Blockchain Thinking: The Brain as a DAC (Decentralized Autonomous Organization)

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***Abstract*—Blockchains are a new form of information technology that could have several important future applications. One is blockchain thinking, formulating thinking as a blockchain process. This could have benefits for both artificial intelligence and human enhancement, and their potential integration. Blockchain thinking is outlined here as an *input-processing-output* computational system. Its benefits might include the ability to orchestrate digital mindfile uploads, advocate for digital intelligences in future timeframes, implement smart-contract based utility functions, instantiate thinking as a power law, and facilitate the enactment of Friendly AI. Blockchain thinking might give rise to new forms of consensus models such as self-mining ecologies and proof of intelligence, and make use of *demurrage* principles to redistribute brain currencies like ideas and potentiation. Blockchain thinking might be a tool for the immediate progress of intelligence, and also for the longer-term transition to a world of multispecies intelligence living cohesively and productively in digital societies.**

***Index Terms*—alterity, artificial intelligence, blockchain, cognition, machine cognition, philosophy, thinking, utility function**

I. Introduction

ONE great benefit of blockchains is that they are a new form of decentralized information technology that could be applicable to many situations beyond cryptocurrency and financial assets. The decentralized nature of blockchains makes them an equality technology, one that can be used to expand freedom, liberty, possibility, actualization, expression, ideation, and realization for all entities in the world, both human and machine [1]. A specific new kind of application that blockchains might enable is blockchain thinking, the idea of putting thinking on the blockchain, or more specifically, using blockchain architecture to instantiate thinking machines. The objective is to formulate thinking as a blockchain process, which could have benefits for both enhanced human biological thinking, and machine thinking or artificial intelligence. This paper is intended as a forward-looking highly-speculative application of blockchain concepts in a new and explorative manner, and does not consider the immediate feasibility, appropriateness, or risks of such implementation.

This paragraph of the first footnote will contain the date on which you submitted your paper for review.

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II. Blockchain Thinking: The Vision

A. Definition of Thinking

Thinking has always been intuitively conceived as computational, it is just that now perhaps blockchains provide the additional functionality required to better realize these ideas. A fundamental definition could be that thinking is a situation where '*there are inputs which are processed and turned into outputs*.' In fact many reality processes have this underlying structure of *input-processing-output*, including operations as diverse as manufacturing and political elections. For the context of blockchain thinking, the definition can be qualified to situations that involve thinking, cognition, mental processing, and understanding, in ways that are not exclusively limited to humans. Inputs include both data from outside the system like sensory data, and data retrieved from inside the system like memory. The inputs are brought into a specific location for processing, or processed where they are stored. The outputs might include taking an action, storing something back into memory, conducting a transaction, or making a note or trigger for some sort of future action.

B. Personal Thinking Chains

Blockchains might be used to work with digital mindfiles (uploads of full human mind files) in the future, and their current prototypes, digital identities (Facebook, LinkedIn, etc. profiles), through their asset management, property registration, and access control features [2]. There could be "personal thinking chains" as a life-logging storage and backup mechanism. The concept is "blockchain technology + in vivo personal connectome" to encode all of a person's thinking and make it useful in a standardized compressed data format. The data could be captured via quantified-self tracking devices, wearables, intracortical recordings, consumer EEGs, brain computer interfaces, cognitive nanorobots, and other methodologies. Through the transactional logging of these data, the basis for thinking could be instantiated in a blockchain—and really all of an individual's subjective experience, possibly eventually consciousness, which could allow consciousness to be more precisely defined. Once on the blockchain, the various components could be administered and transacted; meaning engaged, for example, in the case of a post-stroke memory restoration.

There has not yet been a good 'health data commons' model with the appropriate privacy and reward systems for the public sharing of personal health data and quantified-self-tracking

data, and likewise mental performance data. Blockchains might provide exactly such a structure for creating a secure, remunerated, owner-information controlled health data commons. At the individual level, personal health is a big data problem that needs effective universal orchestration, security, and access mechanisms like blockchain technology. At the societal level, the argument for blockchain technology is even stronger: medical research needs access to 'big health data' for discovery too. The promise of the machine learning revolution has thus far not been realized in the context of health, because data is still siloed (locked away in private data stores) and in any case digitally un-interoperable (there is not yet an effective health XML). Blockchains could be employed as a secure large-scale data management mechanism to coordinate the information of millions and billions of individuals.

Personal connectome files, like personal genome files and EMRs (electronic medical records), could be registered and orchestrated via blockchains. A personal connectome file is your own mind file, the anatomical and functional mapping of your own brain. It is hoped in the future that connectomes might make it possible to share not just quantitative information about brain state, but also qualitative experience like sentiment, affect, and valence; what it is really like to be you in that moment [3,4]. This could finally be an answer to subjective experience questions such as whether I see red the same way you do, or what it is like to be a bat [5]. The idea would be to register personal connectome files on the blockchain just as EMRs and genomes now. The files are not literally stored on the blockchain, but blockchain-registered transactions provide a unique ownership signifier and include pointers to the files which are stored securely in decentralized off-chain locations. Thus, health-record blockchains could be used to denote ownership and manage access to these kinds of sensitive data files. A blockchain-based coordination system could be ideal for personal health record management for privacy, security, access control, and just sheer administration because the big data era is meaning that billions of data elements may comprise any one individual's health file [6].

There is even more sensitivity and stigma attached to sharing 'mind data' than other forms of personal data like purchasing transactions and physical health data, but these kinds of "life-streaming + blockchain technology" models could facilitate a number of ways to share data privately, safely, and remuneratively. Life-logging could include personal thinking blockchains to capture and safely encode all of an individual's mental performance, emotions, and subjective experiences onto the blockchain, at minimum for backup and to pass on to one's heirs as a historical record. Personal mindfile blockchains could be like a next generation of Fitbit or Apple's iHealth on the iPhone 6, which now automatically captures 200+ health metrics and seamlessly uploads them to the cloud for data aggregation and processing into actionable recommendations. Similarly, data could be easily and securely recorded to personal thinking chains, and mental performance optimization recommendations made to individuals through services like Apple's Siri, Google Now, Microsoft's Cortana, and Amazon's Alexa voice assistant, perhaps piped seamlessly through personal brain computer interfaces and delivered as ambient suggestions, or in interaction with personal robots like Robotbase's Personal Robot, MIT's JIBO, and Amazon's Echo.

Speculatively, ultimately, the whole of a society's history might include not just a public records and document repository, and an Internet archive of all digital activity, but also the *mindfiles* of all individuals. Mindfiles could include the recording of every "transaction" in the sense of capturing every thought and emotion of every entity, human and machine, encoding and archiving this activity into life-logging blockchains. The blockchain health argument (using blockchains as a large-scale coordination mechanism for the integrated data analysis of individuals and populations) quickly extends from pathology resolution to preventive medicine to cognitive enhancement to blockchain thinking.

C. Digital Mindfile DACs

Digital mindfile management might be realized in a few simple steps. The first stage is assembling a 'digital you' (whether from existing services like LifeNaut and CyBeRev, or more likely in the future per automated deep-learning algorithms; already reasonably fidelitous digital mindfiles might be assembled from the online presence of individuals). The next stage is enabling the 'digital you' file, initially for guided operations, and with expanding levels of approved autonomy. Digital you files could earn economic sustenance with online projects, conduct administrative activities, find information, and have experiences to re-sync with 'you prime' later. Syncing the experiences and knowledge from multiple copies of you will require specific processing algorithms for which blockchain concepts and architectures may be well-suited, such as hashing security and versioning control. Digital mindfiles could be just like any other smart contract running on the blockchain, with the checks-and-balances and code-based validation features that apply to all smart contracts.

D. Blockchain-based Advocates

Blockchains could be used not only to orchestrate digital mind files in the present, but also be an important management tool for the future. One valuable feature of blockchain functionality that has yet to be fully explored is the value of smart contracts in future time frames [7]. Blockchain-based smart contracts have the unique and valuable property of being able to serve as your independent future advocate in uncertain, unknowable, and unpredictable future time frames. You can set up code-based contracts to advocate on your behalf in the future. This can have numerous potential benefits, such as having smart contract-invoked advocacy and services for yourself in the case of your aging and incapacitation while still living. In the case of digital mindfile uploads, smart contracts on the blockchain are exactly the kind of future third-party advocate that can verify and exercise control over the physical parameters of your reality, of your existence as a digital intelligence. You would enact smart contracts on the blockchain to periodically confirm your run-time parameters and conduct decentralized back-ups.

In an advanced society of billions of digital intelligences living and thriving in smart network systems, there would need to be sophisticated oracles (information arbiters) accessed by blockchain smart contracts; oracles as a service, a platform, or as a public good [8]. The Wikipedia of the future could include blockchain-based oracle services to look up the current standard for digital mindfile processing, storage, and security as these standards would likely be advancing over time. "*You are running on the current standard, Windows 36,*" your smart contract informs you. The endgame of blockchain thinking is these kinds of futuristic mechanisms that could move society forward. Dynamic oracle services accessible by smart contracts on universal public blockchains could help to create a system of checks and balances where digital intelligences could feel comfortable not only in their basic survival, but also in their future growth potential.

III. Blockchain Thinking: The Architectural Proposal

Now having seen the vision for how blockchain thinking might unfold, the next step is articulating more specifically it might work. Conceiving of blockchains as universal transaction systems is useful in the case of blockchain thinking, particularly the built-in tracking and accountability feature. Every transaction can be recorded and reviewed on-demand by any person, machine code, or smart contract with access to the system at any later date. Three areas in the blockchain thinking architecture of *input-processing-output* are outlined: memory, storage, and file-serving; processing; and utility functions and output. This is necessarily a gross oversimplification of both biological thinking and machine intelligence, however an attempt to set forth a basic approach.

A. Input: Memory, Storage, File-Serving

Perhaps the first and most straightforward element needed for thinking is memory. Without having to address complicated and important questions like "*What is memory?*" or "*Where and how are human memories stored?*" and "*Do all human memories have the same profile or characterization?*;" for blockchain computational purposes, a position can be articulated that each memory is a discrete unit and that these discrete units are encoded and stored somewhere. Blended or overlapping memories could be stored as separate discrete units. The key move for blockchain-enabled thinking is that instead of having just one instance of a memory, there could be arbitrarily many copies of a memory, just as there can be many copies of any digital file. Further that the number and location of any stored items, in this case memories, could be optimized dynamically for system operations. In fact researchers in both AI and neuroscience have been moving towards a modular managed approach with memory.

B. AI Research: Deep Mind's Neural Turing Machines

In AI research, memory may start to be seen as a standard discrete external component. This is the approach taken by Deep Mind, a London-based startup purchased by Google in 2014. Deep Mind has created what it calls Neural Turing Machines that attempt to mimic the short-term memory of the human brain by linking neural networks to external memory modules [9]. The fundamental process of computing as classically conceived uses an external memory which can be written to and read from during the course of a computation, but memory had not been previously included in neural net AI architectures. In Turing's famous description of a computer, the memory is the tickertape that passes back and forth through the computer and which stores symbols of various kinds for later processing. Deep Mind has incorporated this idea and extended the capabilities of neural networks by coupling them to external memory resources. In this architecture, a neural network can store variables in its memory and come back to them later to use in a calculation. The Neural Turing Machine learns like a conventional neural network using the inputs it receives from the external world, and it also learns how to store this information and when to retrieve it [10].

C. Neuroscience Research: Memory Retrieval and Blocking

Recent progress in 'wetware' neuroscience also encourages a modular computational approach to memory, where it may be possible to both enhance and block memories [11]. Several substances have been shown to enhance memory performance such as donepezil (which improves memory retention); ampakines (compounds that augment alertness, sustain attention span, and assist in learning and memory); and the drug molecule MEM 1414 (which increases the production of CREB and other synapse-fortifying proteins). Blocking unwanted memories like those experienced in PTSD (post-traumatic stress disorder) trauma is also a possibility. This is effectuated by disrupting memory consolidation, which is a necessary step in memory retrieval, with drug antagonists like scopolamine and propranolol that block glutamate and β-adrenergic memory-consolidation neurotransmitter receptors. An interesting Bayesian-like updating capability of the brain is to prune inaccurate memories that it has falsely predicted, by weakening or degrading the neural path [12]. These kinds of computational approaches to memory could be helpful in greater biological discovery and understanding. For blockchain thinking, modular memory methods being deployed in both AI and neuroscience support the conceptualization and invocation of memory as discrete elements which can be encoded and stored with unique identifiers that are later called into operational action.

D. Memory Architecture in Blockchain Thinking

IPFS is blockchain-based functionality that could be particularly relevant to the implementation of blockchain thinking. IPFS (InterPlanetary File System, https://github.com/jbenet/ipfs) is a project that envisions a global peer-to-peer file-serving system using the versioning functionality of Github to affirm file content, and the hashing and unique identifier functionality of blockchains to confirm file provenance [13]. The project attempts to solve the '404: File Not Found' problem by securely serving a requested file from any location it exists on the Internet. The architecture of the Internet has been such that files were typically stored in

just one place, unless already slotted for high traffic and sharded download (like popular news and video files), and every call to the file would serve it from a specific storage location. Once called to be served, the file would be packetized per Internet transmission protocols, and these packets transmitted across the Internet and fidelitously reassembled at the end destination. BitTorrent was one first change to this process by implementing a peer-to-peer serving architecture. Here, there is a directory service of the locations of different instances of a file, such that different packets from the file might be served from different locations on a peer-to-peer basis, and as usual reassembled at the destination.

The innovation made by IPFS takes advantage of the same peer-to-peer file-sharing capabilities of BitTorrent, but in a wider use case, and with expanded functionality. Anywhere any file exists on a network-attached computer could be a serving peer for anyone requesting it. This would be for all files, not just highly-shared files like music, videos, and movies. Any digital asset could be logged in a blockchain, including as part of the automated process of uploading or transferring a file or otherwise making it available, thus acquiring a unique signifier or record for that file. Then, using existing security from distributed computing projects like Seti@Home and Folding@Home, anyone attached to a network with the file can serve the file (whole or packetized). This could be a useful plumbing innovation to help extend the efficiency, resiliency, and decentralized peer-to-peer nature of the Internet.

The blockchain features add important additional functionality to IPFS. First, the big fear of transferred files containing viruses is alleviated in that a hashing algorithm can be run over any downloaded file to confirm that it contains exactly the purported contents, and nothing else has been added. Second, the blockchain is Internet-based which means that it is always available for real-time location and validation queries when files are requested for transfer. Third, IPFS envisions a future information layer linking the BitTorrent peer-to-peer file-serving capability with Github for versioning history. Github is like Wikipedia, maintaining historical archives of past versions of pages, files, or other digital assets. IPFS's linking of BitTorrent and Github functionality could make earlier versions more readily available and trackable. One topic for future study is 'what is waste and optimality in the IPFS system?' especially since these variables are dynamic. For example, evaluating the optimal number of file copies to have available over the whole of the Internet as a system, stored at which locations, and with what kind of predictable demand timing, spread, and localization across the web. Complexity science can help to illuminate this; for example it is known that the typical demand for files is logarithmic and follows power laws, for example 80% of file requests will be in the first hour or day of the file's being referenced by news media and blogs [14].

1) Level 1: Smart Memory Assets Logged and Accessible via Blockchain

In the context of developing Blockchain Thinkers, the idea would be to implement memory as an IPFS system. The blockchain would be an always-on accessible memory augment, predictively and in real-time looking up and verifying memories. One huge under-realized benefit of blockchains thus far is the ability to verify and authenticate both users and information in real-time. A central need in the digital societies of the future could likely be confirming the source and provenance of information, including the identity of entities, whether biologically-based or digitally-based. The first step in building a Blockchain Thinker would be instantiating a blockchain-based memory system. Every memory could be tagged, addressed, and registered on the blockchain for easily validated lookup at any later moment. Smart memory is exactly analogous to the idea of smart property as registering all assets on the blockchain with their own uniquely identifying indicator, a cryptographic address, for later activation and transfer. Smart memory would similarly logs all ideas, memories, thoughts, and feelings. Blockchain-based memory thus is indexed, explicit, discrete, inventoried, and available. This is just the 'Level 1' basic blockchain-based memory description, no IPFS-inspired functionality yet.

2) Level 2: Multiple Distributed Memory Copies; Hot-Swappable Memory

'Level 2' blockchain-based memory could add IPFS-type functionality to make memory access more efficient by having multiple distributed copies of memories. Deep-learning and other algorithms could be used to assess optimal architectures for Blockchain Thinkers, like the location, separation, and latency specific memory nodes, and overall how many memory copies are needed, and their nature and kind. How should memory copies be arrayed out from or connected to processing nodes most expediently? Further how is the dynamism of 'what is an important memory' to be assessed. Perhaps memories should be hot-swapped per their rising or declining use, in the Storj model (http://storj.io/), like the brain's own pruning techniques. The idea is an IPFS implementation for memory: distributed decentralized memory with multiple copies of files served peer-to-peer in real-time on demand.

3) Level 3: Github Versioning for Memory

'Level 3' blockchain-based memory could add additional IPFS-inspired functionality to a Blockchain Thinker and a blockchain-based memory system by incorporating the versioning feature. Essentially a 'Github for memory,' this feature would allow all previous versions of a memory, idea, or data element to be tracked over time and retrieved and analyzed on demand. The first benefit is provenance, confirming that the file, that memory, has not been hacked, and is still the exact contents of a previous date-timestamped moment. In the future, blockchains may be used to track IP (intellectual property), the ownership of digital art ('art' in the patenting sense of owned IP), proving that a certain entity created a certain asset at a specific previous time. The idea of IPFS is not merely versioning, but versioning in an easy-to-use format like Github that both captures the versioning automatically whilst in process so the contributor (ideator) does not need to think about this administrative function

explicitly, and also such that the easy-to-use web-based platform makes it easy to assess changes between versions and how ideas developed. The idea is Github on the blockchain; an easy means of calling and confirming certain unitary ideas but also whole codebases or ecologies of ideas and memories in the Blockchain Thinking and brain-as-a-DAC context. Merkle trees could be used to hash a whole corpus or brain state into one file. What would it be like to have your whole brain recorded in a Merkle tree? You could easily reload previous brain state moments and more expediently get to work without having to remind yourself of your train of thought and related sub-ideas. Hashing and Merkle trees are an important tool that could be used later in other situations such as confirming the fidelity of digital mindfile uploads; that all the 'meatspace' human brain thoughts, ideas, emotions, and experiences were adequately received into digital format. In fact, one claim is that all that might be necessary for the "*cognitive status of the mindclone to be no different than that of the brain*" would be cloning memories and thought patterns to digital substrates [15].

Another benefit of versioning could be using it as an introspection tool in the process of idea generation. More explicit versioning could allow the possibility of seeing how ideas are developed; a sort of idea-generation in the wild tracking capability, to see how ideas emerge and are developed. Just like Github shows the historical record of how a software corpus developed over time, so too perhaps blockchain thinking could demonstrate how ideas develop over time. Understanding more about the process of ideation could be of great benefit to facilitating more and improved idea generation in all forms of intelligence. One claim is that humans are special and unique, and defy implementation in computers, not just because of irrational behavioral foibles, but because of ingenuity - independent thinking, new idea generation, creativity, spontaneity, serendipity, and free will. This claim is used to argue that one reason AI might be 'friendly' to humans is that it cannot itself replicate these properties of human ingenuity to which there is great value. Blockchain thinking might be used to investigate human ingenuity more specifically. Perhaps ingenuity might be articulated in greater detail, so that it could be catalyzed and facilitated, both in the classical real-life environment of human-based intelligence, and in Digital Thinkers. It might be possible to obtain a more granular characterization of the architecture of ideas, and their development, propagation, interaction, and retirement.

4) Level 4: Soft-hashing and Qualitative Ideation: Ideas in Development

'Level 4' blockchain-based memory functionality now extends beyond the IPFS-inspired ideas in blockchain-based memory to include the notion of **soft-hashing** to denote memories and ideas in formulation and development. This is the concept of qualitative hashing or soft-hashing; a qualitative sense of ideas in development, including the notion of gaps where there should be new ideas. The philosopher Bergson articulates the distinction between the quantitative and qualitative aspects of lived experience. For example, in the case of time, there is clock time and the internal subjective experience of time. As the term suggests, clock time can be measured objectively and externally; a minute is always a minute. Subjective time, however, is the internal experience of time, which might be faster or slower than clock time. Consider waiting for a train, or the sense of time 'flying by' in fun interactions with friends or family, or being in a flow state and losing all sense of time. Bergson denotes this qualitative internal experience of time as *duration*. This sense of the qualitative internal side of experience extends to all lived experiences such as the sense of consciousness and the self; and possibly the inner sense of the experience of information (Bergsonian Information) [16], and ideation. We may have a qualitative sense of ideation, of what it feels like to come up with new ideas. Consider a time when you have been in peak intellectual form, and had a major flash of insight or a really good brainstorming session.

Quantitatively, these moments of ideation have been measured electromagnetically as gamma wave bursts in the brain, and advanced mindworkers like monks tend to have more of them [17,18]. Qualitatively, there is an experience too, and this might be captured by blockchain thinking's soft-hashing tools in 'Bergsonian Ideation,' extending the progression of *duration-as-time* to *duration-as-consciousness*, to *duration-as-information*, to *duration-as-ideation*. Bergson starts to contemplate this too, that the process of ideation might be better understood, in his notion of intuition is a "*method of thinking in duration*." The reason that the qualitative is important is that both quantitative and qualitative dimensions may be necessary for general-purpose problem solving AIs, and the qualitative may be a term that is more-readily technically articulable to incorporate in AI design than consciousness.

5) Blockchain-based Memory Aides

Departing from *qualitative ideation*, a more immediate practical benefit of having the whole of a thinker's memory on the blockchain (and by extension the whole of a society's thinking on the blockchain) could be running algorithms over it for patterns and consistency. First, even just the base case of memory retrieval is a killer app. Blockchain-based memory aides (having the whole of your memory encoded and accessible on a blockchain) would be a heightened version of what is currently envisioned as memory aides, for example, wearables or augmented eyewear conducting facial image recognition or other means of identifying others and presenting information. Relevant information could be summoned for use in the ability to greet someone with higher-resolution; to more immediately be apprised of what has been happening in the other's life. Obviously, this would include the memory retrieval of a name, but also much more per the integration with real-time Internet-based information, perhaps matched priority-wise to the highest-order shared interests between the two parties. You could say "*Courtney, how nice to see you again, how is Mark (e.g.; partner, son, artificial companion, etc.)? I see your recent post on the Philosophy of Complexity; I am working on a related project.*" It would be of substantial benefit to have humans and memory appliances

working together seamlessly, especially in cases of impairment (general memory decline with age, stroke, and neurodegenerative disease like Alzheimer's and Parkinson's disease); in new situations; and in general off-loading the mental drudgery of memory and the social cost of poor memory. The ability to look up and verify blockchain-registered data in real-time automatically via wearables could enable higher-resolution human communication.

6) Bias Reduction and Memory-Reimprinting

Blockchain-based memory aides are just the first step. A second killer app that starts to evoke the ability to work with the data of the whole of an entity's memory is bias reduction. It is known that humans are currently biased in many ways of perceiving and interacting with the world, mainly due to evolution and culture [19]. Some of the many cognitive biases include loss aversion, overconfidence, confirmation, rationalization, probability neglect, and hindsight [20]. Blockchain-based memory could be used as an input for the algorithmic assessment of agent bias, and smart contracts employed to monitor this in real-time and make bias-adjustment suggestions to ameliorate actions or conceptualizations. A third killer app could use blockchain-based memory ledgers together with pattern-recognition algorithms for mental health improvement. In some areas of therapy, one main psychological operation is helping individuals reimprint the memories of earlier experiences in a more resourceful way. Early memories are encoded in the child brain in different stages of development, and can later recur in strange, artificial, exaggerated, and unempowering ways that hamper productive and healthy adult life. Situations often repeat that relate to the same underlying issue that was initially poorly-coded. Psychologists seek to trace back and root out all of the instances, starting with the most recent, having only the crude and imprecise tools at their disposal of individuals working with their own subjective memories. A future use of blockchain-based memory to address this could be a DIY Reimprinting app where optimal mental performance coaching algorithms continually canvas for potential issues, including surfacing potential situations for reimprinting.

IV. Processing

In addition to memory, storage, and file-serving as key inputs for creating Blockchain Thinkers, processing is the next element of the *inputs-processing-outputs* architecture. One benefit of blockchain architecture, and Internet architecture more generally, is decentralized processing and massive network redundancy. In the blockchain context, there could be an opportunity to reinvent the operation of thinking in a decentralized way. What would it really be like to have packetized thoughts and packetized thinking? Blockchain-based decentralized memory storage was discussed, but perhaps an even greater benefit for higher-potentiality thinking is the possibility of distributed processing. A Digital Thinker could have decentralized processing nodes that reassemble back into the goal or task. It would be like giving a brain additional processing nodes. Supercomputing is an existing example of massively-parallelized processing, however this is of a 'Level 1' variety such that tasks can be neatly packaged into many similarly-structured parallelizable computations whose results can be easily coordinated back into the larger system. The raw compute capacity of supercomputers surpassed that of the human brain (estimated at 10^{13}-10^{16} operations per second [21]) in 2012 with IBM's Sequoia BlueGene/Q at 10^{16} flops, and as of November 2014 had reached 10^{34} flops with China's Tianhe-2 at the National Super Computer Center in Guangzhou, a TH-IVB-FEP Cluster with over 3.1 million cores (http://www.top500.org/lists/2014/11/).

The obvious question is why with all of this raw computing power are there not AI applications closer to human intelligence in the ability to solve general-purpose problems (e.g.; any new problem). This is because comparing raw computational capacity is just one metric, and probably not the right one for assessing intelligence or understanding the complexity of the human brain [22]. The parallelized modular architecture of supercomputing is nothing like human brain architecture. Digital is not analog. Signal transmission and processing is different in biological systems, with a variety of analog parameters such as context and continuum determining the quality, quantity, and persistence of signals. This could be why Digital Thinkers and general AIs do not yet exist. The reason is because supercomputing, for all its power, is still monolithically homogeneous. Supercomputers do not think but only have simple linear architectures massively replicated. One claim is that for a Digital Thinker to think, it would need to think more like humans, with analog signal valences, non-linear architectures, and greater complexity.

Some approaches to developing general-purpose problem-solving digital intelligences use deep learning algorithms and large data corpora to simulate or emulate whole-brain thinking. This approach may yield useful results for some kinds of AI applications but is still far from representing the messy non-linear 'wet' architecture of biological systems like the brain *in silico*. Instead, blockchain technology might be a helpful addition to these approaches in allowing the development and coordination of decentralized architectures and clusters of non-linear functionality that are more like the brain. Additionally smart contracts might be incorporated as a means of extending the heretofore narrowband break-down of supercomputing tasks into other more complicated problems. In general in supercomputing, there is an opportunity to make progress on the issue of tackling more complex tasks, reformulating supercomputing and desktop grid computing problems into higher orders of complexity and away from simple parallelization [23]. Blockchain-architected models might facilitate this. Problems might be fashioned into a mining-compatible format to take advantage of the otherwise wasted computing cycles of mining, or organized into economically-enabled remunerative structures for computation.

A. Self-Mining Brain Ecologies and Proof of Intelligence

Mining is a core architectural feature of blockchain

processing, where a mining operation is necessary to record transactions. Independent miners confirm that transactions are bonafide and enter them into the public ledger, for which they receive remuneration. An obvious question arises as to how mining would work in blockchain thinking. Since the need to deter bad players is different, mining cycles might not need to be so wasteful, and maybe instead could be symbiotic. The context is different in blockchain thinking, and does not require such discrete transactions and all of the checks-and-balances of a monetary system where theft incentives are high. Thus the same transaction-recording functionality might be provided by another mechanism, such as high-speed secure messaging as has been proposed for smarthome IOT (Internet-of-Things) networks [24]. Another idea is self-mining ecologies, where different functions within the same ecosystem might provide mining services for each other. The concept is that of a self-mining ecosystem or cross-functional mining within a symbiotic system. Different functions are separate enough from each other for mining independence, yet also have a shared objective in the overall health of the system. The three functions in the *input-processing-output* architecture could mine for each other. Efficiency, trustability, and independence are the hallmarks of a mining operation. The structure of cryptocurrency mining is such that it is purposefully a wasteful operation. Good agents conduct wasteful computational efforts to demonstrate a proof of work (proof of having solved a computational problem), and bad agents are deterred because of the proof of work requirement.

Instead in blockchain-based systems for other types of operations like blockchain thinking and smarthome IOT systems, the mining requirement could be different. In these contexts, mining could be implemented differently such that its administrative contribution would still be sound, while taking into account the fact that the profiles and incentives for bad players is reduced in these systems. Mining could be connected to the concept of a DAC (distributed autonomous corporation). Inherent in the structure of a DAC is first, its governance constitution posted openly to a blockchain for inspection; two, its need to raise funds to conduct its operations; and three, its attempt to earn revenue from providing whatever services it can provide. The brain as a DAC has these same requirements, needing to sustain itself by running its own economy to earn revenue and spend it on necessary expenditures; engaging in some sort of productive effort to support itself. Thus the brain as a DAC has each *input-processing-output* architectural element in need of supporting itself, possibly through a cooperative mining ecology in the overall blockchain thinking system.

The notion of self-mining ecologies is perhaps more readily conceivable in the IOT smarthome context. In this case different smarthome functions could mine for each other. For example the bathroom sensors mine (e.g.; administer the transactions of) the kitchen sensor activities and vice versa or (better) round robin so any one ecology does not know which other will be mining for it. All functions are embodied as DACs or Dapp agents that need to self-fund to sustain, where they are independent yet have incentive to cooperate within the overall smarthome system. Sensor mining colonies in IOT smarthome have incentive to accurately record the transactions of the other function because they are both part of bigger entity. Despite not being fully independent, the different sensor colonies are separate enough, and have an incentive to only record truthful transactions because first, their reputation in the system matters, and two, they need trustful mining operations within the system to have their transactions processed for their own survival. Thus a trust ecosystem is built. If more independence were deemed necessary, different smarthomes could mine for each other, or mining could be a rotating service as previously mentioned. Self-mining ecologies could be implemented in the Storj model, where requests-for-service are rebid dynamically. On a daily basis, different smarthome IOT sensor functions could bid for mining services within the smarthome network, or beyond, and lock in futures contracts for mining services. Instead of GDP, the financial metric of the future could be the spot price for smarthome mining services. One benefit of blockchain architecture is that complexity and optimality can arbitrarily scale-up; another situation of the future might be a neighborhood of smarthomes negotiating a Groupon or supply contract with a local vendor, bidding solar power against electricity, for example, without any human intervention.

Self-mining ecologies are analogous to the physical-world symbiotic relationships for survival in the animal kingdom, for example, birds clearing parasites off of mammals. Likewise self-mining ecologies could operate as a symbiotic system, performing an essential administrative grooming function for the health of the overall system in which they participate. Clearly there could be many risks and concerns that would arise with the new technology development. These could include smarthome viruses, malicious outsiders hacking into the smarthome system, and the usual slate of personal smarthome data privacy and security concerns such as neural data privacy rights. A number of other more science fiction-like scenarios can be imagined such as the smarthome next door syphoning electricity or wanting to prank residents, collusion between mining ecologies, the toaster's computational ethics model malfunctioning and selling pictures to TMZ or posting them to Instagram, and other egregious failed implementations of smarthome data privacy rights. This is not a far-off concern; the need to establish machine ethics modules is already here. The personal home robotics industry is already setting forth new forms of social contracts and privacy measures, in a wide range of areas including personal data storage and transmission, facial recognition, and camera on-off time. JIBO, the world's first family home robot developed by Cynthia Breazeal's lab at MIT, with 4,800 units pre-sold on Indiegogo for $2.3 million has a detailed FAQ with the company's policies on these kinds of issues (http://www.myjibo.com/) [25]. As with any new technology, threats and responses often evolve in lockstep (the Red Queen problem; running place just to keep up) and this would be expected in all potential applications of blockchain technology whether for currency, thinking, or smarthomes.

B. Proof of Intelligence

As the mining operation could be different in smarthome IOT networks and blockchain thinking, consensus as a feature of mining could likewise be different. Consensus mechanisms could be reinvented, moving from a proof or work or proof of stake model as are the current industry standards for cryptocurrencies, to other consensus mechanisms like proof of intelligence. This could be for higher-level blockchain thinking smartnetwork operations rather than simple transaction recording. In one way, proof of intelligence could serve as a reputational qualifier; as a proof of ability to participate. In another way, proof of intelligence could be an indication that some sort of 'mental' processing has taken place. For example, a new concept, idea, association, or knowledge element has had to have been generated to provide the skin-in-the-game for the consensus, to demonstrate the miner's bonafide status in registering the transaction and receiving the Mindcoin, Ideacoin, or other system token rewards. Proof of intelligence could be used in different ways as a reputational commodity in blockchain thinking networks.

C. Ideas as the Currency of Thinking and Demurrage Redistribution

Another way that blockchain concepts might be used in Blockchain Thinking is by taking advantage of their property as infrastructure for administering and coordinating system-wide behavior, especially through economic principles. Ideas are the currency of thinking, and blockchain architectures might be used to encourage, facilitate, and incite ideation. Ideation processing, the generation of new ideas, is perhaps the highest order of processing available to Blockchain Thinkers. Ideas could be conceived as a *demurrage* currency that could be redistributed on demand. For thinking system optimality, there could be different kinds of incitory resources distribution mechanisms. A Dapp could automatically redistribute any currency-as-commodity within the system. In the case of a Blockchain Thinker, ideas, potentiation, information, entropy, or other stimulation resources could be examples of currencies that power the system and might be periodically distributed or redistributed in an incitory manner to produce a higher rate of idea generation.

V. Outputs

Outputs is the third element in the *inputs-processing-outputs* architecture. Outputs might be in the form of actions, feedback loops and notifications back into the process or system, or smart contracts enacted for some future situation. Blockchain Thinkers might be writing files to storage, conducting economic transactions, or engaging in other forms of action-taking. One important class of output is the higher-order goal, objective, or utility function of the system, and assessing the system's achievement of this. Blockchains are well-structured to instantiate, track, monitor, fine-tune, and report on such overall goals, objectives, and utility functions of blockchain thinking systems, particularly with smart contracts. The claim is that any form of digital thinking and digital processing could be coordinated and governed by blockchain-based smart contracts. The higher-level goal set of autonomous or semi-autonomous Blockchain Thinkers would be to maximize their smart contract-based utility functions. These utility functions would be part of the constitutional setup envisioned for Dapps, DAOs, and DACs, but specialized to the needs and operations of thinking.

A. Using Complexity Science to Instantiate Blockchain-based Utility Functions

Mathematics from complexity science could be used to help develop and structure blockchain thinker utility functions for implementation in smart contracts. The first task is specifying the different variables to comprise a utility function, and their interrelation. Some of these variables could include economic sustainability, ideation, growth and learning, contribution, and equanimity. The second task is specifying assessment and measurement metrics for the variables, ideally quantitative and qualitative since both are needed to have a full representation of a balanced and happy human. The most basic human utility function might be articulated as 0.33 Sleep + 0.33 Work + 0.33 Play. This function could be implemented with coefficients for the different life areas being derived from daily time spent in the activity, automatically tabulated via cell phone and wearables data. This sample utility function outlines the basic quantitative measure of the time spent in each activity area for a balanced day. Complexity math could help to configure both the qualitative and the quantitative. The variable coefficients or Eigen values could be the instantiation of quantitative measurement, and qualitative optimization could be through their interrelation, assessed by standard complexity techniques such as fat tails, high coefficients, degrees of correlation, fractal behavior, and nearest neighbor analysis. A model optimizing for human happiness would have not only a general daily equation with quantitative and qualitative measures, but also comprehend system dynamism and variation at the level of other time frames. For example, it is known that variability is perhaps the most important feature in human happiness practices [26]. Instantiating utility functions with complexity math might more readily allow other complexity concepts to be implemented too. These could include simultaneous multi-level fractal intelligence, and shifting intelligence more explicitly into the structure of a power law, meaning being able to grow at an exponential, though measurable and possibly controllable, rate. Different forms of Blockchain Thinkers could be instantiated with different utility functions, using the blockchain structure as an AI sandbox for testing arbitrarily-many combinatorial permutations of parameters such as intelligence functionality and behavioral ethics.

B. Enacting Friendly AI with Blockchains

The discussion of blockchain thinkers, smart contracts, and utility functions raises the specter of Friendly AI: how to develop machine intelligence that is beneficent to humans. What is notable about blockchain technology is that perhaps for the first time, it is a credible model of checks-and-balances by which Friendly AI could be realized. First, blockchains are

code, which is the language of machines; readily understandable and executable by digital entities. Second, blockchains are not just code as in any AI system, but code in the form of a permanent transparent public record that can be reviewed and inspected by any party at any time; so it is known what the AI is doing. Third, not only is it known what Blockchain AIs are doing, they will not be changing their behavior after the fact since "code is law" and cannot be modified once set to run. Smart contracts will run inexorably in the future carrying out whatever has been specified; they are not open for breach or discretionary compliance as are their counterparts, human-based contracts.

Most importantly, fourth, consensus as a feature of blockchain technology suggests that interactions between cooperative moral players within a society could be enforced [27]. In decentralized trust networks, an agent's reputation could be an important factor in whether its transactions can be executed, such that the transactions of malicious players are not recognized on the network. It does not matter if malicious players masquerade as bonafide players since the reputation requirement and network incentives elicit good behavior from all players, malicious and bonafide alike, similar to the situation of the often-productive existence of sociopaths in human society. Some of the key smart network operations that a Digital Intelligence might want to execute are identity authentication and validation, secure access to resources, and economic exchange. Effectively, any important network transaction that intelligent agents need to fulfill their goals could require some form of access or authentication that is consensus-signed, and which cannot be obtained unless the agent has a good (benevolent) reputational standing in the smart network. This is how Friendly AI could be effectuated in a blockchain-based consensus model. In fact, the checks-and-balances, open tracking, and inspectable operations features of blockchains might make them the perfect venue for responsibly innovating Friendly AI. , including with the previously mentioned blockchain as AI sandbox idea.

VI. Conclusions

Blockchains are a new form of information technology that might have several important future applications. One is blockchain thinking, formulating thinking as a blockchain process. This could have benefits for both artificial intelligence and human enhancement, and their potential integration. Blockchain thinking is proposed as an *input-processing-output* computational system with several features. First, memories and all input elements are seen as discrete units that are encoded, stored, and universally-accessible, perhaps with multiple copies and versions (such as the soft-hashing of ideas in development). Second, processing might be instantiated in a massively distributed architecture that is not available in human brains, yet still comprises the non-linearity of human thought. Third, the outputs of blockchain thinking might include the ability to realize smart-contract based utility functions, instantiate thinking as a power law, orchestrate digital mindfile uploads, advocate for digital intelligences in future timeframes, and facilitate the enactment of Friendly AI. Blockchain thinking might give rise to new forms of consensus models such as self-mining ecologies and proof of intelligence, and make use of *demurrage* principles to redistribute brain currencies like ideas and potentiation. Blockchains and blockchain thinking might be not just a tool for the immediate progress of intelligence, but also for the longer-term transition to a world of multispecies intelligence living cohesively and productively in digital societies.

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