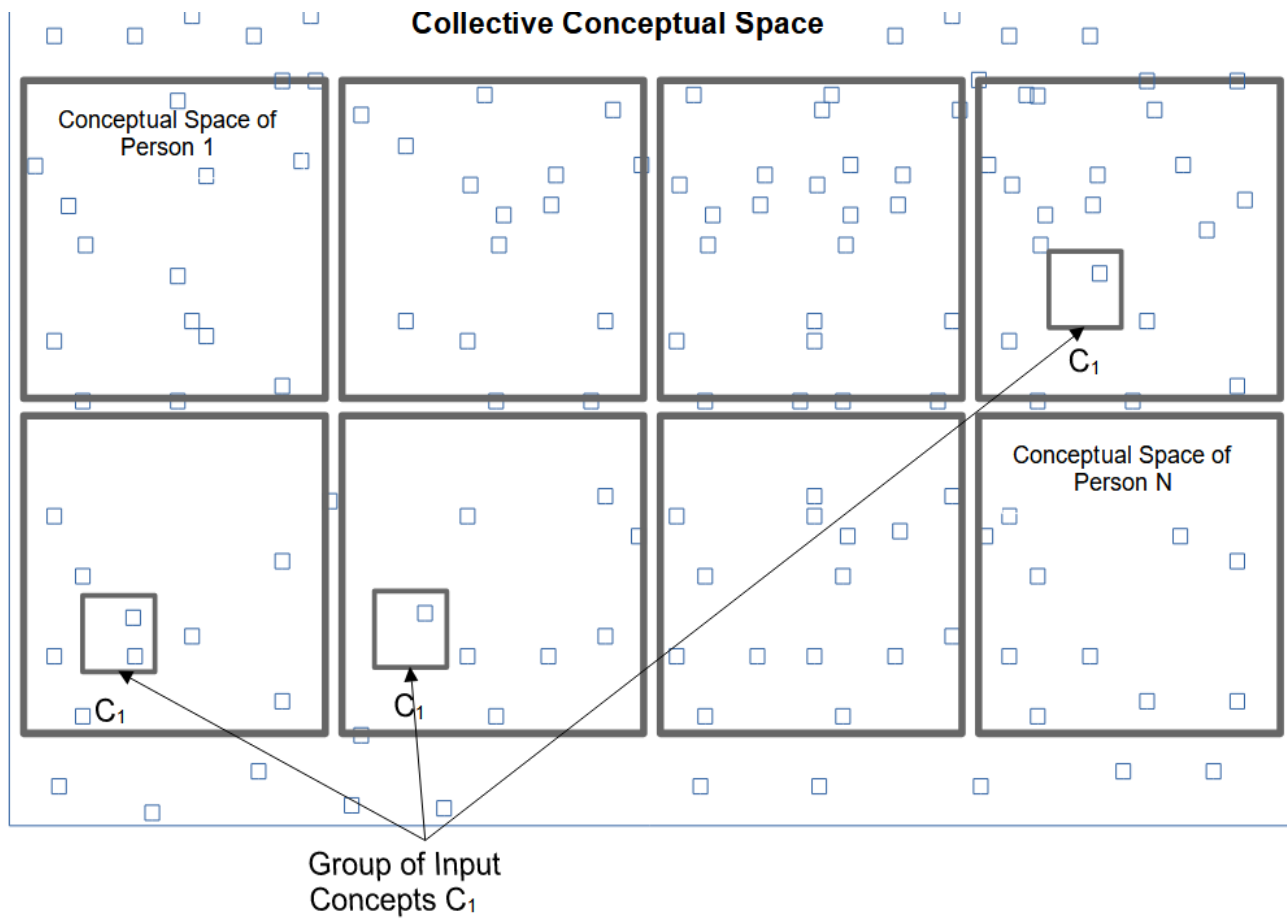
single question having a difficulty of one, any IQ in the range from zero to some fraction of one might be detected as an IQ of zero, and any IQ in the range from some fraction of one to infinity might be detected as an IQ of one. However, if the test is permitted to ask any general question with the same level of difficulty  $D$  that is approximately equal to one, then if reasoning processes defining  $N$  questions that explore different regions of conceptual space can be identified, a total volume of IQ of  $N^3$  can be explored.

One way to increase the probability that the test is navigating to different regions of conceptual space with each question is to chain questions together so that each question relies on a methodical variation of the previous question in order to reliably navigate to a different region of conceptual space. For example, represent the reasoning process defining each question as a function of two input concepts. The position of a concept in conceptual space is defined by its relationship with other concepts. Subsequent questions on the IQ test can then potentially be ensured to explore different volumes in conceptual space if the first concept in any question is a concept from the volume of conceptual space explored by previous question, and the second of those concepts is a concept in a new volume that is adjacent. In order to have a sufficient number of separate pairs of concepts to reliably traverse the entire volume of conceptual space, a number of concepts  $M$  can be identified, each pair of which resides in a different region of conceptual space.

In conceptual space a generalization is represented as a concept that occupies a larger region in conceptual space and that contains multiple other concepts. For example, the generalization “vehicle” contains many different cars, buses, trucks, and other instances. Concepts within the same generalization are located within the same region of conceptual space occupied by that generalization. In order to ensure these concepts are distributed throughout the entire conceptual space, a set of concepts might be chosen that does not share generalizations except those common to large regions of conceptual space or all of conceptual space. For example, the generalization that a concept is an “entity” applies to all concepts so sharing that generalization would not disqualify two concepts. However the generalization that a concept is a “vehicle” might disqualify both the concept “car” and the concept “truck” from both being included in questions in the test, unless the number of concepts required for the test was sufficiently large to prevent this exclusion.

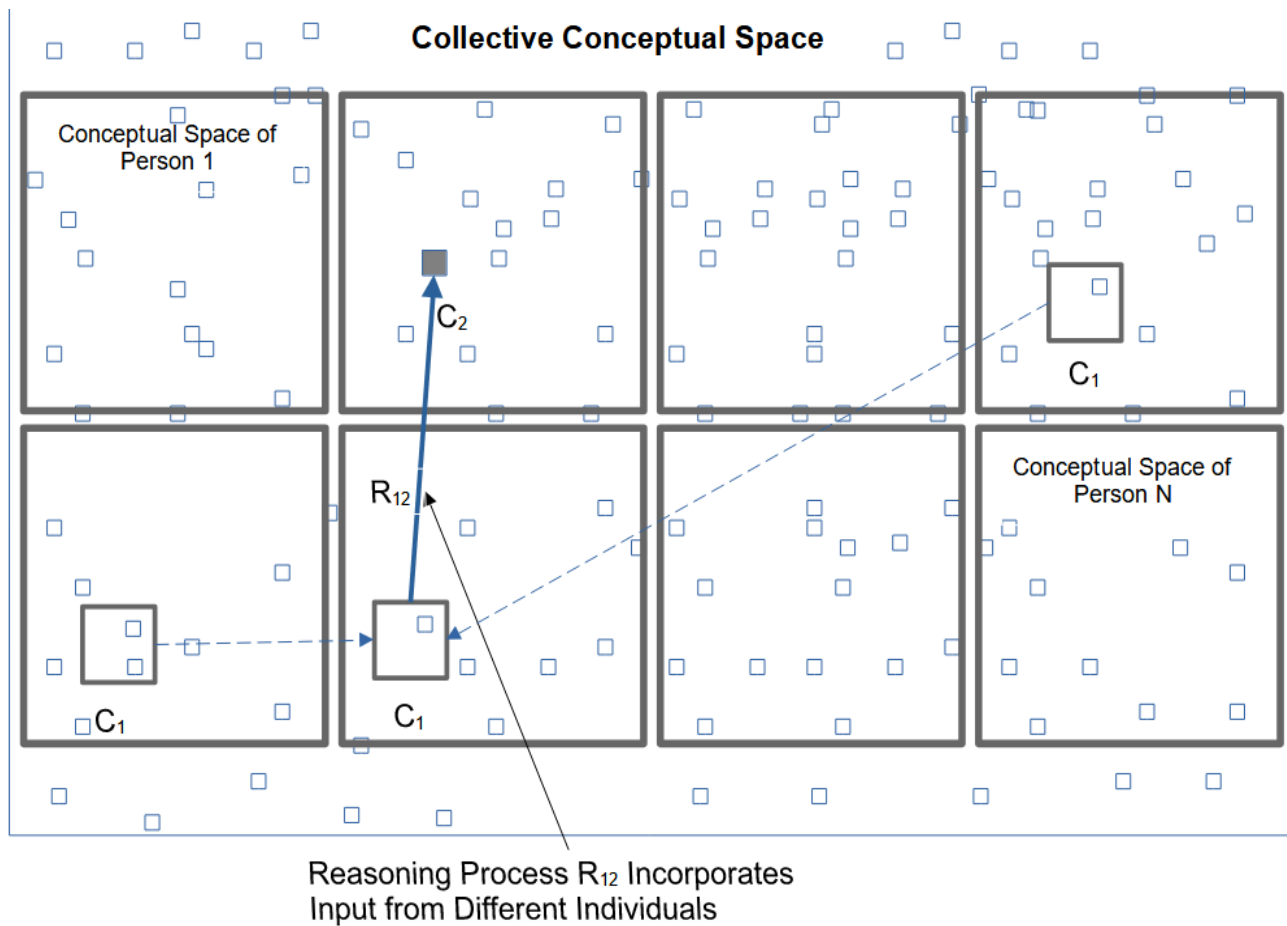
Assuming that for any reasoning process  $P$  of two input concepts  $A$ , and  $B$  that the sequence of the concepts does not matter, and therefore that  $P(A, B)$  is equal to  $P(B, A)$  then the total number of possible combinations for a number of concepts  $M$  is  $M(M-1)/2$ . Since  $M$  must be a positive integer the negative solution to this quadratic equation can be ignored, giving  $M$  equal to approximately ten. That set of 200 combinations of ten concepts must be methodically spread over the volume of 200 units of IQ through the questions. In order to do so, each volume must methodically vary the set of concepts being used across each question. One way to accomplish this is to number the concepts from  $i=1$  to  $i=10$  and to vary the concepts from 1 to five over one axis of the cube, to vary the concepts from 5 to 10 over another axis of the cube, and for the third axis the concepts can be varied in a methodical way that does not repeat any of these combinations.

In order to demonstrate the capacity to navigate these questions through collective reasoning, each question must be assignable to an individual or subgroup. In the same way that the individual navigates an individual conceptual space, any group decision-making process must navigate a collective conceptual space that is a composition of all the individual conceptual spaces. In this collective conceptual space, any group decision-making or other reasoning process can have input concepts that are spread across the conceptual spaces of different individuals.



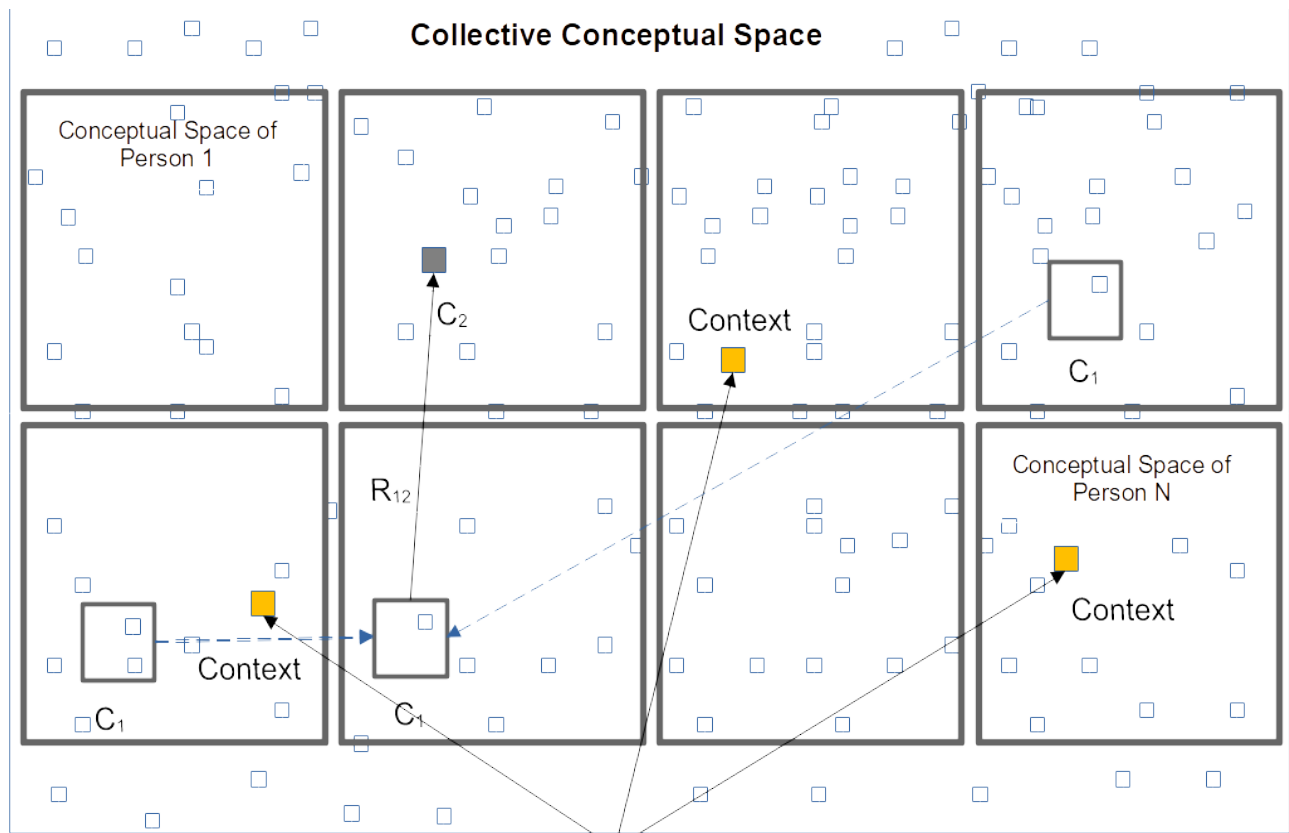
*Fig 3. A group of concepts  $C_1$  which form the input to a collective reasoning process might be spread over different individuals in the group.*

The collective reasoning process might also navigate to concepts that are in the conceptual space of other individuals in the group.



*Fig 4. A collective reasoning process  $R_{12}$  that consumes input concept  $C_1$  and that outputs concept  $C_2$  might also be spread over different individuals in the group.*

Each reasoning process has a context of execution that is defined by all the other concepts involved in the evaluation of the reasoning that are not inputs. For example, in the function  $F = Ax + By$ , the values of the variables  $x$ , and  $y$  are the inputs, and the value of the constants  $A$  and  $B$  define the context of execution. Both input and context are provided by concepts in the conceptual space. Like the input concepts, the concepts that form the context might be distributed over the conceptual spaces of multiple individuals.

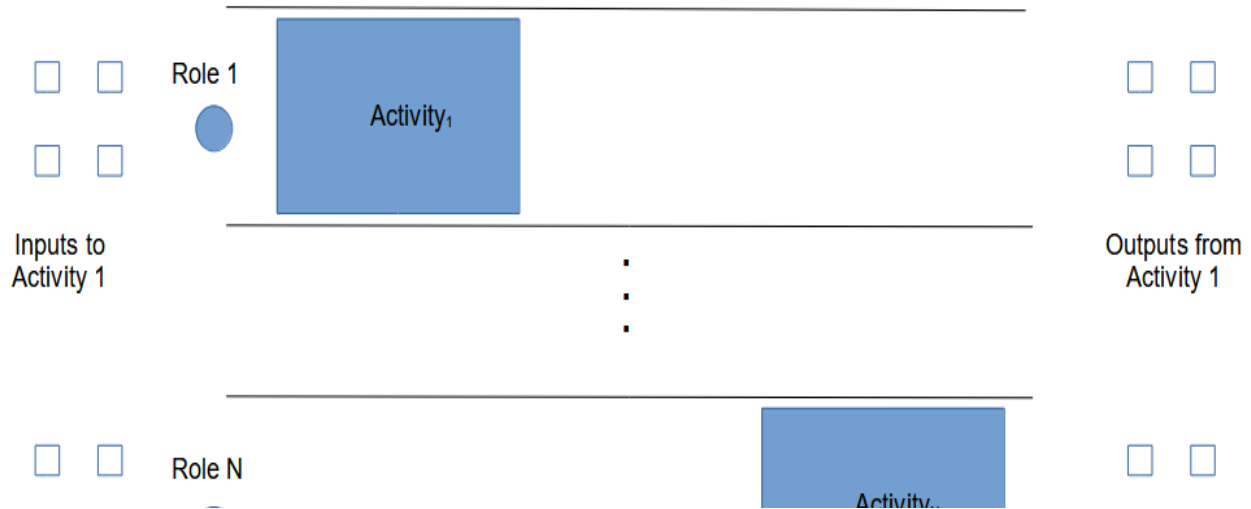


Reasoning Process  $R_{12}$  Incorporates  
Context from Different Individuals

*Fig 5. The context of execution of collective reasoning process  $R_{12}$  that consumes input concept  $C_1$  and that outputs concept  $C_2$  might be spread over different individuals in the group as well.*

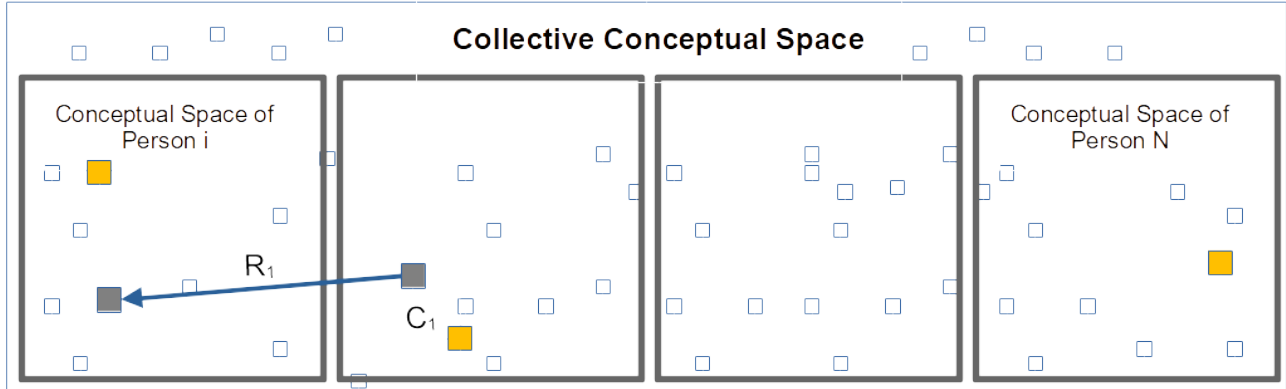
However, in a collective reasoning process, each step in that reasoning might be executed by a different individual or by a different subset of the group. Representing the collective reasoning process using a swim lane diagram, each step in the reasoning process is executed by a given role.

# Collective Processes

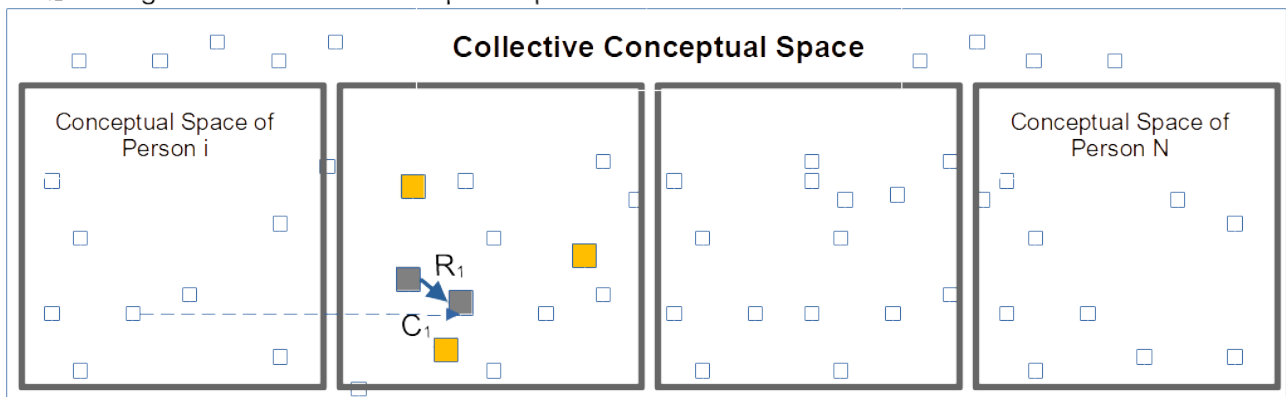


*Fig 6. A collective reasoning process with different roles and activities that are spread over different individuals in the group.*

In order for any given individual or subset of the group to have the capacity to execute any given section of any given reasoning process where they are most fit to do so, that individual or subset of the group must have the capacity to retrieve required input and context from others in the group. When these inputs and contexts are mapped to the conceptual space of the individual executing a step in that collective reasoning they result in an actual reasoning path through the individual's conceptual space that might be represented by an effective reasoning path through the collective conceptual space.



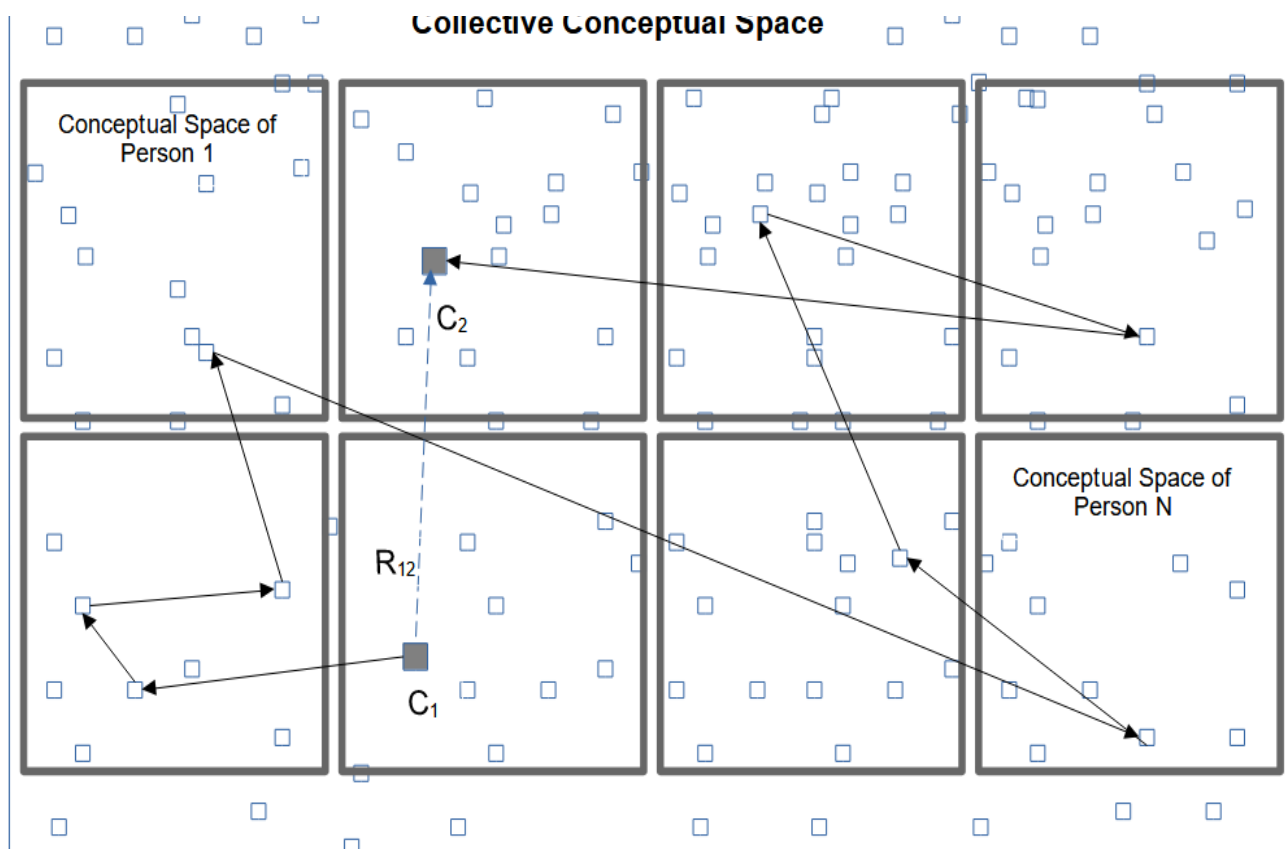
Above: the effective path of the first reasoning step  $R_1$  within the larger reasoning process  $R_{12}$  through the collective conceptual space.



Above: Replicate input concepts and context from the conceptual spaces of other individuals "i" in order to execute reasoning step  $R_1$  within the larger reasoning process  $R_{12}$ .

*Fig 7. A collective reasoning process that effectively navigates from a concept in the conceptual space of one individual to another concept in the conceptual space of a second individual can be mapped to a step in the conceptual space of either individual.*

This effective collective reasoning path through the collective conceptual space might navigate a far larger volume of the collective conceptual space than is possible for any individual to navigate within their own conceptual space.



*Fig 8. The collective reasoning process effectively navigated from a concept in the conceptual space of one individual to another concept in the conceptual space of a second individual.*

Any functional model of cognition must be dynamically stable in that it has repeatable functions. The size of this collective conceptual space and the requirement that the cognitive system have dynamical stability within that conceptual space has implications. If a bird could be blown off course by 100 miles at any time in any direction, but only had the capacity to reliably navigate a range of 1 square miles, then that bird could never reliably repeat its presence at any given location where it might have found food, where it might have nested, or found other resources important to its survival. That existence would not be dynamically stable in the sense that the functional state space of the organism would not consist of a set of repeatable states that could be navigated indefinitely in the sense that the organism can be seen as transforming through procreation into a similar functional state space navigated by its progeny in the next generation. In the same way, if the functions of the cognitive system are dynamically stable, then it must have the capacity to reliably navigate its entire conceptual space, and if the functions of a General Collective Intelligence platform as system of collective cognition are dynamically stable, then a GCI must have the capacity to reliably navigate this entire collective conceptual space. Assuming that the volume of conceptual space that can be navigated per unit time is representative of intelligence, this capacity to navigate what might be an exponentially greater volume of collective conceptual space suggests an exponentially greater intelligence. The question then becomes “what kind of problems is this level of intelligence required for in order for those problems to be reliably solvable?”

## 5. Method

As described, a functional model of collective cognition can potentially be used to define an exponential increase in the general problem-solving ability (general collective intelligence factor) of groups. In this paper a determination was made regarding whether and how it might be possible to quantify the impact of an exponentially higher general collective intelligence factor, and whether it might be possible to detect an exponentially higher general collective intelligence factor.

### **5.1 Quantifying the Impact of an Exponentially Higher General Collective Intelligence Factor**

To quantify the impact of an exponential increase in this general collective intelligence factor of groups, it is necessary to quantify the impact of problem solving in terms of volume of outcomes per volume of inputs. Take for example that the group wants to solve the problem of combining “M” individuals, businesses, or other entities into a network large enough to reliably have the capacity to achieve some collective impact  $I_k$  on some outcome “k”. Assume each type of chain of cooperation “i”, and each instance of that chain of cooperation “j” contributes some amount of value  $V_{ij}$  and has some cost  $C_{ij}$  with respect to that impact. The total amount of impact is given by:

$$I_k = \sum_{i=0}^N V_{ij} + C_{ij}$$

For example, a tree is a network of cooperating functional components that achieves a number of collective outcomes, one of which might be consuming a given mass of carbon per unit time. In order for consuming carbon per unit time to be reliably achievable at the massive scale of a mature tree, all those chains of cooperation and instances of those chains must be implemented from the current state of the group through self-organizing, self-sustaining processes. In this case, the network of functional components in a tree self-organizes in a self-sustaining way from the current state defined by a seed.

Measuring any targeted collective outcome in terms of some total impact  $I_k$ , the question becomes: given a sufficient general collective intelligence factor (c), how can a self-assembling network of cooperation that is self-sustaining and therefore self-funding once launched be designed, so that such a network can be deployed at a scale large enough to reliably achieve this impact? For example, how can this General Collective Intelligence platform organize the group to solve the problem of reliably maximizing employment nationally, or reliably maximizing impact on climate change globally?

The answer to this question can be deduced intuitively, but rigorous proof of this answer has not been achieved. The intuitive answer is that human cognition is dynamically stable so it must have sufficient capacity to potentially solve any problem that can be defined within the volume of the spaces it occupies, and therefore must have the potential capacity to solve the problem of collective optimization in those spaces. From the functional modeling perspective human cognition occupies two spaces, one being the conceptual space, and the other being a “fitness space” (or cognitive well-being space) that represents the fitness of the cognitive system to execute its functions. In addition to requiring a set of functions to navigate all of conceptual space, a cognitive system also requires a set of functions in order to select and execute those navigation functions. Being dynamically stable within the fitness space, the cognitive system must have the potential capacity to solve the collective optimization problem of leveraging the collection of functional components in an individual cognition to reliably and sustainably solve the problem of optimizing any outcome targeted by that individual through the potential capacity to navigate all of their conceptual space. Similarly, if collective optimization problems like poverty or climate change are reliably and sustainably solvable within the general collective intelligence of the entire planet, then to have the capacity to navigate to those solutions the

general collective intelligence must be dynamically stable within the entire available collective fitness space, and therefore must have the capacity to navigate the entire collective conceptual space.

Assume that every individual has an average IQ of one hundred, equivalent to one hundred units of volume in conceptual space that they can navigate, and assume that some ratio  $X$  of that volume on average overlaps with some ratio  $Y$  of other individuals (i.e. each individual tends to share a proportion  $X$  of ideas in common with a certain proportion of people  $Y$ ). In calculating the group IQ required to navigate the entire collective conceptual space also make the assumption that the times required to navigate both the individual and the collective conceptual spaces are the same, so that a global brain might think through this collective conceptual space at the pace required to have a discussion with a single individual, as opposed to a global brain that an individual would ask a question to, and then revisit a year later later to hear the answer. Then for a total number of people  $N$ , the total non-overlapping volume of the collective conceptual space will be  $V$  is equal to  $100 * N * (1 - X) * (1 - Y)$ . Assuming  $X$  is equal to  $Y$  is equal to 0.25, then for the entire human population of 7.5 billion,  $V$  is equal to 421 billion units of volume. Therefore, under these assumptions, the capacity to navigate the entire collective conceptual space requires a general collective intelligence factor of 421 billion units of volume.

## IN UNITS OF INTELLIGENCE

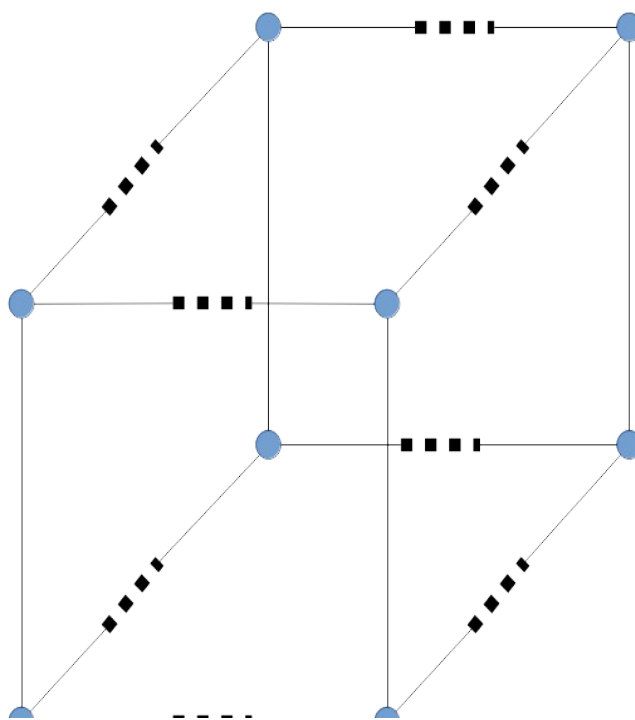


Fig 8. The volume in the collective conceptual space that can be navigated per unit time represented by  $N$  units of intelligence (i.e. an IQ of  $N$ ).

### 5.2 Detecting a General Collective Intelligence Factor of the Order of Billions

In order to have the capacity to detect such an exponential difference between the general collective intelligence factor of one group and that of another, it is necessary to increase the number of tasks in any test of that factor until any exponential difference in this factor can be resolved within the margin of uncertainty in the test.

The ability to measure a general collective intelligence factor 4.21 billion times greater than the individual average intelligence factor of 100, using questions of approximately the same level of difficulty, requires defining questions that together are able to probe a total volume of intelligence having length 7500 on each side. Divided by the average difficulty of one that is shared by each question, this results in a number of questions equal to 421 billion. After implementing a full GCI in which every human on earth might interact with the test through millions of clones of their personal intelligent agent acting on their behalf, incentivizing participation in collectively defining a test containing 421 billion questions and collectively answering such a test might be feasible. Before that point, testing a general collective intelligence factor of this magnitude might be achieved through using a procedural program to define the 421 billion questions, and then to use Monte Carlo methods to randomly sample answers to a much smaller set of questions (perhaps 7500), with the assumption that if the level of difficulty of each question is the same then the group has the capacity to solve any problem by navigating that length of complexity in any direction in conceptual space.

## **6. Findings**

The analysis suggests that it is both possible to quantify the impact of and to detect an exponentially higher general collective intelligence factor. The potential requirements to do so are discussed here.

### **6.1 Requirements to Achieve a General Collective Intelligence Factor of the Order of Billions**

Regardless of which collaborative problem-solving process is used by the group, any problem-solving based on rational methodical reasoning performed on a collective basis will involve distributing each reasoning activity across the group. The fact that required input concepts might be distributed across the entire group implies that an exponential increase in problem-solving ability requires:

#### **Requirements for an Exponentially Greater General Collective Intelligence Factor**

Ability to exchange understanding through a complete semantic model, rather than just exchanging information.

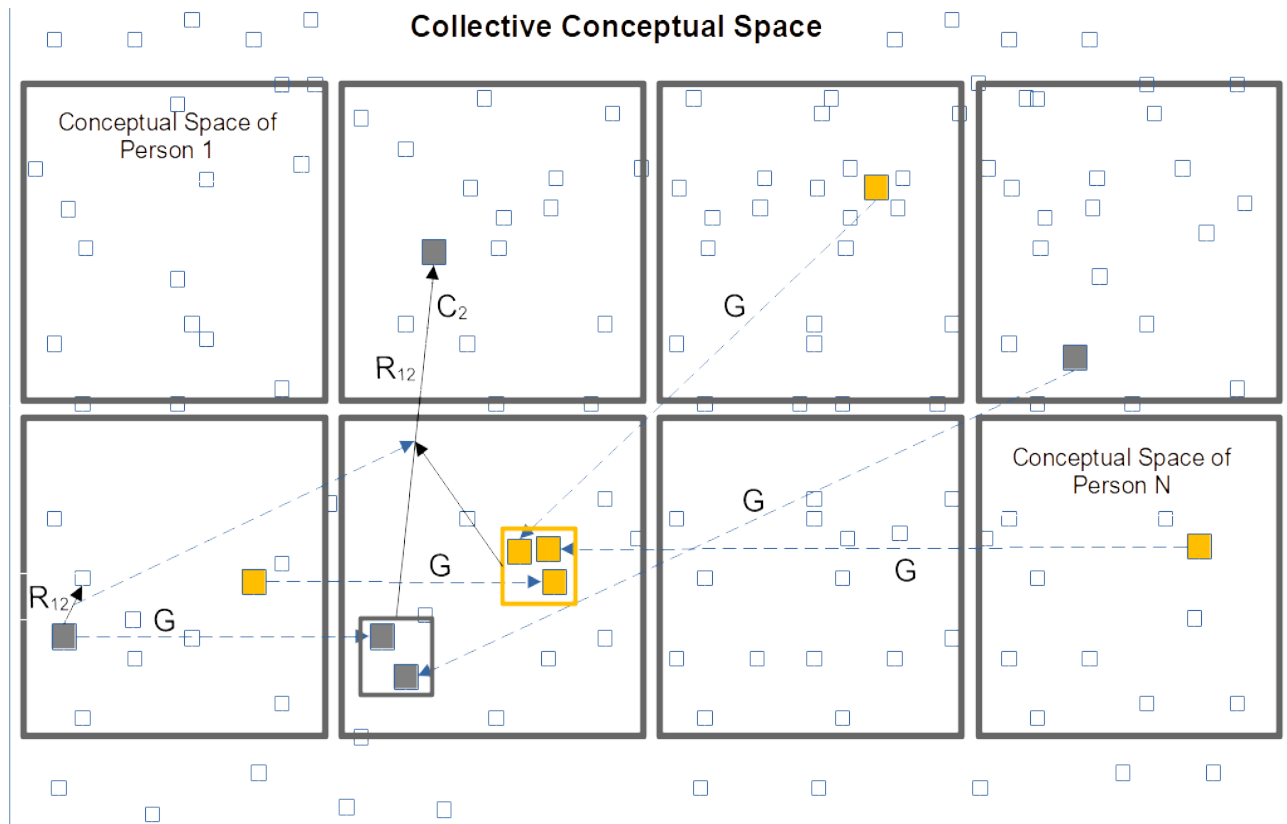
The ability to exchange generalizations and for any given individual to find problem definitions and solutions in their own conceptual space using generalizations defined by other individuals.

The ability to self-organize into as large a network as required to include the required input information and the required reasoning process.

The ability to organize to make any such network self-sustaining.

The ability for each individual to interact through any number of intelligent agents working on their sole behalf, so that the scale and rate of collective interaction can be reliably increased exponentially.

In order for a collective intelligence platform to create the capacity to solve what might potentially be an exponentially greater number of questions, and/or to do with the same or greater accuracy, assume that for a given problem a methodical reasoning process distributed across the collective conceptual space exists and is capable of determining the correct solution. Assume as well that this methodical reasoning process is represented by some function  $F$  of a set of concepts  $[X]$ , where those concepts required as inputs to the problem-solving process are randomly distributed across the entire group. Assume in addition that there exists a rational methodical reasoning process  $G$  that acts on an input set of concepts  $[X]$ , where  $G$  serves to generalize, so that a problem defined in one problem domain can be detected as a pattern and reused to define a problem in another domain where that problem definition applies, and so that a solution in any problem domain can be detected as a pattern and reused to define a solution in another domain where it applies.



Generalization process  $G$  retrieves the reasoning process  $R_{12}$  from other individuals as well as the concepts in input and context required to execute that reasoning.

*Fig 9. Generalizations can potentially be defined by one individual and used by another individual to find concepts in their own conceptual space.*

Assuming the complexity of a problem or solution can be understood intuitively as related to the distance navigated through conceptual space, and assuming the distance of any single step is limited by the cognitive capacity of individual humans in the group, this cognitive complexity will also be related to number of reasoning steps involved. Assuming that the breadth of information required to execute a specific reasoning process in order to solve a problem might be understood intuitively as the size of the region of conceptual space required as input to that reasoning and required to define the context in which that reasoning is executed, then in order to execute any collective reasoning process distributed across the different conceptual spaces of individuals in a group, the GCI must enable each individual to retrieve reasoning processes and information from any other individual. The capacity to find any reasoning or information that exists within any individual in the group requires the capacity to collectively execute a process with the capacity to do so, such as potentially the generalization process  $G(X)$ .

## 6.2 What Does a General Collective Intelligence Factor of 421 Billion Look Like?

The capacity to harness the collective intelligence of Earth's entire population to solve any problem implies that an individual could ask any question on any topic, whether about physics, or about implementing an Artificial General Intelligence and a network of cooperation would self-assemble in a self-sustaining way at any scale required (up to the entire population of the earth) to consider as many possible solutions as required to solve the problem, and as required to choose the optimal solution from all viable ones.

A General Collective Intelligence must have the capacity to use any problem-solving process defined by anyone. One potential GCI algorithm might begin with an individual asking the group a question via the platform. Each individual in the group might then assess whether they can provide information or define a reasoning process capable of doing what is needed, or an intelligent agent working on that user's behalf might then query the conceptual space representing that user to determine if such information or such a reasoning process exists, or if any existing information or reasoning process might be generalized so that they can be reused for such purposes. The reasoning processes needed in this case are:

### **Reasoning Processes Required for General Problem-Solving**

Define the reasoning process that orchestrates participation in collective reasoning

Define the reasoning process that finds incentives for individuals to participate

Define the reasoning process that finds sufficient value in cooperation to sustain the incentives

Define the reasoning process that finds solutions to the question

Define the reasoning process that compares the solutions

Define the reasoning process that selects the optimal solution

Define the reasoning process that communicates the optimal solution to the questioner

The information required is:

### **Information Required for General Problem-Solving**

Any input concepts required to execute any reasoning process.

Any concepts required to define the context needed to execute any reasoning process.

In short, in the case of a question in physics or AGI, a GCI must enable anyone with any information or reasoning that could be generalized so that it contributes to information or reasoning required to answer that question, or anyone with any idea that could be generalized so that it contributes to information or reasoning that contributes to information or reasoning required to answer that question, and so on to as many degrees of separation as needed, so the group might self-assemble into as large a self-sustaining network as required to consider all possible theories and all components of theories until a suitable solution is found.

One way to navigate an exponentially larger volume in the collective conceptual space per unit time, is to navigate reasoning processes and information from an exponentially larger number of people in the same unit of time. Another way to navigate an exponentially larger volume in the collective conceptual space per unit time during the retrieval process is to use intelligent agents working on the behalf of each user to navigate reasoning processes and information of each user exponentially more quickly. As mentioned, in order to follow any collective reasoning process it is necessary to find reasoning processes and information in the conceptual spaces of other individuals. It has been proposed that this might be facilitated both through Human-Centric Functional Modeling. That is, representing systems in terms of functional models that are universal in that they define all human-observable functions of the system being studied from the perspective of each knowledge domain (discipline) it is being studied in. In physics, collective problem-solving using GCI requires a common semantic model of the physical world in which all experimental and theoretical information and reasoning can be stored. Because truth can potentially be differentiated from untruth in this semantic space (or in any other functional state space) through using AI to detect "unphysical" patterns of motion in that space, and because AI can potentially do so at a speed and scale many times greater than any individual has the capacity for, then intelligent agents working in a GCI might enable all theories and all components of all theories to be

validated against all data collected by anyone about any physical system. In solving the problem of implementing an AGI, collective problem-solving using GCI defines a model that has been suggested to represent all the human-observable functions of cognition [3], so that it might be possible to collectively optimize capacity to leverage all work of all AI and AGI researchers to implement these functions in a methodical way [5].

## **7. Research Limitations**

Validity of the concepts discussed in this paper, such as the difficulty of a question on an IQ test being represented in terms of a distance in conceptual space, as well as the notion of the conceptual space itself, remain to be confirmed experimentally.

## **8. Implications**

This analysis raises the question: what is the maximum general collective intelligence factor achievable within a given group, and is it sufficient to solve “wicked problems” like poverty or climate change? The question of what the maximum general collective intelligence factor achievable within a given group is set aside for now, but has been considered briefly in other work [6] which has suggested that General Collective Intelligence is a pattern that might increase to the Nth order, with each increase in order creating the potential for an exponential increase in the general collective intelligence factor.

As to whether wicked problems like poverty or climate change are reliably solvable within the general collective intelligence factor of a group, since those problems have not yet proven reliably solvable, it can be assumed that they cannot reliably be solved within any general collective factor that is innate to human groups, which is the only general collective intelligence factor that might be in existence today since GCI has not yet been implemented. While any general collective intelligence factor might theoretically serve as a system of collective optimization with general problem-solving ability, it is not known how to separate this general collective problem-solving ability from individual intelligence and to separately target it at collective problems. As to whether wicked problems like poverty or climate change are reliably solvable within the general collective intelligence factor of a group organized by a General Collective Intelligence platform, the fact that the navigation of the GCI within the collective conceptual space must be dynamically stable suggests that such a GCI will have the capacity to navigate to any solution that exists within that collective conceptual space, and that it will be inclined to do so until it has solved the problems most important to the group’s collective survival.

The implications of an exponential increase in the general collective intelligence factor of a group are profound. If any given collective problem, such as perhaps “wicked problems” like poverty or climate change, are not reliably solvable within the capacity of current group problem-solving models, and if they are reliably solvable with an exponential increase in this general collective intelligence factor, then implementation of a GCI is required to achieve the ability to reliably solve such problems. If GCI is of such importance then perhaps the biggest risk is failing to communicate a simple answer in response to the question “why GCI is fundamentally new and why it is so important?” The best answer might be that while there are other models of Collective Intelligence (CI), any model of CI without general problem-solving ability, and without the capacity for self-assembly of networks as well as without the capacity for self-sustainability, where both are required to exponentially increase the general collective intelligence factor, can’t reliably address wicked problems. Furthermore, no other currently existing model of CI is a fully decentralized model of collective optimization with the potential to reliably explore all possible solutions in the collective conceptual space [7].

## **10. Conclusions**

Given the assumption made in the paper that IQ is related to the volume of conceptual space that the individual cognition can navigate per unit time, and that group IQ is related to the volume of the collective conceptual space that the collective cognition can navigate per unit time, the group IQ required to navigate the entire collective conceptual space was calculated by making the assumption that the unit of time required to navigate both the individual and the collective conceptual spaces is the same. That assumption of course can change the group IQ by orders of magnitude. But it's more useful to imagine a global brain that can think through this collective conceptual space at the pace required to have a discussion with a single individual, as opposed to a global brain an individual would ask a question to, and then come back to a week later for the answer.

By definition, a General Collective Intelligence can potentially orchestrate the execution of any collective reasoning process targeting any outcome, and can potentially orchestrate the self-assembly of self-sustaining networks of cooperation through which the probability of achievement, magnitude, and sustainability of that outcome might be exponentially increased. Because cooperation can be modeled, algorithms can be defined to solve the specific problem of searching for opportunities to cooperate to help achieve this exponential increase in ability to impact outcomes of any specific problem-solving process in general, and therefore to help achieve this exponential increase in specific problem-solving ability. However, part of general problem-solving ability is also the more general problem of searching the collective conceptual space from all available perspectives to find the optimal collective reasoning process to apply this cooperation to. An exponential increase in the general collective intelligence factor  $c$  implies exponentially increasing capacity to search the collective conceptual space from all available perspectives, thereby maximizing diversity of opinion.

Wicked problems are collective optimization problems in that in order for them to be reliably solvable, a system of collective optimization having general problem-solving ability as well as having sufficient capacity for complexity and breadth of information is required. Assuming that the optimal solution to achieving any collective outcome involves optimizing that outcome for each individual, then all information about that individual might be required to solve that optimization problem. As a result, some part of the solution to each wicked problem might reside in the conceptual space of every single individual on earth. While it might be possible to collect this information in a centralized way and to use it in a centralized optimization process targeting the same outcome, that centralization would eliminate the diversity of opinions required to explore the entire collective conceptual space. Even if such a program were run by the most powerful supercomputer in the world, it might not have the capacity to exponentially increase the general collective intelligence factor to the point that the group can reliably solve wicked problems. Because that centralized problem-solving process could not be constrained so that it's most stable dynamic was not serving those centralized interests, and therefore it could not be constrained to have dynamically stable general problem-solving ability that serves the collective, or in other words dynamically stable collective general problem-solving ability.

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