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Human-Centric Functional Modeling and the Metaverse

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***Abstract*— Human-Centric Functional Modeling represents systems in terms of functional state spaces defined through analogy with the functional state space hypothesized to be occupied by human cognition. These functional state spaces are hypothesized to define a complete representation of the human meaning of the system being modeled, and therefore are hypothesized to define the first complete semantic model of any given system, or of information itself. One potential use of functional state spaces is to represent the physical world or any virtual world. This paper explores the barriers to and implications of using Human-Centric Functional Modeling to define a functional state space as a semantic model of any real or imaginary world, and explores how those barriers and implications impact upcoming applications such as the metaverse proposed by the company formerly known as Facebook, as well as others.**

Keywords*— *Human-Centric Functional Modeling, functional state space, General Collective Intelligence, metaverse.

I. Introduction

In the study of logic, a discipline within philosophy, there is an established tradition of using semantic models for representing information such as scientific theories [1]. The philosopher Bas C. van Fraassen has been attributed credit [2] for the concept of the "state space" as a semantic modelling approach, and a number of researchers citing his work have taken the concept of "state spaces" and applied them to all of science in general, including to physics and to modeling the physical world [3]. A state space is the set of all possible configurations of a system [5] and state spaces are useful abstractions for reasoning about the behavior of a given system that are now widely used. The difference between this paper and those previous works appears to be that this paper has made the additional refinement of using the human system, particularly the cognitive system, as a basis for this state space modeling approach, so that these models could be understood intuitively by first person introspective observation (by looking "inwards" to understand the human system, and by understanding the external world in comparison to this system), which removes the need to understand any logical frameworks at all. Hence the name "Human-Centric Functional Modeling" or HCFM.

Human-Centric Functional Modeling or HCFM [4], [8] describes systems as having a set of potentially human-observable functions fi through which the system might transition from one state "a" to another state "b", or in other words fi(a) = b [6]. Each state is then defined in terms of which functions are available to transition to other states. These states described in terms of functions are referred to as "functional states", each of which might be composed of other functional states. All of the functions of a system within a given domain of behavior map between functional states belonging to the same category, or in other words, for all "a" and "b" in the functional state space, both a and b belong to the same category. Any given category of functional states then forms a "space" of functional states or a functional state space.

As an example, in the cognitive system each concept is a functional state. Concepts as functional states might consist of larger concepts and therefore larger functional states. Reasoning processes function to transition the cognitive system from one concept (one functional state) to another. The cognitive system can then be represented as navigating a space of concepts connected by reasoning processes which act as functions that enable the cognitive system to transition from one concept to another. This representation of cognition as moving through a "conceptual space" has been used to define a model of artificial cognition (Artificial General Intelligence or AGI [7]).

In the theory of dynamical systems, the state space of a discrete system defined by a function f can be modeled as a directed graph where each possible state of the dynamical system is represented by a vertex with a directed edge from a to b if and only if f(a) = b [6]. In network terminology the functional state space of cognition is represented by a directed graph containing a network of nodes each representing a functional state (concept), where those functional states are connected by edges representing the reasoning processes through which the cognitive system might transition from one functional state (one concept) to another. HCFM utilizes this open network to make it possible to represent every possible concept and every possible reasoning process connecting each concept. If the graph of the functional state space of the cognitive system (the conceptual space) represents the complete human meaning of each concept and each reasoning process, it is therefore a complete semantic model.

II. Modeling the Physical World or Virtual Representations

The physical world or even the entire physical universe can also potentially be represented as a functional state space [9], as can other systems such as blockchain platforms or other computer software [10], as well as biological organisms [11]. In Human-Centric Functional Modeling the universe is represented in part as a "distributed cognition" that computes the evolution of matter according to the forces represented in one functional state space. Since forces are not transmitted instantaneously, the universe is also represented in part as a "distributed consciousness" that computes the evolution of the awareness of the state of matter according to awareness processes represented in another functional state space.

Seeing the universe as a distributed cognition and a distributed consciousness doesn't change the laws of physics or result in new physics. But this perspective allows it to be seen that consciousness and cognition are fractal patterns that repeat [17] in that metaphorically the universe can be seen as a zeroth order cognition and consciousness, individual humans can be seen as instances of first order cognition and consciousness, a General Collective Intelligence can be seen as a second order cognition and consciousness, right up to an Nth order cognition and consciousness.

In HCFM, the well-being of a system is represented by its fitness to execute all of its functions, and is described in terms of a position in a generalized "fitness space". Life is a self-regulating process by which an organism tends to maintain stability. In terms of HCFM, any living system is hypothesized to move through its functional state space in a way that reliably keeps its fitness within the bounded range of not going to zero (dead) and not increasing to the point of magical abilities. The same pattern of dynamics that solves the problem of adapting to stay within a bounded region in one fitness space for one system, then potentially solves that problem for all fitness spaces for all systems. If this adaptation is intelligence, then all of these intelligences are potentially instances of the same pattern of dynamical stability in a generalized "fitness space". The importance of modeling the physical world this way is that it potentially facilitates:

- The same model that solves the problem of simulating the evolution of the universe from the perspective of Human-Centric Functional Modeling can also potentially be reused to simulate an Artificial General Intelligence, a General Collective Intelligence, or a higher order intelligence, as well as a wide variety of other biological processes, and vice versa.

- Modeling the physical world as a distributed consciousness and cognition then facilitates defining the needed infrastructure for simulating the evolution of semantically represented matter and awareness at any scale from quantum scales to cosmological scales.

- Modeling the physical world as a distributed consciousness and cognition facilitates the use of Human-Centric Functional Modeling to define a semantic representation of physical matter, and for matter in one region it facilitates the use of Human-Centric Functional Modeling to define a semantic representation of the awareness of the state of matter in another region [4], [7].

- Creating a semantic representation of the physical world means modeling the physical world as a functional state space that is a human-centric representation (a fully self-contained representation of human meaning). This semantic model of physical matter must then be capable of storing all the properties of that matter at any scale without the need for any external reference or translation table, so that any physical effects at any scale can be explored using the same "semantic simulation" infrastructure. With a semantic model any representation of the physical world in every simulation, every computer game, every Computer Aided Design (CAD) tool, every Computer Generated Image (CGI), or every other computer interaction becomes part of a single data format. This data format is a directed graph. Modeling the real or virtual world in terms of the directed graph of a functional state space creates the opportunity to decouple every component of every model since it is completely represented by the corresponding piece of that graph, enabling it to potentially be reused in every other simulation, production, game, or other interaction.

- General Collective Intelligence is predicted to exponentially increase the general problemsolving ability of groups, and therefore is predicted to exponentially increase ability to solve any problem in general, including the problem of finding opportunities for reusing components of models of real or virtual worlds. This suggests that GCI might exponentially increase opportunities to reuse such components. One way is that every simulation involves a model of the entity being simulated, and also involves simulation infrastructure to calculate the evolution of that model. Modeling the physical world or virtual world as a functional state space that defines a universal data model for such representations might then contribute both models and simulation infrastructure that might be used in all other simulations or other physics research and vice versa, thereby effectively multiplying research funding.

- Taking the approach of modeling the metaverse as a functional state space then effectively represents the physical or any virtual world as a functional state space navigated by the distributed consciousness and cognition of the universe. Spreading the use of Human-Centric Functional Modeling has deep implications for all sciences studying all systems, since an exponential increase in general ability to solve problems in understanding any system is hypothesized to be achievable through the same pattern of solution in all functional state spaces, and therefore in the functional state space of every system [18]. For example, in physics, modeling the metaverse as a functional state space and therefor representing the physical or virtual world as a functional state space is implicitly a path towards exploring how Human-Centric Functional Modeling might be used to represent simpler universes as functional state spaces that interact to create the known universe, and why this approach might methodically step through all possible options to more reliably achieve a Unified Field Theory, as well as how General Collective Intelligence might orchestrate collaboration to make this massive effort feasible.

III. HUMAN-CENTRIC FUNCTIONAL MODELING, QUANTUM COMPUTING, AND THE METAVERSE

If the metaverse is a model of the physical world or imaginary virtual worlds, then computing power determines the level of detail of that world that is manageable, as well as the speed and scale at which it might be possible to interact with that world. Quantum computing is therefore intimately related to the future of the metaverse, since the promise of quantum computing is to revolutionize high-performance computing enabling computations that were not previously considered possible. Quantum logic gates provide a minimum set of operations that quantum computation can be expressed in terms of. However, the speed at which it is possible to access stored data is a fundamental limitation that means conventional quantum computers which express computation in this way are poorly suited for certain types of problems, namely those requiring a great volume of input data as compared to the possible calculations that potentially need to be made. Interactions with a very realistic and therefore a very detailed and data intensive representation of the metaverse is one of those problems that conventional quantum computers might be poorly equipped to solve.

Human-Centric Functional Modeling on the other hand defines functional state spaces that are essentially distributed databases of information about the systems they describe. Furthermore, simulations based on Human-Centric Functional Modeling essentially distribute the problem of computing the evolution of any interaction involving such systems. In addition, Human-Centric Functional Modeling hypothesizes the complete set of functions required to represent human cognition [7]. Most importantly, in addition to the six internal (not consciously observable) functions hypothesized as being required to navigate fitness space in a way that results in general problemsolving ability (intelligence) in conceptual space, only four external (consciously observable) functions are hypothesized as being required to navigate all of conceptual space. In other words, four functions are believed to span all of conceptual space so that any concept can be reached through reasoning consisting of some composition of those four functions, and another six functions are believed to be required to execute these four functions in an intelligent way that creates the capacity to solve any general problem. If this Human-Centric Functional Modeling theory is correct, then implementing those four functions as quantum logic gates implies the ability to represent all reasoning in terms of some composition of quantum logic gates. Human-Centric Functional Modeling theory also posits that any open functional state space is spanned by some set of four operations in that any process can be represented in terms of some composition of those four operations. In the physical world these four operations presumably correspond to the four physical forces. It remains to be explored whether and how applying these basic functions to quantum computing, and applying quantum computing to a distributed graph of data might greatly increase the problems to which quantum computing might be applied to.

In systems and software engineering, functional modeling approaches are commonly used to permit massive collaboration in developing complex systems. By defining functional components with welldefined interfaces, functional modeling removes the need for experts in one discipline to understand another involved in the solution, and also permits them to work independently. Reducing all quantum computing algorithms to be expressible in terms of a set of basic functions could have the advantage of making all implementations of those functions in every quantum computer compatible, so comparing those implementations could potentially improve all quantum computers. Furthermore, this compatibility between implementations of those operations could also significantly simplify implementation of any quantum computing algorithm expressed in terms of such functions. The implication of representing the metaverse as a functional state space, and in doing so building mind share about the power of HCFM, is that doing so might have the potential to radically accelerate research in quantum computing. These implications of quantum computing on the metaverse remain to be explored.

IV. Elaborating the Missing Elements of Conceptual Space Required to Implement the Metaverse

If all open functional state spaces can be represented as directed graphs, and if the conceptual space is the only functional state space that is by definition reliably conceptualizable, then solving the problem of defining an implementation for conceptual space will solve the problem of representing an implementation for any other functional state space. There are a number of assumptions in the statement that conceptual space is a “complete” semantic representation and therefore a complete representation of human meaning. One assumption is that descriptions (meanings) are self-contained within every region of conceptual space in that there is no “Rosetta Stone” to store translations that give meaning. Meaning must be conveyed through patterns in the nodes and their connections as in Figure 1.

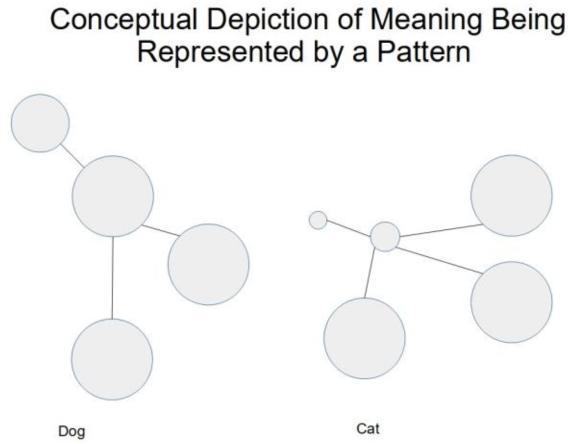

Fig 1: Conceptual depiction of meaning in conceptual space being represented by a pattern.

Although the combination of this conceptual space and cognitive system are together suggested to define a complete model of semantic meaning, the model of conceptual space has not yet been completely implemented. A number of challenges remain, for example how to define absolute and relative position in this space? How to quantify distances? How to define the extent (size) of concepts? How to specify the reasoning interactions between concepts? How to specify directedness in the graph? Furthermore, how far does the analogy of a conceptual “space” extend with regards to the relationships governing the many other types of spaces used in modern mathematics, such as Euclidean spaces, linear spaces, topological spaces, Hilbert spaces, or probability spaces?

Other literature confirms the opinion that current semantic modeling approaches fall short in a number of areas including at minimum: inability to express intended meaning and as a result leaving their intent to interpretation, classification of concepts that is ambiguous and can be done many different ways, lack of a comprehensive methodology for translating semantic models into computing methods and software, and semantic technology and knowledge repositories that remain in silos [12].

The incompleteness of current semantic modeling approaches is also reflected in the need for human’s in adapting semantic models for new data sources, and in the difficulty humans have to even understand these formal semantic models once defined [13]. Some approaches other than HCFM define semantic “spaces” differently [14], in the attempt to address the incompleteness of current semantic modeling approaches. However one problem such definitions of a semantic “space” might suffer from is that they are not part of a coherent model of cognition that represents individual words in a complete way. Depending on the representation, any distance measured between words might be the same, so that such representations cannot be used “to indicate semantic distance for individual words” [14].

A number of assumptions made in Human-Centric Functional Modeling remain to be validated and a number of properties defined in functional state spaces remain to be quantified. The extent of any concept (its resolution) in conceptual space has been hypothesized to depend on the number of reasoning relationships linking it to other concepts (i.e. the number of edges connecting the node in the graph representing the concept). But the dependency of size on number of edges has not been quantified. Similar concepts have been proposed to be those with many of the same relationships (many of the same edges that connect them to the same nodes) and similar concepts have been proposed to be closer to each other in conceptual space than concepts that are dissimilar. But this distance has not been quantified. It has been proposed that two concepts might move closer in the conceptual space over time if they come to share many of the same relationships (e.g. if the cognition learns over time that those concepts are similar). Therefore concepts might move in the conceptual space. If concepts move then they have the equivalent of "forces" moving them. But these forces have not been quantified. Assuming that concepts have some location, then the conceptual space might be mapped to a three dimensional space. Or it might also be mapped into some shape matching the structure of the brain. In addition to quantifying sizes and distances in conceptual space so that a representation of conceptual space in 3D can be defined, any mapping of conceptual space to the physical layout of the brain as the only known cognitive system currently in existence must be determined.

If any node (concept) in conceptual space is described by its relationships, then its relationships must be described within the concept in order to ensure the description of the concept is fully self-contained so that reasoning can be executed on it. Fully self-contained descriptions in conceptual space are complete self-contained descriptions of meaning, and are therefore semantic descriptions. Any implementation of this conceptual space is a semantic description of concepts and potentially a language-free representation of meaning if each meaning is represented by a particular pattern of nodes and edges in conceptual space regardless of language. The usefulness of a semantic representation as a "semantic storage" format is that it provides a way to store data that can never become unreadable because of new hardware or software. This is true whether the semantic representation is of concepts and reasoning as otherwise described by human language, or whether the semantic representation is of the physical or virtual world as otherwise described by some specific data format.

Any generalization of a concept is a concept that covers a larger region in conceptual space and therefore might contain other concepts. Being a concept as well, the description of this region must also be self-contained. In summary, for any implementation of the conceptual space, all regions must have descriptions that are self-contained in that region. The importance of validating the assumptions and quantifying the properties that remain open questions regarding conceptual space is that any functional state space, whether the functional state space representing cognition or the functional state space representing the physical universe or any virtual universe like the metaverse, are expected to have the same representation. Therefore solving these representation problems for one system like cognition will also solve them for the metaverse.

V. Simulation of a Network of Nodes Representing Concepts in a Conceptual Space

An implementation of conceptual space might potentially be validated by simulating the behavior of the cognitive system in that proposed implementation of conceptual space. Some requirements which might be addressed by an implementation of a graph that is able to satisfy the requirements of conceptual space and is therefore able to satisfy the requirements of any functional state space, such as that representing the metaverse, are that this conceptual space might respond to a simulation as below:

- A simulation of conceptual space might demonstrate that "level of interest" or other potential attractive forces cause concepts to move in conceptual space, such as towards a concept of interest. Forces are associated with acceleration. If interest is such an attractive force then level of interest might be detected in conceptual space by the resulting acceleration of motion of concepts over time. Similarly, in a simulation of the metaverse, objects in a functional state space representing the physical world should accelerate and otherwise behave according to the observed laws of physics.

- A problem in conceptual space is defined by the lack of a path from some concept A to some concept B. A solution is reasoning that provides a path from concept A to concept B. Any reasoning that creates a link between concept A and concept B moves both closer together. A simulation of conceptual space might demonstrate that "attention" behaves in experimentally observed ways, such as perhaps causing concept A to move in conceptual space in the direction of the problem being solved (concept B). If so then attention can be represented in conceptual space by the resulting motion of concepts over time. Similarly, in a simulation of the metaverse physical objects can undergo transitions. Solutions to these physical transitions provide a path through functional state space that solves the problem of transitioning from one physical state to another. To validate this one might show that physical transitions continue in the direction dictated by the laws of physics. Of course, one might define a metaverse with a different physics, or one might describe the metaverse in functional state space using a low resolution that leaves out most physics, but for simplicity the same physics might be assumed.

- An abstraction is a larger concept that encompasses other concepts. A simulation of conceptual space might demonstrate how a cluster of concepts can act as a single concept. Similarly, in the case of the metaverse a simulation might show how a graph representing macroscopic objects might be constructed from graphs representing microscopic components.

- In any simulation of any functional state space it remains to be demonstrated that all nodes can be described in a way that contains all their edges (descriptions are self-contained within the node).

VI. General Collective Intelligence

The same Human-Centric Functional Modeling can be used to define a collective conceptual space navigated by a hypothetical collective cognition, where the general problem-solving ability of that collective cognition is measured by a general collective intelligence factor (c) [15]. Implementations of Collective Intelligence (CI) are solutions which might increase ability to collectively solve problems in a narrow area. A General Collective Intelligence or GCI platform is a CI that provides general problemsolving ability (intelligence), and that also creates the possibility of exponentially increasing that collective intelligence [16]. Creating social media platforms is one such problem that GCI might be turned towards. This has profound implications regarding social media platforms that might interact with the metaverse, since it predicts that with GCI such platforms might self-assemble to eliminate any possibility of censorship or surveillance, and do so at unprecedented speed and scale in ways that current centrally controlled social media platforms would not have the ability to compete with until the advent of Artificial General Intelligence or AGI [22].

VII. Conclusion

A functional state space representing any region in the physical universe would not only be important to physics in enabling all theories to be tested against all data. It would also provide a common format for representing the world in games, simulations, experiments, or any other computer interaction. This would enable a "metaverse" that could be managed through a common platform such as a General Collective Intelligence, rather than a proprietary platform owned by Facebook, Apple, or some other company. A number of companies are investing heavily in the metaverse becoming very prominent, and some believe the metaverse to be important to the future of work because the greatest opportunities to create jobs are in areas such as virtual reality that are not constrained by finite natural resources. Since all functional state spaces are likely to have the same representation, solving the remaining problems in implementing a working representation of any functional state space is likely to solve the remaining representation problems for all functional state spaces. Human-Centric Functional Modeling attempts to define an objective model of human perception that allows it to be seen that all problems and solutions that can be perceived by humans are represented by patterns in human perception that can be reused in defining other problems and in discovering other solutions. As an example, it is hypothesized that properties such as sustainability in the environment or in sustainable development are patterns in some functional state space, and that by understanding those patterns we might exponentially increase our capacity to solve wicked problems like poverty and climate change to the point that those challenges are reliably solvable for the first time [19], [20], [21]. It has also been hypothsized that the use of functional state spaces to define semantic models of information that a General Collective Intelligence might use to exponentially increase the general problem-solving ability of groups, might also radically accelerate progress in every field from physics to quantum computing. Perhaps given the massive resources being invested in the metaverse, this potential use of functional state space to define the metaverse might inspire participation in the challenge of defining a functional state space to benefit all of these other areas.

Human-Centric Functional Modeling is in its early stages and remains to be explored both experimentally and theoretically. Implementations of the functional components suggested by HCFM as being required for semantic computing have not been defined using classical computing hardware and software, much less quantum computers. However, the great theoretical benefits of the functional modeling approach make this line of inquiry worthwhile. Namely, defining cognition in terms of a minimally reducible set of cognitive functions has the potential to radically scale cooperation in defining problems, as well as cooperation in modeling data to be provided as input to solutions, and cooperation in modeling the solutions themselves. And from this point of view the biggest limitation that currently exists on both classical and quantum computers is not their computing power, but the constraints to cooperation that force researchers in domains such as quantum computing to develop solutions that are not easily reusable to solve all other problems researchers in the same or other domains might face.

References

[1] Suppe, F. (1989). The semantic conception of theories and scientific realism. University of Illinois Press.

[2] Lloyd, E. A. (1984). A semantic approach to the structure of population genetics. Philosophy of Science, 51(2), 242-264.

[3] Niiniluoto, I. (1987). Quantities, State Spaces, and Laws. In Truthlikeness (pp. 103-121). Springer, Dordrecht. Doi : 10.1007/978-94-009-3739-0_3

[4] Williams, A. E. (Accepted) A Revolution in Systems Thinking?, Proceedings 2021 Congress of the World Organization of Systems and Cybernetics (WOSC)

[5] Nykamp, D. (2019) "State space definition". Math Insights. Retrieved 17 November 2019.

[6] Laubenbacher, R., & Pareigis, B. (2001). Equivalence relations on finite dynamical systems. Advances in applied mathematics, 26(3), 237-251. Doi: doi:10.1006/aama.2000.0717

[7] Williams, A. E. (2020) A Model for Artificial General Intelligence. In: Goertzel B., Panov A., Potapov A., Yampolskiy R. (eds) Artificial General Intelligence. AGI 2020. Lecture Notes in Computer Science, vol 12177. Springer, Cham. Doi:10.1007/978-3-030-52152-3_38

[8] Williams, A. E. (2021). Human-Centric Functional Modeling and the Unification of Systems Thinking Approaches: A Short Communication. Journal of Systems Thinking. 5-5.

[9] Williams, A. E. (2022, February 1). The Importance of Representing the Physical Universe or Virtual Universes in Functional State Space to the Progress of Physics. Retrieved from osf.io/preprints/africarxiv/54qrz

[10] Williams, A. E. (2021) "Cognitive Computing and its Relationship to Computing Methods and Advanced Computing from a Human-Centric Functional Modeling Perspective", In: Pal R. and Shukla K. P. (eds), SCRS Conference Proceedings on Intelligent Systems, SCRS, New Delhi, India. pp. 16-33. Doi:10.52458/978-93-91842-08-6-9

[11] Williams, A. E. (2022, February 1). Modeling Biological Systems Using Functional State Spaces. Retrieved from osf.io/preprints/africarxiv/6k4z5

[12] Bandara, M., Rabhi, F. (2020)."Semantic modeling for engineering data analytics solutions." Semantic Web 11: 525-547.

[13] Burgdorf, A., Pomp, A., & Meisen, T. (2020). Towards NLP-supported Semantic Data Management. arXiv preprint arXiv:2005.06916.

[14] Nielsen, F. Å., & Hansen, L. K. (2020). Creating semantic representations. In: Sikström S., Garcia D. (eds) Statistical Semantics. Springer, Doi:10.1007/978-3-030-37250-7_2 Cham.

[15] Woolley, A. W., Chabris, C. F., Pentland, A., Hashmi, N., & Malone, T. W. (2010). Evidence for a collective intelligence factor in the performance of human groups. science, 330(6004), 686-688.

[16] Williams, A. E. (2020, July 11). Human Intelligence and General Collective Intelligence as Phase Changes in Animal Intelligence. Doi:10.31234/osf.io/dr8qn

[17] Williams, A. E. (2020, April 17). Using a Functional Modeling Framework to Compare Some Leading Models of Consciousness. Doi:10.31234/osf.io/8bzv6

[18] Williams, A. E. (2022, March 12). Automating the Process of Generalization. Doi:10.31730/osf.io/fb4us

[19] Williams, A. E. (2021) Are wicked problems a lack of general collective intelligence?. AI & Soc (2021). Doi:10.1007/s00146-021-01297-8

[20] Williams, A. E. (2022) Is General Collective Intelligence a Reliable Path Towards Achieving Green Growth, International Journal of Global Environmental Change, in press (2022)

[21] Williams, A. E. (2022, February 1). Is Sustainability a Pattern of Solution in a Functional State Space?. Retrieved from osf.io/preprints/africarxiv/cb2xh

[22] Williams, A. E.(2022) General Collective Intelligence as a Platform for Social Technology, Proceedings of the 2nd International Conference on Pervasive Computing and Social Networking (ICPCSN 2022), in press (2022)