Cognitive Computing and its Relationship to Computing Methods and Advanced Computing from a Human-Centric Functional Modeling Perspective

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Recent advances in modeling, human cognition has resulted in what is suggested to be the first model of Artificial General Intelligence with the potential capacity for human-like general problem-solving ability, as well as a model for a General Collective Intelligence, which has been described as software that organizes a group into a single collective intelligence with the potential for vastly greater general problem-solving ability than any individual in the group. Both the models require functional modeling of concepts that is complete in terms of meaning being self-contained in the model and not requiring interpretation based on information outside the model. The combination of a model of cognition to define an interpretation of meaning, this functional modeling technique represents information that way together results in fully self-contained definitions of meaning that are suggested to be the first complete implementation of semantic modeling. With this semantic modeling, cognitive computing and its capacity for general problem-solving ability become far better defined. However, semantic representation of problems and of the details of solutions, as well general problem-solving ability in navigating those problems and solutions is not required in all cases. This paper attempts to explore the cases in which how the various computing methods and advanced computing paradigms are best utilized from the perspective of cognitive computing.

Keywords: Human-Centric Functional Modeling, Artificial General Intelligence, General Collective Intelligence, Computing Power, Computing Flexibility

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1 Introduction

Cognitive computing is a fairly new field [1], [2], [3]. This paper explores the implications of cognitive computing approaches (Artificial General Intelligence and General Collective Intelligence) on the development and execution of computing methods, where these cognitive computing approaches have been defined from a human-centric and functional point of view using a technique called "Human-Centric Functional Modeling". With Human-Centric Functional Modeling first person observations of systems can be represented as forming mathematical spaces that can in turn be used to increase capacity to understand these complex internal systems, or to understand complex external systems such as computing technology, allowing complex properties of those systems to be computed where not possible before. In the case of approximating cognition as an internal human system that might be replicated in an artificial system, Human-Centric Functional Modeling represents any cognitive system as using reasoning or understanding processes to move through a space of concepts (a "conceptual space"). This applies to both an individual artificial cognition and to a platform that might organize groups of humans to act as an artificial collective cognition. This conceptual space then reflects all possible behaviors of the individual or collective cognition (all the functions that can be executed within the capacity of individual or collective cognition).

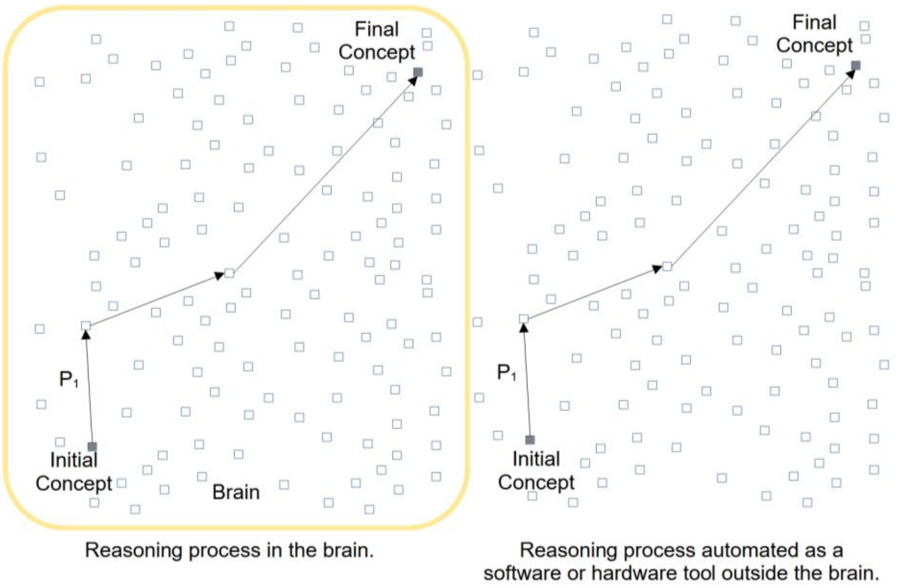

Figure 1 In the conceptual space defined by Human-Centric Functional Modeling a reasoning process in the brain is represented by a path from one concept to another (left). All software or hardware processes are an automation of some reasoning process but are still represented by the same path representing that process (right)

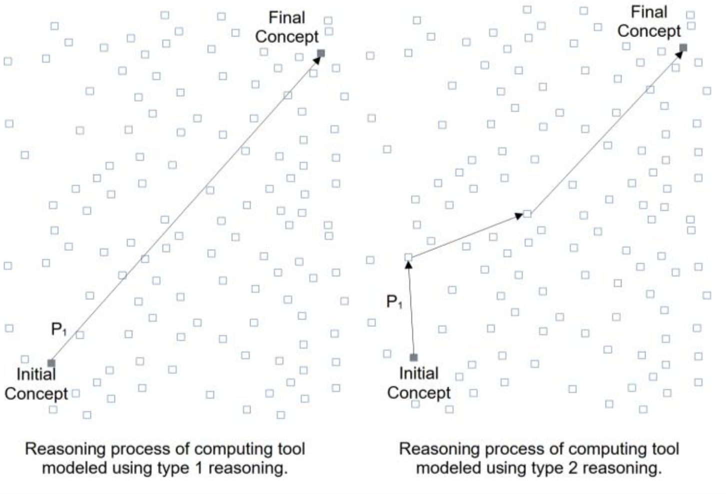

Figure 2 The processes automated by external computing tools (hardware or software) can be understood within the brain by single step intuitive or type 1 reasoning (left) as well as by multi-step rational methodical or type 2 reasoning (right).

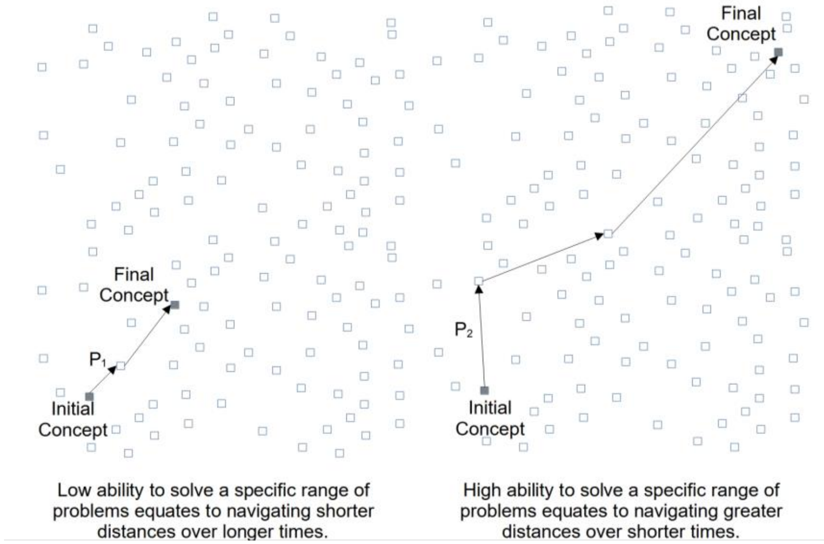

Figure 3 The complexity of reasoning in conceptual space is the product of the linear density of concepts and the distance in conceptual space. The composite parts of simple reasoning processes executed within the brain (left) can be replaced with more complex ones (right) in order to significantly increase outcomes of problem-solving.

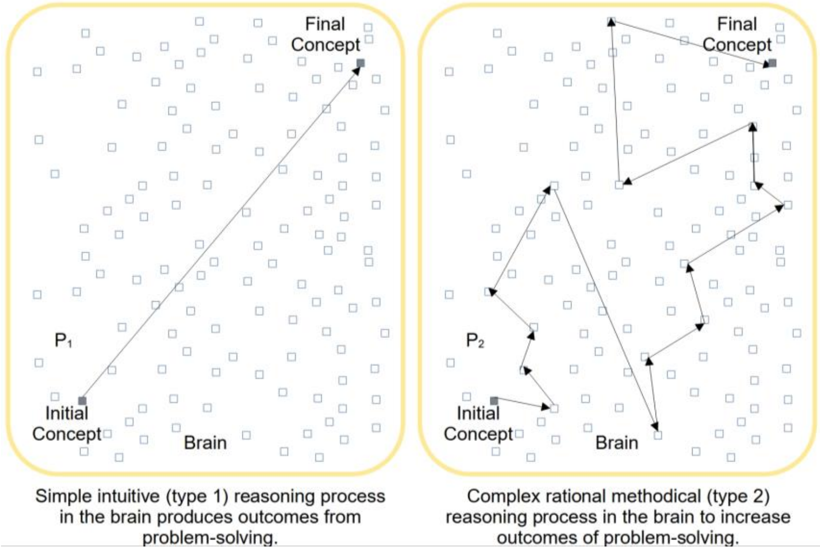

Figure 4 Narrow problem-solving ability is the length of reasoning path that can be navigated per unit time. Just like some runner specialize in sprinting and some specialize in distances, this problem-solving ability might differ for short problems (left) and for lengthy ones (right).

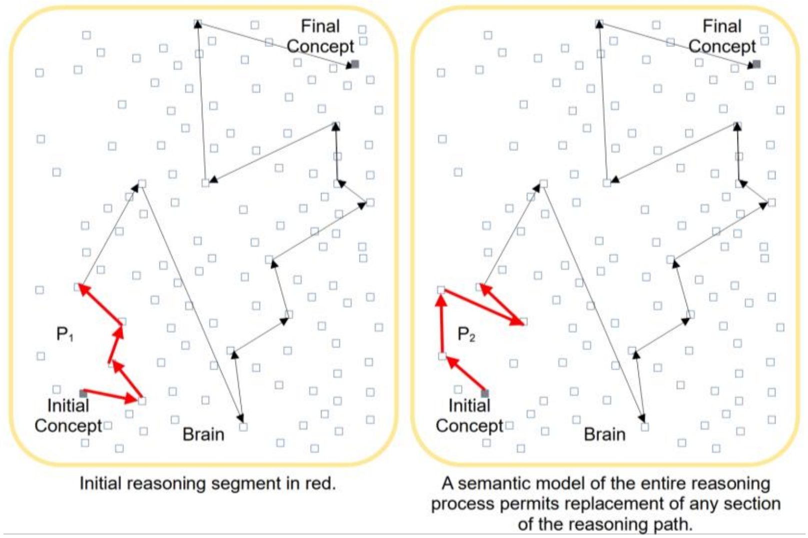

Figure 5 Semantic integration means that within the cognitive computing system there is a complete semantic representation of the computing process so that the cognitive awareness process of that system can change any part. This allows the complexity of processes executed and the magnitude of user outcomes achieved to potentially be increased radically. However, processing power is limited to that of the cognitive awareness process. Because computing operations performed in external tools don't have to incorporate all the processing needed for cognition, such processes can be much more powerful in terms of speed and distance through conceptual space.

Though functionalism [4] has been well studied, and though the implications of functionalism on computability have also been explored [5], to the author's knowledge, no work other than that of the author has synthesized these concepts to define a model for cognitive computation from this Human-Centric Functional Modeling point of view. Because this approach and its application are so new, there is no other work available to cite. So by necessity the examples discussed in this paper refer overwhelmingly to the author's own work. Since case studies suggest that cognitive computing applications or platforms platform containing a subset of functionality required to implement these AGI and GCI models might radically increase both individual and collective outcomes from the use of software [9], such as facilitating the development of software and hardware radically more quickly while enabling that development to be vastly scaled so it benefits a much greater number of projects. As explored in a proposed large scale collective intelligence-based program to accelerate achievement of the sustainable development goals, this might significantly accelerate the development of platforms in healthcare, education, and a wide variety of other areas, while also dramatically lowering costs. In such applications and platforms, the flexibility of cognitive computing to redefine the problem being solved or to simply choose another computing solution to solve it, has the potential to significantly increase are social impact or economic impact like job creation in such an intervention, in some cases an increase in impact of 750X per program dollar has been projected with the applications and platforms currently being designed for that program [9]. This potential to radically increase impact gives cause for exploring this approach. Through defining functional models of computing infrastructure, AGI and GCI are intended to enable those models to achieve such increases in outcomes.

General Collective Intelligence or GCI has been described as software that organizes a group into a single collective intelligence with the potential for vastly greater general problem-solving ability than any individual in the group. A recently defined model of GCI incorporates some subset of functionality from recently defined model of AGI [8] as intelligent agents to interact on behalf of users, to enable users to interact and achieve outcomes at potentially exponentially greater speed and scale [6], [7].

Since complexity has a well-defined meaning in conceptual space as the product of the distance in conceptual space occupied by the solution, multiplied by the linear density of concepts [14], GCI is predicted to give groups the capacity to reliably define and solve problems that are "higher order" in that the problems are too complex to be defined and solutions too complex to be discovered by any individual human cognition, or by any human group without GCI [9]. Both this model for GCI and this model for AGI require functional modeling of concepts that is complete in terms of meaning being self-contained in the model and not requiring interpretation based on information outside the model. The combination of a model of cognition to define an interpretation of meaning, and this Human-Centric Functional Modeling technique to represent information according to that definition, then together result in fully self-contained definitions of meaning that are suggested to be the first complete implementation of semantic modeling [10].

2 Why Consider AGI and GCI as a Basis for Navigating Computing Methods?

In Human-Centric Functional Modeling a "system" is defined as an entity with behavior that is confined to a mathematical space defined by a single category of domain object describing all states in that space (e.g., all the functional states in the conceptual space are categories of "concept"). In conceptual space or any other functional state space, a problem is defined as a gap (lack of a path) from one point in conceptual space (one concept) to another. A solution is the reasoning which provides that path. The importance of a solution is hypothesized to be the increase in the volume of the space that can be navigated as a result of that solution. This importance increases over time. Since AGI and GCI represent the opportunity to achieve an exponential increase in general problem-solving ability and therefore an exponential increase in the volume of conceptual space that can be navigated, and since it is hypothesized that this exponential increase has never been possible before and will not be possible again until the transition to a second order AGI or GCI, the transition to cognitive computing represents one of unique historical significance.

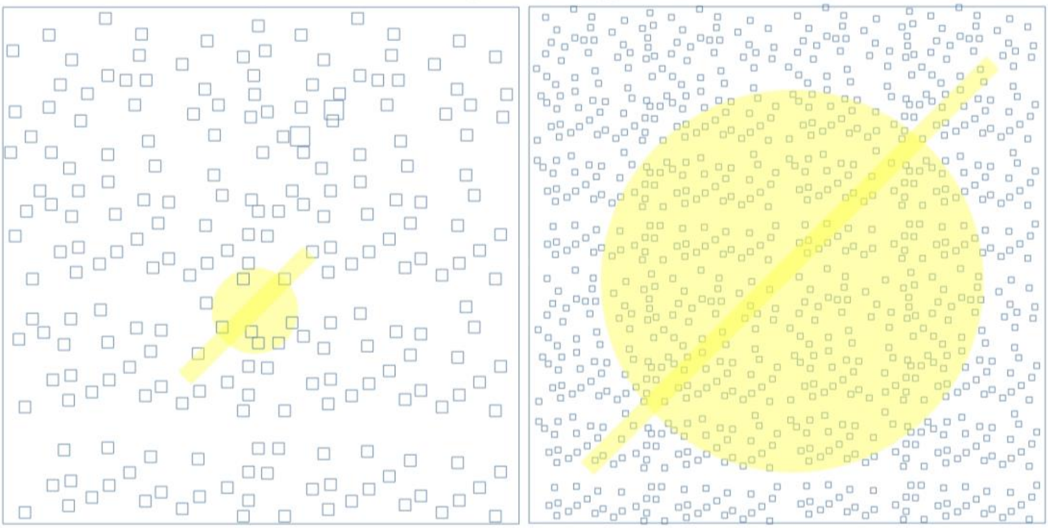

Figure 6 Importance of cognitive computing vs computing tools.

Since potentially suitable models of AGI and GCI have just recently been defined, but have yet only been partially implemented, the question arises why an AGI and GCI based framework for navigating computing methods should be considered at this early stage, and how the high-level properties of such a framework can be objectively validated and therefore why they add concrete value rather than being mere speculation. As for why one should consider such a framework, the simple answer is that doing so creates the potential to exponentially increase outcomes targeted by any computing methods, where doing so can be demonstrated to be outside the capacity of any human intellect to reliably achieve otherwise. The reason is that human cognition faces limits to the complexity it has the capacity to navigate. Similarly, in the computing domain, where computing methods utilized by any individual human without AGI, or by any group without GCI can only define the problems that can fit inside human cognition, and can only solve those problems with the solutions that are discoverable within human cognition, the combination of AGI and GCI can be demonstrated to have the capacity to reliably generate an exponential increase in general problem-solving ability [10]. Measured in impact on any outcome, such as the outcomes targeted through the design of computing methods, this can be expected to drive an exponential increase in impact on those user outcomes.

AGI creates the potential to explore the fitness of every combination of different technologies in implementing every computing operation, and AGI creates the potential to explore interactions between computing operations that are much higher order (much more complex) than currently possible, and to do so at vastly greater speed and scale, in order to achieve vastly greater impact on any targeted outcomes of computation. GCI creates the potential to collectively store information about which combination of different technologies is most fit in implementing every computing operation, so that the computing operations executed by any one individual benefit from intelligence gained from the execution of any computing operation by any other individual. GCI also creates the potential to enable higher order interactions between computation operations that orchestrate group processes, and to do so at vastly greater speed and scale, in order to achieve vastly greater impact on targeted collective outcomes of computation for all users. As for how the high-level model of such models of AGI or GCI can be validated as being correct, that question is left for future exploration.

3 Conceptual Example of the Use of Cognitive Computing to Navigate Computing Methods

From the functional modeling perspective, cognitive systems consist of a well-defined set of functionalities, including functional modeling. The model of cognitive computing discussed in this paper utilizes this set with the goal of achieving human-like computing (adaptive problem-solving in the space of concepts). One adaptive problem-solving process suggested to require human-like general problem-solving ability is generalizing problems in a way that makes it possible to see other better understood problems as equivalent in a general sense to a poorly understood one, so those better problem definitions can be reused to reframe the problem in a more optimal say. Generalizing solutions in turn makes it possible to see solutions in a more abstract way that makes it possible to reuse the best solutions in solving many other problems that currently have poor solutions.

As a specific example, where the term "cognitive radio" describes a system that automatically adapts to use the best available band for communication, cognitive computing might address any problem of communication whatsoever. In a GCI orchestrated communication process, intelligent agents based on some subset of AGI might work behalf of each user to negotiate the best available physical connection, electromagnetic spectrum, protocol at each protocol layer, network topology, and every other function of Internetworking and telecommunication for each user, in order to optimize collective outcomes for all users. And GCI might orchestrate that cooperation to adaptively learn which implementation of each function is most fit in each context from all possible occurrences of Internet and telecommunication use by each user in order to do so. The usefulness of doing so would be expected to be significantly increased collective outcomes that benefit every member of the group, including sustainability across the entire telecommunication product life-cycle, an increase in affordable access to communication, and an increase in quality of communication at each level of affordability. One reason is that network changes or upgrades resulting in inoperable devices that have to be discarded would be expected to disappear where such waste does not serve the public good, since a GCI must optimize fitness to achieve collective outcomes for all users.

Where operating systems have gained tremendous flexibility through essentially defining functional models of hardware through a Hardware Abstraction Layer (HAL), AGI based operating systems might increase that flexibility tremendously further still by defining functional models that abstract all functions of the operating system itself until the functional model represents all operating systems. Using GCI to orchestrate cooperation to adaptively learn from all possible uses by all individuals of any implementation of any operating system function could enable an AGI to determine which implementation of a function is most fit in each context, whether that context be execution on a cell phone compatible with the Android OS, or a server compatible with some flavor of Unix. When all instances of all operating systems then fall within a single functional model, an intelligent agent might choose the best implementation on the fly. In other words, operating systems might construct themselves for any device in a way that enables any semantically defined software application to construct itself to run on it. And in addition to the design process, those intelligent agents might execute maintenance, and all other processes across the entire product life-cycle to self-assemble into structures with a level of complexity not achievable otherwise, and do so at speeds and scales that provide unbeatable competitive advantage for the group.

Through using that functional model to decompose every operating system into a set of functional components separated with well-defined interfaces, those components might be added to a library that the GCI with its increased general problem-solving ability might use to systematically enumerate the combinations of implementations and the different contexts (devices) those combinations might be deployed in to find opportunities to create such improved processes. In this way it might be possible to explore implementations with all available computing methods so optimization of collective user outcomes is possible.

Of course, adaptive problem-solving on the individual or group level is not always required. How might one systematically identify all the opportunities to do so where it is useful? And how might all available computing methods be best employed? As described above, cognitive computing can be performed at the individual level with an intelligent agent consisting of some subset of AGI functionality, or at the group level with a platform consisting of some subset of GCI functionality. A group process might potentially be executed by a GCI, whether as an internal process of the GCI, or as an external tool. In both cases the process is used to target the optimization of collective outcomes for all users. An individual process might potentially be executed by an AGI, also as either an internal process, or as an external tool. In both cases the process is used to target the optimization of outcomes for its individual owner.

According to this model, general problem-solving ability requires AGI or GCI. Some problems requiring general problem-solving ability that can only be addressed by the cognitive computing of an AGI through the execution of external processes are problems requiring the flexible use of all such external processes, and involving the use of datasets with centralized ownership in ways that don't align with the collective interests of the group, where that data is not internal but is accessible to the AGI (e.g problems involving mass surveillance of other users). Some types of problems that can be addressed only through group processing are problems requiring the flexible use of all such external processes where access to data is decentralized to each individual and solutions must be aligned with the collective interests of users (problems involving collaborative sensing for purposes of collectively optimizing any outcome).

Generalization as a process of adaptive problem-solving is just one process requiring human-like general problem-solving ability. How are the various computing methods relevant to execution of this and all other processes requiring such general problem-solving ability? Firstly, assume that an AGI or GCI exists. That AGI or GCI might execute an external software program that automates some processing operations. Or that AGI or GCI might gain an understanding of those processing operations and execute those operations internally. What types of problems can be addressed through processing internally within the AGI or GCI as opposed to externally? What is the benefit of processing internally within the AGI or GCI as opposed to externally?

Table 1. Benefits of executing computing within or outside a system of cognitive computation.

Location of Process	Positive and Negative Characteristics of Location
Internal to AGI/GCI	**Pros:** Process is "understood". Complete semantic level integration with other cognitive processes enables creativity, generalization, and other characteristics of human-level general problem-solving ability to be applied to a process that is understood. **Cons:** Processing can only occur at the speed of the cognitive system. In the functional model of cognition referred to in this paper this speed might be constrained. For example, resolution of concepts and complexity of reasoning are limited by the resolution and complexity of the cognitive system.
External to AGI/GCI	**Pros:** Processing speed (operations per second) can potentially be increased to a far greater extent, and processing scale (total number of operations) can potentially be increased to the scale at which materials are available to build the required hardware. **Cons:** The process being executed is not necessarily understood by the cognitive system executing it.

Adaptive problem-solving through generalization is one of the types of problems requiring human-like cognitive attributes that is only definable or solvable through executing computation within an AGI or GCI. AGI or GCI are also expected to include other problems and solutions. Types of problems that are definable or solvable through executing computation outside an AGI or GCI include problems or solutions requiring computation greater than any limits of this individual or collective cognition.

Table 2. Relevance of computing methods for individual or group cognitive computing.

Model	Requirements on Computational Processes to be Executable Externally or Internally	Relevance to Computing Methods
AGI	**Externally:** Semantic modeling of process interface only.	For external processing outside of an AGI, computing methods can be used to determine and compare the relative fitness of any implementation of any given computing process.
AGI	**Internally:** Semantic modeling of entire process and complete semantic level integration with cognitive system.	For internal processing within an AGI, computing methods must be invisible to the AGI if they exceed the concept resolution and reasoning complexity boundaries of the cognitive system. As an example, if assessing the relative fitness of big data computing methods versus traditional relational database methods in a given reasoning processes is too complex to occur within that reasoning process while still allowing the AGI as a cognitive system to function, then the choice between big data methods or traditional relational data-based

		method must be made outside that cognitive process.
GCI	**Externally:** Semantic modeling of process interface only.	Unknown (subject of future investigation).
GCI	**Internally:** Semantic modeling of entire process, and functional modeling (an additional layer of abstraction required for groups to more easily exchange information). Complete semantic level integration with cognitive system.	Unknown (subject of future investigation).

4 Background on the Cognitive Model

In understanding how AGI and GCI must interact with all computing hardware or software, it is useful to understand the underlying model of cognition. As mentioned, in the model of individual and group human cognition discussed in this paper, the cognitive system moves through a space of concepts, or a "conceptual space". The path between two concepts is a "reasoning process" if directed, and an "understanding process" if passive. These spaces are hypothesized to be spanned by a set of four functions, that is, a set of four functions with the capacity to compose any cognitive (reasoning or understanding) process. Functional models of these paths or cognitive processes are represented as having input concepts, output concepts, and additional concepts defining the context of execution. Since a problem in this functional modeling approach is the lack of such a path, functional models of problems have a similar representation. This model of cognition is part of a larger functional model of the human system that defines other parts such as the “body” to represent physical components, which is relevant in using this human-centric approach to increase our capacity to model physical computing hardware.

Detection of where the cognitive system is in this conceptual space, and selection of the next cognitive process to execute, is performed by a “cognitive awareness” process. From this functional perspective the computing operations that occur inside a system of cognition-based computing, whether AGI or GCI, are any operations executed within the conceptual state space of the cognitive system. For computing operations to be executed within the conceptual state space of the system they must be executable by the system (i.e., by the cognitive awareness process), and those operations must provide the cognitive system with access to semantic models of all inputs, outputs, and context so that their execution can potentially be integrated with the execution of any other process within that system of cognition. This integration is described here as “semantic level integration” for convenience.

By contrast, external computing operations (such as computing the result of an arithmetic equation in an external calculation program executed by the AGI) are executed not by the cognitive awareness process, but by a reasoning process executed by the cognitive awareness process (reasoning through the process of interacting with the computer doing the calculation). Such external computing operations as a whole might be modeled semantically, and execution of those operations might be initiated by the system of cognition, but where the system of cognition lacks access to interact with a semantic model of the intermediate processing steps, that processing cannot be integrated with other processing in that system of cognition. Because integration of that computational tool with human-like processes such as creativity is impossible, processes like creativity are not possible in directly adapting the tool itself, except through the interfaces the tool provides for that adaptation. In other words, an AGI might creatively use any combination of external tools, but the processes implemented in those tools must be internalized within the AGI in order for the AGI to adapt each one creatively.

5 Understanding the Interaction of a Cognitive Computing System with Hardware and Software by Analogy

Hardware and software then consist both of external computing hardware or software that can be considered to be tools of the cognitive computing system, as well as computing hardware and software that can be considered to be part of the cognitive computing system. All connected hardware that is semantically integrated becomes part of the individual "body" for an AGI and part of the collective "body" for a GCI. Similarly, all processing that is integrated at the semantic level becomes reasoning processes that can be executed within the AGI, or collective reasoning processes that can be executed within the collective cognition. All processing that is not semantically integrated becomes a tool that can be executed.

The analogy with the human organism has limits. In a body there are specific structures with a specific function. In a system of cognitive computing, functional components are abstractions, with a potentially great implementation. In the case of network connectivity, a GCI might select whatever implementation of a given function that is most fit at achieving the targeted outcome in a given context. Where an individual human requires their spinal column to be functioning in order to live, a GCI might not need any particular instance of any type of hardware infrastructure at all for connectivity, but instead might simply need some hardware infrastructure to provide that function. The capacity to manipulate tools at this higher level of abstraction places specific requirements on user interfaces and other computing functionality.

As an example of abstraction, a GCI based communication process might involve simultaneous interaction with all devices in the GCI to define the optimal local network topology in each residential neighborhood, then the optimal network topology in each section of the city, and so forth until the optimal global network is defined. These multiple hierarchical layers of interaction might result in networks self-assembling into an interaction of higher order complexity than an individual without GCI could design. As another example, designing computing hardware in terms of such functional models permits design processes in which the GCI varies the functionality in each functional component, as well as varying the interfaces to that functionality, so that the collective can explore all possible design configurations and reliably adapt to utilize the best design components created by any individuals in the group. This is intended to replicate the capacity of nature's evolutionary design process to navigate a vast potential design configuration space, creating the potential to self-assemble structures with levels of complexity not possible today. Current hardware and software designs can only solve problems their designers can understand, and can only do so with solutions their designers are able to discover. Of course, using such a process would be expected to require vastly greater general problem-solving ability to navigate the resulting complexity. If GCI does indeed have the potential to drive an exponential increase in general problem-solving ability, applying that ability to such a process to design computational methods that have never before in human history been possible, as well as applying that ability to collective problems in general, has been suggested to potentially represent the most important impact in human history, and the most important impact in the immediate future of human civilization until the transition to a second order GCI creates the potential for another exponential increase [10].

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6 Application in Navigating Computing Methods and Advanced Computing

If executing semantically integrated reasoning processes within an AGI or a GCI can exponentially increase individual or collective user outcomes, and if automating reasoning processes in computing hardware or software tools and executing those tools outside the AGI or GCI can exponentially increase processing power, then where should each be used in a cognitive application for individual use or in a cognitive platform for group use? Consider a cognitive simulation application that is intended to model the external environment. In some cases, outcomes can be maximized by defining a library of simulation tools, perhaps one for each element of the environment, and allowing an intelligent agent to choose between those tools. In simulating whether the atmosphere in the room is comfortable the simulation might include a simulation of wind and light through the window that includes average values per season, it might include a simulation of air flow from fans or other cooling devices, as well as air flow within the house through its doorways. Here the best outcome of the simulation might be achieved through the flexibility of semantic integration that results in being able to incorporate any new simulation element available in order to maximize the fitness of the simulation, which is the outcome targeted by the user. On the other hand, modeling the entire earth's atmosphere in climate simulations can require massive computational resources. In simulating the impact of climate change on the temperature in the house over the next hundred years, the flexibility gained from executing that simulation within a cognitive app might be far less important than the speed and power gains from executing that simulation externally in far more powerful computing platform.

Ongoing work is currently exploring how HCFM might be used to represent physical systems as well as to represent virtual systems such as the future Internet [11], the Internet of Things [12], or even enabling interoperability between all blockchain platforms [13] so that cognitive computing can be applied. In this way, in cognitive computing, such as AGI and GCI based computing paradigm, terms like: pervasive computing, green computing, grid computing, soft computing, cloud computing, cyber security, and the other computing and advanced computing methods might be used to classify implementations according to their fitness in different contexts within each domain. All these computing methods might be semantically integrated, and therefore occur within the boundaries of an AGI or GCI. But given that the semantic modeling involved might require human-like general problem-solving ability, which without AGI must be done manually, it may be some time before semantic integration of all computing methods can be achieved. However, even the subset of AGI or GCI that might be available today has the potential to significantly increase collective capacity to navigate these computing methods and their implementations. In the meantime, while waiting for complete semantic modeling, for all non-semantically integrated computing processes it might be worthwhile to begin the far simpler task of defining semantic models for their external interfaces alone, so that in each different context cognitive computing might make optimal use of all such computing processes, and all the computing methods such computing processes contain, in all their great many different implementations.

7 Directions Forward

In order to define the complete AGI and GCI based computing paradigm, much work is still required to define functional models of both hardware computing processes, as well as software computing processes that might occur in either applications or operating systems. However, in some domains, such as the User Interface Domain, or the Information Processing Domain (business logic), functional models, as well as reference implementations of each functional component in those functional models, have already been proposed. With this work, practical examples implementing a subset of this functionality are currently being developed such as a “Social Impact Marketplace” platform [15] containing a subset of AGI and GCI based computing currently being designed for a proposed large scale collective intelligence-based program to accelerate achievement of the sustainable development goals. Many research questions remain. For one, the implications of defining what is within or outside of a cognitive computing-based system in terms of semantic integration must be explored. For example, hardware or software might be semantically integrated with multiple cognitive computing system instances, switching between them when required, and therefore might be "within" several instances of such cognitive systems.

8 Conclusions

All computing methods represent cognitive processes. If these processes are individual and outside the boundaries of an AGI they represent the automation of individual reasoning or understanding processes. And if these processes are collective and outside the boundaries of a GCI, they represent automation of collective reasoning or understanding processes implemented by external computing methods. For both AGI and GCI, semantically integrated processes executed internally are advantageous where user outcomes can be most impacted through increased flexibility or increased capacity to navigate any general complexity. For both AGI and GCI, non-semantically integrated processes executed externally are advantageous where user outcomes can be most impacted by through increased processing speed and power.

Cognitive computing is a brave new world in which semantic modeling of hardware and software has the potential to introduce the possibility of another level of abstraction for developers. With this abstraction, computing methods might be elaborated and potential applications for those methods might be found at exponentially greater speed and scale. And developers of computing methods might gain the capacity to cooperate across an unlimited number of such methods to achieve levels of integration, and complexity of functionality that is not possible today. Where processes aim to increase impact on problems through being executed as tools by the adaptive problem-solving of cognitive computing, by generalizing models of these processes to be more common, and by classifying them according to computing methods, it may be possible to not only find other opportunities to increase impact this way, but to systematically find them.

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