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Decentralized Blockchain for Autobiographical Memory in Cognitive Robotics

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Abstract

Memory in biological beings is as complex as the rational complexity of that concrete being requires. Clearly, memory helps to conform knowledge bases to serve the needs of the specific natural being. To analogize from Robotics concepts, it seems that the degrees of freedom in the biological being's memory are higher or lower depending upon the rationality of each living being.

Robots and artificial systems appear to require analogous structures. That is, to build a reactive system, the requirement of memory is not highly demanding with respect to the degrees of freedom. However, the required degrees of freedom seems to grow as the ability of the artificial system to deliberate increases. Consequently, to design artificial systems that would implement cognitive abilities, it is required to rethink memory structures.

When designing a Cognitive Artificial System, memory systems should be thought of as highly accessible discrete units. In addition, these systems would require designs in the form of distributed architectures with non-linear features, such as those of human thought. In addition, they should allow for complex mixed types of data (text, images, time or so).

Blockchain has attracted great interest for a few years now, especially since the appearance of Bitcoin. A blockchain is a distributed ledger that combines an append-only data structure designed to be resistant to modifications, with a consensus protocol [1, 2]. This innovation can be thought of as a sequence of containers, the blocks, that store two things: the information of a "system" and the "service" that such system provides [2], and it provides an interesting starting point to rethink memory systems in robots.

Keywords: cognitive robotics, artificial emotion, robot memory, robot self, robot episodic memory, artificial intelligence, blockchain, bitcoin, ethics, metaverse, emotion, memory y cognitive systems

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1. Introduction

Already in 1950, in his work “Computing Machinery and Intelligence”, Alan M. Turing pondered whether a machine could think, being convinced that there were no arguments to deny this possibility [3]. By 1937 he had proposed a mathematical formalization of discrete finite state machines, with the possibility of being reconfigured to represent computable numbers [4]. He referred to computable numbers as those numbers whose decimals should be able to be calculated by finite means, arguing that—just as it happens with humans—memory is necessarily finite. By decoding Enigma with its universal machine, during the Second World War, he proved his theory. This machine was capable of replicating finite state machines, reconfiguring itself every day to solve the bases on which the Germans encrypted their messages daily, thus achieving an “intelligent machine” that would change the course of history. With this result, his idea of increasing the intelligence of a machine continued for the rest of his life, convinced that the intelligent capacity of a machine would be related to its ability to acquire knowledge.

The term Artificial Intelligence (AI) was first introduced by John McCarthy and Marvin Minsky during a workshop at Dartmouth College in 1956 [5]. The goal of these researchers was to design human cognitive abilities such as reasoning, decision making, and planning using machines. A year earlier, Herbert Simon and Allen Newell developed Logic Theorist, the first Artificial Intelligence as a computer program, which was able to prove 38 of the 52 theorems in Whitehead and Russel’s Principia Mathematica. In 1965 Edward Feigenbaum and Bruce Buchanan of Stanford University began work on DENDRAL [6], an Expert System intended to model human reasoning in an application. This was the first expert system that automated decision-making and problem-solving processes, based on hypothesis modeling. Later, the design of Expert Systems became a generally accepted field creating the areas of Knowledge Based Systems (KBS) and Systems Based in Rules (SBR).

Technology has been evolving to the extent that electronics and microelectronics have developed into increasingly powerful processing systems and chips. Today we can witness the prodigious learning capacity of our machines, and their ability to solve problems with an efficiency that humans cannot match. Nonetheless, even though our machines can work with unsurpassed efficiency, they do not have the autonomy to think in the sense of intent and willingness. Our robots do not act to enhance self-benefit. They do not create knowledge to solve scenarios that could adversely affect them nor develop any type of self-reference to appraise its own benefit. Thus, our machines cannot change the operation for which they have been designed, whatever the danger or negative effect it has on them or even on the human-being.

Robotics and Artificial Intelligence go hand in hand in this challenge of seeking for an artificial intelligence analogous to that of the human being, and new lines of study have been created as a result of this challenge. Cognitive Robotics has spent several decades searching for autonomous systems in the widest sense of this term: intelligent systems capable of being aware of themselves and thinking. Following this challenge, over time, highly relevant architectures have been developed to integrate knowledge, so that artificial systems can become creative, capable of manifesting consciousness or having autonomy to change their own rules ([7–12] or [13] among many other classics). However, although great progress has been made with widely accepted results, the truth is that machines still cannot think as human beings do.

If we refer to an autonomous system under the conceptualization of the capacity of a system to not rely exclusively on the prior knowledge of its designer, we think on an early idea of an intent-based machine. That is the ability to derive its own chain of conclusions, leading to some type of desired goals. And, to allow for an autonomous system of this class, some awareness concerning self-references and self-goals should be required.

This requirement is not trivial since it behooves creating information, rather than simply learning or reconfiguring what has already been defined. However, creating information approaches the concept of "creativity" when we understand it as the ability to link concepts from different sources. A link is a loop in a chain. The way in which the system ascertains a proof, or decides what is true or not, from different pieces of information, their "source", is determined by the previously designed logic that the system has. The relation between a block of information and another block of information that follows from it, is part of an entailment made by algorithms designed for inference.

Artificial systems are highly efficient on using rules and knowledge bases, learning and making inferences, in the sense that they can integrate, use, and manage data. Inference rules are applied to derive chains of conclusions to lead towards desired goals. System goals have already been decided beforehand, as it is required in the design of intelligent systems. However, what about letting the system use its own references or goals? If a system were to be able to determine its own goals, it would be able to derive unpredictable chains of conclusions that would lead to its desired goals.

To allow for the creation of new goals, it is necessary to change the point of view with respect to the design. The result of an inference is based on a compilation of knowledge relinquished into a rule-structured knowledge base. To make decisions, machines make deductions by using an inference engine that uses rules and knowledge base. However, to let the system make unpredictable decisions, we need to rethink the process of knowledge base construction (knowledge engineering).

Knowledge bases require that engineers delineate the range of questions and the types of facts for each specific problem domain. Thereafter, engineers need to design the assembly of the relevant knowledge, encode knowledge and design queries, inference procedures and answers. The process of engineering knowledge requires goals that are decided by the designer. Nonetheless, it is not about engineering knowledge but about the system constructing its own knowledge. To this end, the system requires some type of self-reference to be aware of its needs. Furthermore, the system requires enough degrees of freedom to choose links between memory blocks, while searching to address its own needs.

2. *The role of emotion*

Autonomy refers to the capacity of a system to not rely exclusively on the prior knowledge of its designer. In artificial learning, we refer to modify and increase knowledge from what the system perceives, so that after a interactions with the environment, the system gains autonomy.

However, designers need to specify the domain of the problem so as to design the type of solution that the system perform. One of the main tasks in robots design is to model the problem environment: A second task, is to fulfill the additional requirement of designing their performance. Consequently, any type of robot's intent, awareness, or willingness comes from their designers decisions. They do not create their own goals nor their own knowledge.

In nature, the autonomy of biological systems is deeply influenced by their need to maintain a natural systemic balance. The intent or willingness of these systems will change depending upon their environment and their own needs, and their behavior and decision making are intently related to maintaining or improving their well-being. One might even say that systemic balance is manifested in a feeling of well-being. Natural beings act to enhance benefit, and creativity suddenly appears to solve scenarios that could adversely affect the goal of benefit. So that, the goal of natural systems seems to be some self-reference to benefit.

Furthermore, emotion could help designers draw the system's beliefs. In science, the being's believes have been thoroughly studied from different angles. Some theorists accept that a belief "presupposes at most self-representation" even when other authors argue that it can be tokened without solving the problem of (self) consciousness. So that, what it seems to be the key is the feature of the Self [14].

Currently, artificial systems do not have self-references, or self-awareness nor willingness. Consequently, they cannot identify goals chosen to improve their own conditions. They are not able to operate with the ability to continuously maintain their systemic balance, nor are they able to activate behaviors not previously designed. Hence, they cannot build responses to the situations raised by their environments with the aim of maintaining their "well-being".

Even without an accepted universal theory, emotion is generally argued as a cognitive process of biological beings that prepares them to adapt to the environment in which they live, thus helping to improve their survival [15, 16]. It forms a set of processes that influence their ability to reason, and that leads them to optimize their ability to make decisions and behave in search of their survival and well-being [17–20] among other classical theories widely accepted.

The argument that systems search for systemic equilibrium is not new. Already in 1947, Ashby proposed that, in a system, any transition from one equilibrium state to another requires the appropriate selection of a series of states that determine a decisive stability [7]. Somehow, perception helps natural beings sense their own systemic equilibrium under the form of "well-being", and perception involves the reference of the Self.

Thus, to build artificial systems that Self maintaining their "well-being" we need to endow systems with some type of Self-reference. That is, to build artificial systems with the ability to select that set of intermediate states, towards some goal which provides profit regarding themselves (goal towards an improved systemic equilibrium).

Biological Emotions began to be of interest and to be studied at the end of the 19th century, when attempts to elucidate their operating principles, their biological objectives, and the physiological processes that they trigger, were started [21–27]. More recently, studies by Damasio [28] and relevant authors such as Oschner [29], Lewis [30] or Miller and Cohen [31], among others, revealed the adaptive nature of the biological Emotional response. It seems that Emotions help to evaluate the environment and its influence on the well-being and balance of living beings, something that Damasio has explained from an interesting systemic perspective [28].

Appraisal theories of Emotion began to gain relevance with the work developed by Arnold [32], who understood Emotion as a process through which biological systems assess relevant stimuli from their environment. The understanding of Emotion as a cognitive evaluation process is widely accepted nowadays ("Cognitive approach of Emotion") and has given rise to very relevant works in the field of Artificial Intelligence (see as classic examples the works of Ortony [20] or Bartneck's [33]). Without going into the depths and details of the complexity of the Emotional subjective experience, it is generally accepted that Emotions serve as feedback loops for living beings.

This notion of feedback loops to obtain information from the environment and the consequences that certain behaviors have on that environment has been successfully applied to artificial systems [34]. From the classic thermostat to complex modern control systems, control loops constitute the functional basis for designing operating strategies that maintain systems at desired balance points [25] or have Self-adaptive capabilities to achieve those balance points [35].

The extent to which Emotion helps detect goals to profit is the reason why it is assumed as a key factor for Self-adaptation to the environments of natural beings. This essential feature of Emotion has been used to propose it as a cornerstone for intelligent decision making (the ability to manage resources) [36–38]. Furthermore, now the question researchers propose is whether an artificial system could be intelligent without Emotion [39].

Also, the connection between Emotion and the ability to resolve relevant stimuli in a complex environment is deemed highly significant. In particular, the ability of the Emotional process to increase the efficiency in the use of the resources, by effectively selecting at each moment those Emotions that are necessary to respond to that environment. This could be considered a way to identify and select subsystems of necessary resources, from among those available in a complex amalgam such as that of biological beings, and of discarding those which are not needed at that point in time. The complex vision that Magee and deWeck [40] had of artificial systems seems to have found a resource to optimize the work of their decentralized internal system structures and subsystems: artificial Emotion. An idea that, despite being increasingly accepted, still constitutes a great challenge for Artificial Intelligence and Cognitive Robotics: design artificial Emotions, to increase the autonomy and intelligence of machines.

3. Artificial emotion

As explained above, living beings are provided with a sensory system that allows them to perceive and measure their environments. And it is through their senses that they recognize a whole range of physical changes, and take in information about the world. This is how they interact with the world around them. Perception mechanisms integrate not only physical signals from senses, but the subsequent analysis on the basis of cognitive processes which uses self references to appraise that world, the one from which signals come from [41]. This ability seems to provide natural beings with an improved adeptness and flexibility to survive, since they are aware about what happens and how the world affects them.

Analogously, this can be transferred to the evaluation of the shortcomings that our artificial systems, our robots and in general our machines, currently have. They use sensors to get information from the world, and they process the information that comes into them with a very high degree of efficiency. Nonetheless, they cannot relate the sensor's information relative to self-references, nor they perceive such as biological beings can. Thus, they cannot aware what happens in the world nor how the world affects them.

Emotion seems to play a principal role in this objective of "the feeling of what happens". Under Damasio, references to the Self are required to relate the world to the concrete needs of beings to adapt and survive and to manage efficiently their resources [28, 42]. The path towards the development of a complex intelligence seems to require the analysis of emotion.

This idea configures an scenario where artificial emotion might help to provide measures related to Self-references. Artificial emotion seems to provide meta-objectives destined to guarantee an optimal systemic balance with respect to an "artificial Self", a systemic balance which can be assumed as a sort of "well-being".

The operation of the artificial Emotion would show an image of this balance to the system to help the system represent its own state and thus exploit its resources to optimize it. Therefore, the process of the artificial Emotion would determine the behavior of the system resulting from changes related to the systemic balance of the robot, either in positive or negative ranges. And the systemic balance would be controlled through the fulfillment of emotional goals.

Let us imagine that the artificial Emotional system could create an abstract environment internal to the machine, provided with a "space of emotional evaluations" that coexists with what it receives from the real world through its sensors. These evaluations would have an influence on the reasoning processes integrated in the machine, and therefore on its response. In this context, emotional actions or behavior are not triggered without previous causes (causes that are related to the Self references). The physical signals coming from the surroundings are measured by the sensors, and this allows the artificial system to deal with its external environment, that is, the real physical world where it operates. The artificial Emotion would be in charge of translating what these external signals and the response of the system both mean for the robot itself. In short, it would be measuring the physical environment, the impact of the physical environment related to the general state of the robot, the response of the robot, and the appraisal about the feedback from the environment after the response of the robot.

This conceptualization leads to additional levels of abstraction with respect to what we have now. Artificial emotions would serve to detect inconsistencies in the relationship between the system and its environment. A high-level abstraction feedback loop, the concept of feedback being another of the argument bases for the intelligent behavior of biological beings [36–39].

If we make an analogy between the systemic equilibrium and the system's well-being, the artificial Emotion will appear as a "potential" or "resource" destined to trigger meta-commands to stabilize patterns of well-being within each dimension of evaluation. Ergo, the Emotion would be a meta-adaptive engine designed to provide artificial systems with transversal adaptability, through various levels of abstract operations established within the system itself. Furthermore, since we accept this transversal operation of artificial Emotion, we will assume that the operation of this meta-adaptive engine is mostly distributed. From this perspective, the final objective of the artificial Emotion would be to transform some type of environmental information into another type of information that is relevant to the well-being of the machine, that is valued-based knowledge. This way, machines could measure their well-being and act with the objective to maintain or improve it.

Accordingly, we consider artificial Emotion to be a distributed meta-adaptive engine intended to cause transversal adaptability, in order to provide the means to control the systemic balance of our machines.

4. *Emotions and autobiographical memory*

The Emotional effort of beings seems to be deeply related to perceptions and some type of references to the Self. Also, the usefulness of Emotions appear to be strongly connected to the identification of goals for Self-benefit. And the identification of goals for the own benefit suggest a relation with a positive derivative towards the "well-being" or systemic equilibrium of the system.

Under Damasio, memory in biological beings is highly complex. Furthermore, this author defends memory is related to experiences and is connected to their "Self", being fundamental in the Emotional process since they maintain references helping to build emotions [40].

The work of Conway and Pleydell-Pearce [43] describes Autobiographical Memory, Emotion and essential features of the Self like a federated work (among them) in natural systems. This work of Conway and Pleydell-Pearce conforms an essential support to our contribution: it argues that the Self-referential characteristic of biographical memory is what differentiates it from other memories.

Conway and Pleydell-Pearce consider that Autobiographical Memory is of key significance for Emotion and for the Self, assuming that this memory is a complex set of dynamic and transitory mental constructions that are generated from an underlying knowledge base. The Autobiographical Memory would be characterized by what they called Self-Referring, a differentiating factor with respect to any other type of memory system in biology, and which seems to relate memories with personality factors, with Emotion or with the schemes of the "Self" among others. In fact, they assert "[…] there appears to be a consensus that autobiographical memory and the Self are very closely related, even, according to some theorists, intrinsically related so that autobiographical memory is part of the Self" [43].

A notable feature of biographical memories is that they would contain knowledge at different levels of specificity. The authors identify three broad levels of specificity called (a) Lifetime periods, (b) General Events, and (c) Event-Specific Knowledge (ESK). The contents of a life period (Lifetime) would represent the thematic knowledge with common characteristics in that space, and temporary knowledge about the duration of a period, assuming chronological spaces made up of life periods. The general events (general events) would be considered as more specific and more heterogeneous memory structures, encompassing both events that have been repeated and unique events. However, Conway and Pleydell-Pearce differ from other theorists in their idea that general events can also represent associated events and, therefore, encompass a series of linked memories.

An essential characteristic of general events is that they would present vivid memories of events related to the achievement or failure of personal goals. In this sense, there is again a connection with the science of Emotion, and it is that the so-called basolateral region of our cerebral amygdala (BLA) a structure intimately related to the Emotional process, seems to be associated to the encoding of relevant experiences or memorable events [44].

Last, event-specific knowledge (ESK) is a slightly more abstract concept, strongly related to the concept of image or imaginary abstractions that we keep in our memory. The ESK would help characterize the vivid memories of the events we remember, providing that set of images with which we represent them. This set of images seem to be "introduced" into our minds without apparent order but in response to signals related to the ESKs, and these ESKs would link the images with the general events, a complexity of links to which the degradation of those links should be added over time.

Damasio's perspective on feeling and Emotion is that we humans mentally represent any change in the state of our organism through neural patterns and resulting images. And that if these images occur with a "sense of Self" an instant later (which result in the connections between them), they become conscious experiences (the feeling of feeling) [40, 42]. So, it seems that the "one instant later" feature justifies the validation of the created links to retrieve general events from images in ESK.

Autobiographical memories would provide a basis for generalizations about the Self and "everything else", so recent approaches to the "Self" suggest new ways in which this relationship might be conceptualized. In the case of the authors Conway and Pleydell-Pearce, whose work serves as a basis for us, they would outline some principles that would draw us a relational architecture for a future technological solution. At this point, although the objective of this article is not to provide a final solution but rather a proposal that we consider essential to reach it, to offer a global understanding of the complex functional relationship of the Autobiographical Memory, the Self and the Emotions, we consider necessary to show the principles proposed by Conway and Pleydell-Pearce which serve as the basis for the design of an artificial Emotional system.

Conway and Pleydell-Pearce use the concept of "Working Self" to make a connection with the concept of "Working Memory", a brain structure that integrates central processes to control separate systems. According to this view, Working Self goals are assumed to be a subset of Working Memory control processes, structured hierarchically to constrain cognition and behavior. They hypothesized that the goals of the Working-Self can be considered fundamental artifacts to control the Self-discrepancies established in autobiographical memory, this autobiographical memory being a knowledge base that "limits the range and types of goals that a healthy individual can have. realistically" [43].

In essence, Conway and Pleydell-Pearce contemplated this Working-Self as consisting of three domains [45]: (a) the "current Self" as a precise representation of oneSelf, (b) the "ideal Self" that would establish what one aspires to become, and (c) the "ought Self" related to what has been learned through experience or learning. Based on these three domains, they argued that discrepancies between them would lead to characteristic forms of negative Emotional experience. This argument establishes a good computational framework with respect to our goals, since it provides the basis for building and using dimensions to measure states.

Discrepancies among those self-domains of Conway and Pleydell-Pearce seem to require some type of feedback that will help gather more information with respect to those discrepancies. Feedback on discrepancies could be conceived as negative feedback loops in the same way as those conceived in Control Theory by authors such as Klir [46] where inputs represent 'the state of the world' (the state of discrepancies). A feedback loop is a powerful tool in the design of control system. Feedback loops take the system outputs into consideration, and enables the system to adjust its performance to meet a desired output response. This way, if we take into consideration the theory of Conway and Pleydell-Pearce, if negative emotions appear this implies the existence of discrepancies which might be measured. In this manner, emotional goals might be those which allow for maintaining balance among the self-domains of the systems and, consequently, those that help maintain their "well-being").

This comparison is conceived under the evaluation of a complex structure of competing goals that are responsible for the generation of emotional experiences, as by Oatley *et al.* [47]. The relationship between the Working-Self and the General-Events of Conway and Pleydell-Pearce, would be justified under the idea that vivid memories would arise in response to experiences that would closely relate to the "Working-Self" and the "General Events" of the "autobiographical memories". Here, the extent to which individuals can effectively use appropriate cognitive reactions to deal with dissonant memories is positively related to their sense of well-being, suggesting that memory control is necessary for emotional control.

That is, we could consider that positive emotions could reflect an acceptable rate of discrepancy reduction, while negative emotions would reflect an increasing failure to reduce these discrepancies between the three domains of the Working-Self. The perspective supported by Conway and Pleydell-Pearce becomes a perspective where the objectives of resolving discrepancies in the Working-Self domains would serve as artifacts for the Self-governance of the system and would be closely linked to processes and structures of the cognitive system such like autobiographical memory, in a complex amalgamation of functional relationships.

5. *Autobiographical memory as an underlying blockchain*

Autobiographical memories seem to provide the means for Emotions, but do not appear as simple structures to storage knowledge. Memory in natural beings is extremely complex because of its structure, relations, links and performance. It is difficult even to elucidate the processes used by the memory, even when relevant approaches are proposed [47].

Clearly, memory in artificial systems needs to ensure sufficient degrees of freedom. The conceptualization of autobiographical memory might allow us to provide a computational means to implement mental-type processes to support Emotion. Since the biographical Self is linked to the Self goals, and the Emotional system acts as a control system to keep discrepancies in check, the entire structure i.e., goal control under the Emotional system and autobiographical memory, is a complete system which could transmit signals from part to part. In this way, any thought (i.e., image, abstract representation, etc.) that can become any goal estimation discrepancy will trigger the same processes as if this discrepancy is caused by an event that comes from the real environment.

Technologically, an artificial autobiographical memory requires to offer flexibility and degrees of freedom enough to support complex processes such as those of Emotion. At the same time, the technology for an autobiographical memory needs to characterize processes such as the representation of separate experiences according to different Emotional experiences, to relate all of those representations, and to give solution to those arguments of Conway and Pleydell-Pearce.

Blockchain has attracted great interest for a few years now, especially since the appearance of Bitcoin [48]. This is a complex technology of a large-scale distributed blockchain system, where the operation is based on distributed ledgers (DLT) [1, 2]. Although one of the greatest stumbling blocks of this technology is the evaluation of its performance [17, 49], the truth is that, as Turing said, the memory of the human being does not have to be infinite, but it is assumed limited. Given that this limitation does not refer to storage space but to performance capacity, the Blockchain technology does not limit us for our purposes [3].

A blockchain is a distributed ledger that combines an append-only data structure designed to be resistant to modifications, with a consensus protocol [1]. This innovation can be thought of as a sequence of containers, the blocks, that store two things: the information of a "system" and the "service" that such system provides [2]. The blocks may contain any type of data records such as orders that transfer crypto-tokens, or application and execution orders written in the platform-supported language. These application codes or "smart contracts", encode arbitrary processing logic, such as agreements. The interactions between the parties to the contracts and the platform are based on messages called transactions. These may hold orders to transfer tokens or calls to the smart contract functions [49, 50].

In a blockchain, subsequent blocks are linked to each other with a cryptographic hash function that secures their incorruptibility. The chain grows as new blocks are added after the acquiescence of the network of participants running a consensus protocol who must agree on the fairness of each transaction stored within the blocks before any block is added to it. The consensus nodes maintain a replicated state of the blockchain and are incentivized to perform these works with the fees they receive for these activities.

Although the better known blockchains are public, there are also consortium and private blockchains [51]. In table 1, we summarize the characteristics of various Blockchain groups [52, 53].

In 1997, Nick Szabo introduced the term 'smart contract' describing it as a 'computerized transaction protocol that executes the terms of a contract' [54]. For distributed ledgers, it commonly refers to a set of instructions sent to the network that will be executed automatically by nodes when conditions are met. The conditions that trigger the actions may refer to a signature, a transfer of tokens, or an update of the ledger. Such as in memory, chunks of instructions might be sent to the underlying knowledge base of the memory, and blocks of memories can execute when conditions met (any reference about identity, updates about learning, or so on).

A smart contract can be deployed in a blockchain that keeps track of state of the things and are executed by the nodes of the network. Through the use of smart contract functions, the blockchain can be operated to orchestrate digital memory files in the present and for the future. Thus, blockchain thinking is a key future

Table 1. Blockchain groups.

Public	*Permissionless*	The consensus mechanism is done by miners but is open to anyone who can make the necessary investment to participate.
	Permissioned *	Everyone with an internet connection can transact and see the transaction log, but only some nodes can participate in the consensus.
Private	*Permissionless*	Restricted with respect to who can transact and see the transaction log, but the consensus mechanism is open to anyone.
	Permissioned *	The consensus mechanism is done by one organization. The owner of the blockchain decides who participates in the system.
Consortium	*Permissioned* *	The consensus is done by a set of selected nodes because consortium ledgers are typically governed by an association made up of companies and organizations. The implication is that there is no competition among the nodes on the network. In some there is no notion of block reward, in others, one has to obtain a permit to become a node, or there may be just a group of fixed chosen nodes controlled by the association. This results in a high degree of centralization.

*A permissioning system grants access through "accredited" management. The common models are require accreditation to reach the node network, or to access the user network limiting participation in the consensus process. Here there is a trade-off between gained efficiencies, and high centralization and dependence of a company or association. Often, these models offer less transparency, more susceptibility to being censored, and higher barriers to integration.

application that can develop from these, if we structure thinking as a blockchain process.

This process could be thought of as an *input–output* system with at least the following characteristics [49, 50]:

(a) Memories and other inputs are discrete units that are encoded, stored, and generally accessible.

(b) Processing may be done through a distributed architecture that includes the non-linearity feature of human thought.

(c) Outputs may include the capacity to initiate smart-contract based utility functions, and so on. In addition, outputs can also be employed to register into the ledger data such as text and images.

The key principles to the blockchain underlying the technology are [2, 55]:

(d) Computational Logic: blockchain transactions can be tied to computational logic and be programmed. Thus, algorithms and rules can be easily set up to trigger transactions.

(e) Irreversibility of Records: all transactions entered update the network in a way that the recording is permanent, chronologically organized, and available to any person entering the network. To reverse a transaction one needs to create a new transaction that works opposite to the first. This way, a "healthy" memory system can be ensured.

(f) Distributed Database: all parties in the network have access to the entire database and no single node controls any aspect of the information in the network. Records can be verified directly without the assistance of a third party. Distributed control of memory is essential to the objectives of this research.

(g) Peer-to-Peer Transmission: communication occurs directly between peers. Each node stores and forwards information to all other nodes. This feature helps to think on different ways of thinking [A1] or fast emotional bodily changes [41].

(h) Pseudo anonymity: transactions occur between blockchain addresses. Still, paths and flows of transactions can be followed if required.

(i) Security: private keys, strong cryptographic techniques, and the universe of the large numbers protect the access, a requirement for complex and high density memory systems.

The blockchain's capacity is further enhanced by the fact it delivers a notion of discrete time, for instance the delay until the block is minted. It is highly interesting further explore the properties of Blockchain if it can provide such a clock in our context. One possibility is the "abortion of operations" a process allowing the machine to reconsider an earlier decision in the face of new information or feedback it may receive from its references or from its Self. On the other hand, this clock can also be used to punish "aborting" machines when and if necessary to ensure the stop of the machine if task cannot reach success (without the requirement of define at design time the exact moment to stop). To give an example, we could let the machine appraise the moment to which it should stop and search for new options.

Clearly, the architecture of a Blockchain-based Autobiographical Memory system, needs a deep research to elucidate the structure of the system. It will comprise components, properties and relationships which should be based on relevant works such as the one we are using of Conway and Pleydell-Pearce. Requirements for building a memory architecture and works on neurology that provides theories under a systemic viewpoint, will provide an important meeting point for our research objectives. We are basing our search on Blockchain under the assumption of that it will provide ability to fulfill those requirements that an Autobiographical Memory needs in Cognitive Robotics.

6. Conclusions drawn

Going back to Conway and Pleydell's approach to Autobiographical Memory, the contents of a Lifetime would represent a thematic knowledge with common characteristics in that field, such as moments related to the working life. These contents integrate knowledge that carries the temporary variable (the duration of that period, moment, etc.), so we must add chronological spaces associated with Lifetime. This leads us to a complex structure of memory blocks related to each other based on common field characteristics, and which in turn is related to another complex structure of chronological memory blocks that affect these blocks and other structures.

In the case of General Events, they could be considered more specific and more heterogeneous memory structures, different from the previous Lifetime ones, since they cover knowledge and its repetition over time, and are once again related to another chronological memory structure. In addition, these General Events represent events associated with each other, which leads us to think of a new relational form between blocks of knowledge.

The ESKs are even more abstract memory concepts which demand an even greater complexity to implement a computational solution that outputs this concept. They are related to the abstract "image" that we keep in our memory and that we turn into the "representation" of a concept. That concept may be the feeling of an Emotional process (as described by Damasio [41]), but it seems that these abstractions of representation appear and remain related to the structures of memories and the memory. It appears that they help to characterize memories and provide images of them (a limited set of images) and relate them to General Events. This, again, constitutes a relational complexity that, in addition, suffers temporary degradation as time goes by.

Both, Conway and Pleydell as well as other relevant authors such as Damasio imply memory as an essential factor in the Emotional process, and the Emotional process seems to be an essential factor in the formation and the determination of the will of the machine. Just as the work of a robotic arm is characterized, among other factors, by its degrees of freedom, the memory of an artificial system should be thought of in the same terms. The degrees of freedom of a robotic arm determines its ability to move in space and, therefore, its greater or lesser capacity and flexibility to position its tool at a given work point.

One of the great problems of memory architectures for intelligent systems is the lack of a high number of degrees of freedom, and this limits the possibility of positioning in more complex reasoning. This leads us to think about the need for memory architectures that increase the degrees of relational freedom between the different types of memory blocks.

The Blockchain allows us to conceptualize memories as a process of blockchains, decentralized and with the capacity to considerably increase the degrees of freedom of the knowledge bases [53]. The concept and architecture that Blockchain technology proposes, allows us to think about the use, not only of those memory structures demanded in the context of an inference or decision making of a machine, but also of involving underlying structures or related in a distributed way, from apparently unrelated memory contexts in a first degree of connection, increasing resolution complexity and artificial cognitive capacity.

The increase in the degrees of freedom of a memory refers to the relational flexibility of the knowledge blocks of that memory. We could think not of knowledge bases, but of interrelated knowledge base structures, and inferences based on distributed information and rules. The data is integrated not only from a sensory source or direct knowledge base, but can be recorded and structured as transactions, instantiated in memory block chains, stored (learned), managed, or with determined and conditioned access management, for example.

Turing increased the intelligence of his machine by increasing the degrees of freedom of his memory using functions, increasing the abstraction in the configuration of the discrete states of his machine. Blockchain thinking might may make use of penalties and rewards to redistribute brain currencies like ideas and potentiation. The benefits this system provides for organizing, storing, and accessing information ensures a number of benefits including: Immutability of past transactions, Security, Verifiability, and Resilience.

Data availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of interest

All authors declare that they have no conflicts of interest to disclose.

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