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A Proposed Theory of Mind Based on Interactive Computation

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The interest in Interactive forms of Computation have been growing in interest for some time in the field of Computer Science, with an emphasis on human-computer interaction and interactive programming. Sadly, Cognitive Science, Cognitive Psychology, Neuroscience and Philosophy of Mind has not taken advantage of this growing section in theories about the mind, with having only Classical Computation being held by the majority of researchers. However, there are extreme limitations placed the Classical Computational Theory of Mind (CCTM) but that these limitations can be eliminated or reduced by formulating a Interactive Computational Theory of Mind (ICTM) and therefore having an expanded version of the orthodox theory of the mind. The goal of this paper will be to formulate a ICTM and explain how it overcomes the problems set before the CCTM. This paper will be split into a introduction, three sections explaining the details of both Classical and Interactive Computation, and a final conclusion that gives a summary of the results in this paper. The first section is about the outline the distinctions different forms of information processing and computation and explains what from an Interactive Computation. The second section will show how CCTM has been applied in the past by the fields in Cognitive Science and the present limitations of the theory. The third section is where I form a (ICTM) to solve the problems that occur in CCTM.

Keywords: Interactive Computation, Classical Computation, Church-Turing Thesis, Information Processing

Introduction

In the field of Computer Science, Interactive Computation has been growing in interest and thus there has been a growing research around it. To simply summarize what Interactive Computation is, it is a mathematical model of computation that still contains input/output communication but rather then be a closed system without much or even no connection to the external world, Interactive Computation is a open system that has a connection to the external world.[1] It maintains the Church-Turing Thesis but goes beyond the thesis but not just focusing on computability functions but also tries to account for interactive tasks that are not themselves reducible or have the functions supervene below the interactions.[2] With that being stated, Interactive Computation is seen as more empirical-based but also uses

[1] Goldin, Dina and Wegner, Peter. "Principles of Interactive Computation". Interactive Computation The New Paradigm. Goldin, Dina, Smolka, Scott A. and Wegner, Peter (Eds.). *Springer-Verlag Berlin Heidelberg*. forthcoming URL = interactiveComputationTheNewParadigmGoldinSmolkaWegner.pdf. 2006. 31-32.
[2] Ibid., 35-36.

concepts from computability logic, deals a lot of human-computer interaction, game semantics, interactive programming, and quasi-empiricism theory of mathematics.[3] Sadly, as Interactive Computation is growing in research within Computer Science, this can not be said to be the same with Cognitive Science or disciplines connected to it, like the Philosophy of Mind, Cognitive Psychology, and Developmental Psychology. Even today, when researchers in those fields discuss computation, they are usually confined to its traditional forms with it being treated as a closed system with very little interaction with the external world. This model only deals with functions rather then interactions as stated above which has lead to many problems surrounding the computational model as applied to conceptualizing the mind and thus has lead to other alternatives being developed to account for interaction, which is lacking in traditional computation models.

What I want to do with this paper is use outline a theory of mind based on Interactive Computation. The reason for this is because viewing the mind as a information processor and as a computer like entity has been at the foundation of Cognitive Science since the Cognitive Revolution of the 1950's and 1960's,[4] if this way of visualizing the mind is overthrown, then a great deal of work done by researchers in the fields of psychology, linguistics, artificial intelligence, and generally the philosophy of mind have to radically re-conceptualize their whole research programmes and the present findings we can conclude from their research. The present author will argue that the reformulating the Computational theory of Mind on interactive grounds will not only save past research in the fields mention above, but aid in furthering research of those fields in further and to answer more pressing questions and concerns. To prove that final point, I will divide this paper into three sections. The first section is outline the further differences between computation in traditional lens from an interactive lens. The second section will outline how Classical Computation has been applied in the past by the fields of psychology and philosophy of mind and present limitations of those applications. The third section I will apply Interactive Computation to overcome certain objections and limitations present in the classical Classical Computational theory of Mind (CCTM) and to aid in further research in Cognitive Science about the nature of the Mind.

Section 1:

Differences of Classical Computation and Interactive Computation In this section I will outline the major differences in mathematical form and in overall representation of Classical or "Pure-Turing" based Computation as opposed to Interactive Computation. However, a few more distinctions and concepts must first be made clear. That being the difference between information processing and computation. The reason for this is because these two concepts, particularly in fields like psychology, linguistics, and other research dealing with cognition,

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[3] Ibid., 36-37.
[4] Piccinini, Gualtiero and Scarantino, Andrea. "Computation vs. information processing: why their difference matters to cognitive science". *Studies in History and Philosophy of Science* 41. 2010. URL=Computation_vs_Information_Processing.pdf. pp. 238.

get confused as the same idea which leads to more ambiguity then there needs to be.

1.1: Distinctions between Information Processing and Computation

The difference in information processing and computation are first from origin and then from operation. Information processing came from the fields of control engineering and cybernetics with the works of N. Wiener and C. Shannon in the 1940's and 1950's being foundational. With Computation, that came from the fields of mathematics and logic in the 1930's and 1940's with the primary research being done by Alan Turing.[5] There are two forms of computation, digital computation which is a fixed step by step algorithm internal to its own system and this form of computation is what informed Cognitive Science's view of the mind as a computational object.[6] The second form of Computation is generic which designates "any process whose function is to manipulate medium-independent vehicles according to a rule defined over the vehicles".[7] Other computational forms like neural or analog computation, but usually these forms can either fall into either the digital or generic varieties. Computation can also be semantic or non-semantic, which basically means that computation can maintain a representation or not even have a representation.[8]

Information processing also has distinctions that have to be addressed. There is a distinction between Shannon information and Semantic information, where the former does not need semantic content in its message signals and is narrowly defined for communication proposes and where the latter has particular content in there message signals.[9] There is also a distinction between Natural and Non-Natural information, where Natural semantic information is treated as having the characteristics of intentional content, entails a truth-value, and have a physical connection when in Non-Natural semantic information these three characteristics are not needed and is interchangeable with representation or meaning.[10]

These distinctions are important because we can now see which of these forms overlap with each one another, like how Shannon information does not need digital computation but just a string of digits. When digital computation is dealing with semantic information, it is usually dealing with Non-Natural but can include natural semantic information. Finally, generic computation is general enough where semantic information, be it natural or not, has to deal with some kind of generic computation.[11] In short, all cognition deals with generic computation, but this is trivial due to the generality of how generic computation is defined.[12] This is problematic because the CCTM relies on the need for digital

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[5] Ibid., 238.
[6] Ibid., 238-239.
[7] Ibid., 239.
[8] Ibid., 239-240.
[9] Ibid., 240.
[10] Ibid., 240-241.
[11] Ibid., 242-243.
[12] Ibid., 243-245.

computation, but its possible to deal with information, Shannon or Semantic, without invoking digital computation.

Section 1.2: What is Interactive Computation

Going back to Turing, Interactive Computation sees Turing’s findings that computers could not automatically decide all mathematical theorems as a refutation of a priori type of rationalism and promotion of a empiricist project and that interaction is an extension of this empiricist project.[13] Interactive Computation or “interactive machines” does not need to run by strict algorithmic patterning and can deal more in-depth with the external world and is more powerful then traditional algorithmic or digital computation, interactive machines are more like open systems rather then closed systems, and that input and output are more connected to one another which change with incoming empirical data from the external world.[14] Basically, its a form of generic computation and not digital. Interactive Computation also deals more fully with sequential interaction and the notion of the persistent Turing machines (PTM’s) comes into play.[15] PTM’s are interactive machines which deal with dynamic streams and persistence, where input is a stream of tokens/strings that are generated dynamically from the environment which also has input and output that token/strings that are interleaved, which results in a interactive system. PTM is an infinite sequence of macro-steps where “ the i’th macro-step consumes the i’th input token a: from the input stream, and produces the i’th output token for the output stream”[16] which themselves contain “multiple N3TM transitions (microsteps), just as each input and output token is a string consisting of multiple characters” and is a interaction stream with { (a1, o1), (a2, o2), ...}.[17] Persistence is analogous to memory when one marcostep goes to the next, thus the output (as oi) is dependent on the input (as ai) and contents at the beginning of the marcostep.[18] Persistence also effects inputs be way of having an input token effecting a corresponding marcostep and creates the property known as history dependence.[19]

Three results follow from the example above. The first result being that PTM’s are isomorphic to interactive transitions system (ITS) where effective transitions machines with actions that that consist of input/output.[20] The second results is that PTM’s have greater effectiveness then amnesic Turing Machines which are extensions of traditional Turing Machines which can deal with dynamic streams but without creating memory.[21] The third result is the existence of a universal PTM, which can simulate the behaviour of any arbitrary PTM can, like how universal Turing Machine can simulate the behaviour of any arbitrary

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[13] Goldin and Wegner, 38.
[14] Ibid., 39.
[15] Ibid., 43.
[16] Ibid., 43-44.
[17] Ibid.
[18] Ibid., 44.
[19] Ibid.
[20] Ibid.
[21] Ibid.

traditional Turing Machine.[22] PTM's can preform what is called Sequential Interactive Computation (or SIC). This is where a sequential interactive computation can continuously interacts with the environment and alternate accepting input strings and corresponding output strings, which can be non-deterministic, history-dependent and all output strings rely on all the previous input strings.[23] This premise is supported by the assumption called the Sequential Interaction Thesis (or SIT), which states that "Any sequential interactive computation can be performed by a persistent Turing machine".[24] This expansion still accepts the Church-Turing Thesis where any effective algorithm for computing a mathematical function can be completed by a Turing Machine.[25] However, PTM's is an outright contradiction to the Strong version of the thesis that states any Turing machine can compute anything that any computer can compute.[26] This later version was never supported by either Church or Turing and is considered a myth that still holds water in the programming field.[27] This strong version is rejected due to being placed on purely rationalistic grounds and that Interactive Computation provides a stronger and less mythical manner of computation with going against the Church-Turing Thesis and not bastardize it as the Strong version has done.

Section 2: Applications of and Objections to the Computational Theory of Mind

Section 2.1: Previous Applications of Computation to the Mind

The first major proponent of the CCTM and the first to apply the metaphor as a mind as a Turing Machine was the late American philosopher Hilary Putnam.[28] Putnam in 1967, promoted and formulated a view called machine functionalism as a means talk about the nature of mental states which did not results into either logical behaviourism or type-identity theory.[29] Putnam at that time emphasized what is called a "probabilistic automata" which is like a Turing Machine but deal with computational states which are stochastic or non-deterministic.[30] This position was rebutted due to concerns over the productivity of thought. Where a normal human brain could potential entertain an infinity of thoughts or propositions. However, machine functionalism with unstructured machine states comes into issues over explaining the systematic relations from one state to another.[31] The second major CCTM view was proposed by Jerry Fodor and is called the representational theory of the mind. This theory is meant to deal with both the systematicity and productivity of thought by way of focusing attention on symbols that are manipulated during Turing-style (aka. digital) computation.[32] This theory argues that mental activity involves Turing style

[22] Ibid., 44-45.
[23] Ibid., 45.
[24] Ibid.
[25] Ibid.
[26] Ibid., 45-46.
[27] Ibid., 46.
[28] Rescorla, Michael. "The Computational Theory of Mind". *The Stanford Encyclopedia of Philosophy. Spring 2017 Edition.* Edward N. Zalta (ed.). Forthcoming URL = <https:// plato.stanford.edu/archives/spr2017/entries/computational-mind/>. Sec. 3.1.
[29] Ibid. 3.1
[30] Ibid.
[31] Ibid.
[32] Ibid., 3.2.

computation over the language of thought and manipulating those symbols in accord with mechanical rules.[33] To explain Productivity, there is a finite amount of expression in a language which can produce a infinity of proportional attitudes and to explain Systematicity, relations are between propositional attitudes a thinker can entertain.[34] Unlike machine functionalism, the representational theory only affirms digital computational, where every mental processes is computational (in a digital form), but does not endorse functionalism, where are mental states are functional states.[35] Fodor, since the formation of this theory, states that is the foundation to Cognitive Science and other researchers in the field have also stated this as well.[36] However, there are a great deal of objections to basing a theory of mind computation, or at least on digital computation.

2.2: Refutations to the Classical Computational Theory of Mind

However, with assuming this model, three major problems come into play, mainly temporal problems, limits of computational modelling, and embodied cognition. As stated before, general applications of computation in psychology, linguistics, and philosophy of mind has mainly been digital computation and the fear that such style of computation can not account for cognition as it happens in time.[37] The reason for that is that digital computation makes no mention of time when a computational process is occurring and that because of this, the computational theory must be rejected or at least digital computation must have supplements to account for time.[38] Another temporal objection is a distinction between discrete and continuous temporal evolution and states that Turing-machines only deal with discrete stages rather then continuous mental activity and that actual mental activity is continuous. Therefore, the mental activity does not match up well to the theory of states being computational.[39] However, this assumes that physical time is continuous but that does not follow that cognitive states must have a continuous temporal structure.[40] It could be assumed that physical states and cognitive states are divided from one another. Physical states are continuous and dynamic, and cognitive states are discrete and computational in digital form, thus the elimination of the temporal argument. There are also objections based on the limitations of computational modeling. Activities that are intuitive, creative, or skillful tends to have a tendency to avoid formalization in a digital format.[41] Limitation arguments against which state that digital computation is only localized to certain properties or mental representation, non-local or abduction properties make up many mental states like relevance, simplicity, and conservatism, and therefore such digital forms of computation ought to be rejected as a theory.[42] There is some debate about whether or

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[33] Ibid.
[34] Ibid.
[35] Ibid.
[36] Ibid.
[37] Ibid. 5.
[38] Ibid., 7.4.
[39] Ibid.
[40] Ibid.
[41] Ibid.
[42] Ibid., 7.3.

not digital computation is localized or can handle non-localized properties, from the analysis in section 1.1, digital computation can account for informational states, in both Shannon and Semantic, but that informational states does not need digital computation to be process, but merely need a string of digits. The fact that digital computation is limited and at times not needed to account for certain processes is a major problem that is at time not accounted for in the literature of the field of Cognitive Science.

The final set of objections comes from the idea of Embodied Cognition. The basic idea of Embodied Cognition is that cognition is linked to its surrounding environment and also to bodily actions.[43] Like temporal arguments, Embodied Cognition places great importance on the dynamic nature of cognition, that the static symbol manipulation can not account how cognition is embodied in environment, and Agent-environment dynamics are the key to explaining cognition, not internal mental computation.[44] There have been some models of digital computation that has tried to accommodate Embodied Cognition. However, if the distinction between cognitive states and physical states are broken down for the sack of explaining embodiment. With that, Temporal arguments about discrete states and continuous states are open back up again and pose a threat to digital computation at that end. If the distinction between cognitive states and physical states remain divided, that temporal argument become avoid but the problem of Embodied Cognition is still left unexplained.

Section 3: How Interactive Computation Overcomes Classical Computation's Short-Comings

Section 3.1: Interactive Computation and Embodied Cognition

Going back to the formulation of Interactive Computation in section 1.2, input of PTM's are tokens/strings that are dynamically connected, it is gathered from the environment and produces output tokens/strings which are more fundamentally tied to the input tokens/strings. Viewing the mind as a PTM, mental activity and content is analogous to tokens/strings that represent a string of digits and that these strings of digits can produce both Shannon, natural and non-natural Semantic Information. Persistence as it is connect to the marcostep of informational tokens/strings where the output has to be dependent on the input. Basically what goes out from cognition is dependent what comes into cognition processing. This would be analogous to the "stream of thought" described by William James[45] but also emphasizes what Immanuel Kant called the "unity of consciousness"[46] where cognitive input is tied continuously with output and experienced subject or agent that is unified. Now how does Embodied Cognition come into activity here?

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[43] Ibid., 7.5.
[44] Ibid.
[45] Goodman, Russell. "William James". *The Stanford Encyclopedia of Philosophy. Fall 2016 Edition*. Edward N. Zalta (ed.). URL = <https://plato.stanford.edu/archives/fall2016/entries/james/>. Sec. 3
[46] Brook, Andrew. "Kant's View of the Mind and Consciousness of Self". *The Stanford Encyclopedia of Philosophy. Winter 2016 Edition*. Edward N. Zalta (ed.). URL = https://plato.stanford.edu/archives/ fall2016/entries/kant-mind/#3.4 . Sec 3.4.

Embodied Cognition relies on the idea that features of cognition are deeply dependent on beyond-the-brain bodily actions and that these action play a significant causal role in a agent cognitive processing and which sees the body as a Constraint, Distributor, and Regulator.[47] The general thesis of the theory and it can be argued that this thesis can be connected or be drown from the Sequential Interactive Thesis and viewing the mind as a PTM which carries memory or mental content not only in the brain, but also the body. Through Sequential Interactive Computation, there is continuously activity with the environment. The body can be used as a constraint which constrains certain representations being processed in a cognitive system/agent by means of seeing these constrains as mircosteps. In the role distribution, mircosteps play a key role as well with displaying multiple characters to different bodily functions the cognitive system/agent maintains. Finally, for regulation, the role of persistence is key because we can account for regulation by activity over space and time by accounting for history-dependent input and output tokens/strings, which interactive computation does with the property of history dependence. Basically, Sequential Interactive Computation and the notion of Persistence found in Interactive Computation can outline a approach to cognitive processing which connects mind, brain, and body together computationally. This is important because we can in a computational manner explain and account for bodily interactions with the environment. There are further questions over modularity, mental representation, and Nativism,[48] sadly enough, there is not enough time for those concerns to have sufficient coverage here.

Section 3.2: Interactive Answer to Temporal Arguments

Going back to the temporal arguments from section 2.2, these type of arguments rely on the same reasoning that Embodied Cognition has been used against the CCTM. The argument rejects the CCTM on the grounds that it either it does not take into account processes that appear in time or that discrete digital computation can not as a theory of mind prove how mental activity operates and is inadequate because it does not deal with the continuous and dynamic experience assigned to mental activity. In traditional formulations of the CCTM, proponents can just claim that this argument states that cognitive states are like continuous and dynamic physical states. However, there is no necessary reason to assume that cognitive states must be like physical states and a clear distinction can be maintained. However, if this distinction was true, then the proponents of the traditional forms of CCTM will have problems with refuting or fusing with Embodied Cognition. So the dilemma is this, make the distinction and avoid the temporal argument but fail to integrate Embodied Cognition or do not make the which provides more ability to deal with Embodied Cognition but fall for the any type of the temporal arguments presented. As with Embodied Cognition, these concerns about the computability of time or temporal

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[47] Wilson, Robert A. and Foglia, Lucia. "Embodied Cognition”. *The Stanford Encyclopedia of Philosophy. Spring 2017.* Edition. Edward N. Zalta (ed.). Forthcoming URL = <https://plato.stanford.edu/archives/spr2017/entries/ embodied-cognition/> . Sec 3.

[48] Ibid., 4.3.

aspects can be answered with Interactive Computation. Unlike digital computation, Interactive Computation has the property of history dependence which can account temporal computation and account for tokens/strings as they are processed in time. Since these token/ strings are analogous to mental activity or content, the content is processed in time and able to change while maintaining an input/output distinction. For PTM, this divide is less substantive and more epistemic based as a way to clarify what cognition takes in and what it puts out. There, when viewing the mind as a PTM or interactive system, we can have an account of temporal change to cognitive content while at the same time have a computational theory of mind.

Section 3.3: Interactive Answer to Limitation Arguments

The answer to the last and what I would argue to be the most present and powerfully line of objections to an theory of mind based on computation is the Limitation Argument/s. Fodor himself, developed a internal critique of his own representational view and saw that when it comes to notion about creative thought or reasoning by way of abduction presents difficulty.[49] Now Interaction Computation was basically tailored to go beyond digital computation but whether or not it can account for two notions listed above is another issue altogether. Unlike the objections concerning Embodied Cognition and Temporal arguments against a computational theory of mind, Limitation arguments can not be solved by way of simply by connecting mental cognition to physical surroundings. Limitation arguments could toe the line on concerns with qualia and is of major concern when surrounding discussions around AI.[50] I would argue that Interactive Computation if coupled with advancements with Abductive logic programming and maybe computational semiotics could explain such Limitation arguments, but this is however a speculative answer rather then empirical or applicable answer. To try to give a substantive answer, Interactive Computation unlike traditional digital Computation does not need to be a step by step algorithmic process and can be an open system rather then a closed system, which leads to better grounds at solving such problems and issues for future study and research.

Conclusion

From the material that was covered a simple summary will be needed. In the first section, the distinctions between various forms of information processing and computation were outlined and noted due to importance in clarity and a formulation of what Interactive Computation is and how it works. In the second section, there was an outline how the CCTM has been applied to Cognitive Science and highlight various flaws, issues, and limitations of the classical Modelling. In the third and final section, I applied Interactive Computation to account for mental activity and to overcome the major problems found in the traditional CCTM but still maintain a computational account of the mind.

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[49] Rescorla, 7.9.
[50] Ibid., 7.3

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