Was Collective Intelligence[1] before Life on Earth?

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Abstract Collective Intelligence (*CI*) is formalized through a molecular model of computations and mathematical logic in terms of information_molecules quasi-chaotically displacing and running natural-based inference processes in the environment. *CI* abstracts from definitions of a communication system and Life. The formalization of *CI* is valid for social structures of humans, ants, and bacterial colonies. A simple extrapolation of the definition of CI suggests that a basic form of *CI* emerged on Earth in the "chemical soup of primeval molecules", before well-defined Life did, since *CI* is defined with fewer and weaker conditions than Life is. Perhaps that early, elementary *CI* provided basic momentum to build primitive Life. This successful action boosted a further self-propagating cycle of growth of *CI* and Life. The *CI* of ants, wolves, humans, etc. today is only a higher level of *CI* development. In this paper we provide formalization and a proposed partial proof for this hypothesis.

1. Introduction

We can ask, "What is the relationship between *Life* and *Intelligence?*" We can now build computers able to win chess matches against top masters and to emulate intelligent behavior of animal/human problem solving, but we do not attribute *Life* to such an artificially *intelligent* computer. There are research efforts tackling this problem, e.g. analysis of *Life* through its complexity e.g. [12], attempts to define and simulate *Artificial Life* e.g. [11], etc. Such attempts increase the depth of our knowledge, but still the question remains "How are *Life* and *Intelligence* related?" Formalization of *Collective Intelligence* [15], [16] sheds some light on this problem. The formal definition of *CI* has only three requirements. Information_molecules must emerge in a certain computational space (CS), and such CS can be almost anything: chemical molecules, software agents, ants, humans, or even social structures like cooperating villages. Later on some interaction must emerge between CS, which in a given environment results in the ability to solve specific problems. The emergence of *CI* is viewed in terms of the probability that specific inferences will result. As a result of this restricted set of requirements, we can analyze the problem of the *CI* of human social structures and we can as well go down to the edges of Life, to biofilms of

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interacting bacteria in bacterial colonies [4] considered as collectively intelligent [3], [5], [6]. We cannot at this moment provide direct evidence that viruses or prions cooperate and create any CI; however - indirectly we can claim it by referring to the DNA computer [1]. Molecules in such a system are able to run inferences (computations) like a digital computer running an Expert System [10]. They are not alive at all. Moreover, the "conclusions" in such a DNA computer are active chemical molecules, thus able to output, i.e. implement a solution to the problem discovered by this CS. If we look at our present perception of *Life* [13], [14] and *Intelligence* through the complexity of individuals and the social structures they create, it is obvious that it is a dynamic system, and that *Life* and *Intelligence* are interleaved. The question is how does it happen? This paper poses for further discussion the following hypotheses:

- PRECEDENCE HYPOTHESIS: *CI* first emerged (perhaps accidentally) as a result of interacting chemical molecules on Earth.
- HYPOTHESIS ON ORIGIN: *Life* emerged later on, probably from *Collectively Intelligent* activity "looking" for stabilization and how to develop/propagate itself.
- HYPOTHESIS ON CYCLES: Dependency between *Life* (at different levels of complexity) and *Intelligence* (individual and collective) is the consecutive result of a spiral (development cycle) of evolution fired at that time and still active.

In our paper the computational model of *CI* will be briefly given and a definition of *Life* presented. On this basis we will try to demonstrate that *CI* is less complicated, and therefore could emerge more easily on a primeval Earth. A draft of the proof for the PRECEDENCE HYPOTHESIS will be also given.

2. Computational Collective Intelligence

CI can be easier to formalize and measure than the intelligence of a single being. Individual intelligence has only been evaluated on the basis of external results of behavior during processes in real life or during IQ tests. As a result, it is necessary to create abstract model activity based on neuropsychological hypotheses e.g. [7], or to use models like Artificial Intelligence. In contrast, many more elements of *CI* activity can be observed, measured, and evaluated. We can observe displacements, actions of beings, exchange of information between them (e.g. language, the ant's pheromone communication system, the language of dance of the honeybees, the crossover of genes between bacteria resulting in spreading a specific resistance to antibiotics, etc. Moreover, individual intelligence and behavior is scaled down as a factor. Underlying the presented *CI* formalization and modeling are these basic observations:

- In a socially cooperating structure it is difficult to differentiate thinking from non-thinking beings (abstract logical beings must be introduced, e.g. messages).
- Observing a being in a social structure, we can extract, label, and define rules of social behavior, e.g. use of pheromones. However, real goals, methods, and interpretations are mainly hidden until a detailed study is done. Thus use of mathematical logic is suggested to allow describing and simulating *CI*, postponing an interpretation of the clauses that label given elements of social behavior.
- The individuals inside a social structure usually cooperate in chaotic, yet non-continuous ways. Even hostile behavior between some beings can increase, to

some extent, the global *CI* of the social structure to which those hostile beings belong. In the social structure, beings move randomly because needs and opportunities of real life force them to do so. Inference processes are made randomly, most of which are not finished at all. This suggests using quasi-Brownian movements [18] for modeling social structure behavior. As a result, the probability of whether a problem can be solved over a certain domain of problems must be used as a measure for the *CI* of a social structure.

- Resources for inference are distributed in space, time, and among beings. Facts, rules, and goals may create inconsistent interleaving systems, multiple copies of facts, rules, and goals are allowed.
- Most of the concepts of human IQ tests are matched to culture, perception, communication, problem solving techniques, and methods of synthesizing the answer. Thus it is necessary to propose a new concept for testing *CI*, which is absolutely independent from points of view.
- The conditions given above are fulfilled by the efficiency of the N-element inference, with separately given interpretations for all formal elements of the test into real inferences or into a production process. *With this concept, in the same uniform way we can model inferring processes within a social structure, as well as production processes. This is very important because some inference processes can be observed only through resultant production processes, e.g. ants gathering to transport a heavy prey.* Separating N-element inferences from interpretation allows us, among other things, to test the intelligence of beings through building a *test environment* for them, where the sole solution is known to us as a given N-element inference.
- Humans infer in all directions: forward, backward, and through generalization. The N-element inference simulated in this model reflects all these cases clearly.

2.1 Computational model of Collective Intelligence

The 1st level computational space *CS* with inside quasi-random traveling facts, rules, and goals c_i is denoted as the multiset $CS^1 = \{c_1,...,c_n\}$. The clauses of facts, rules, and goals are themselves 0-level *CS*. For a given *CS*, we define a membrane (similar to [2]) denoted by $|\cdot|$ which encloses inherent clauses. It is obvious that $CS^1 = \{c_1,...,c_n\} \equiv \{|c_1,...,c_n|\}$. For a certain kind of membrane $|\cdot|$ its type p_i is given, which will be denoted $|\cdot|^{p_i}$ to define which *information_molecules* can pass through it. Such an act is considered Input/Output for the given *CS* with a given $|\cdot|$. It is also allowable to define degenerated membranes marked with $\cdot|$ or $|\cdot$ i.e. the collision-free (with membrane) path can be found going from exterior to interior of an area enclosed by such a membrane, for all types of *information_molecules*. The simplest possible application of degenerated membranes is to make, e.g. streets or other boundaries. If the *CS* also contains other *CSs*, then it is considered a higher order one, depending on the level of the internal *CSs*. Such internal *CS* will also be labeled with $\hat{v}_j$ e.g.

$$CS^2 = \{|c_1,...CS^1_{\hat{v}_j},...c_n|\} \; iff \; CS^1_{\hat{v}_j} \equiv \{|b_1,...,b_n|\} \; where \; b_i \; i = 1...m, \; c_j \; j = 1...n \; are \; clauses$$

Every c_i can be labeled with $\hat{v}_j$ to denote characteristics of its individual quasi-random displacements. Usually higher level *CSs* will take fixed positions, i.e. will create structures, and lower level *CSs* will perform displacements. For a given *CS* there is a defined position function *pos*:

$$pos: \; O_i \rightarrow \langle position\ description \rangle \cup undefined \quad where \quad O_i \in CS$$

If there are any two internal *CS* objects O_i, O_j in the given *CS*, then there is a defined distance function $D(pos(O_i), pos(O_j)) \rightarrow \Re$ and a rendezvous distance *d*. We say that during the computational process, at any time *t* or time period Δt, two objects O_i, O_j come to rendezvous iff $D(pos(O_i), pos(O_j)) \leq d$. The rendezvous act will be denoted by the rendezvous relation ® e.g. O_i ® O_j which is reflexive and symmetric, but not transitive. For another definition of rendezvous, see [8]. The computational process for the given *CS* is defined as the sequence of frames *F* labeled by *t* or Δt, interpreted as the time (given in standard time units or simulation cycles) with a well-defined *start* and *end*, e.g. $F_{t_0},\ldots,F_{t_e}$. For every frame its multiset $F_j \equiv (|c_1,\ldots,c_m|)$ is explicitly given, with all related specifications: *pos(.)*, membrane types *p*, and movement specifications *v* if available. The simplest case of *CS* used in our simulations is the 3-D cube with randomly traveling clauses inside. The process is initialized to start the inference process after the set of clauses is injected into this *CS*. More advanced examples of the *CS* include a single main CS^2 with a set of internal CS^1 which take fixed positions inside CS^2, and a number of CS^0 who are either local for a given CS^1_i (because the membrane is not transparent for them) or global for any subset of $CS^1_j \in CS^2$. Modeling the *CI* of social structures, interpretations in the structure will be given for all CS^m_n, i.e. "this *CS* is a message"; "this is a single human"; **"**this is a city", etc. As has been mentioned, the higher level CS^i_j will take a fixed position to model substructures like villages or cities. If we model a single human as CS^1_j, then $\hat{v}_j$ will reflect displacement of the human. Characteristics of the given $\hat{v}_j$ can be purely Brownian or can be quasi-random, e.g. in lattice, but it is profitable to subject it to the present form of CS^i_j. When $\hat{v}_j$ has the proper characteristics, there are the following essential tools: • The goal clause, when it reaches the final form, can migrate toward the defined *Output* location, e.g. membrane of the main *CS* or even local *CS*. Thus the appearance of a solution of a problem in the *CS* can be observable. • Temporarily, the density of some *information_molecules* can be increased in the given area of the *CS* in such a way that after the given low-level

CS_j^i reaches the necessary form, it migrates to specific area(s) to increase the speed of selected inferences in some areas.

2.2. The Inference Model for Collective Intelligence and its measure

The pattern of inference generalized for any CS has the form:

DEFINITION 1. GENERALIZED INFERENCE IN CS^N

Assuming that $CS = \left\{ ...CS_j^i ...CS_l^k ... \right\}$, we can define:

$$\frac{CS_j^i \;\text{®}\; CS_l^k \text{ and } U(CS_j^i, CS_l^k) \text{ and } C(\text{one or more } CS_n^m \text{ of conclusions})}{\text{one or more } CS_n^m \text{ of conclusions}, R(CS_j^i \text{ or } CS_l^k)} \vdash$$

■

The above description should be interpreted as follows: CS_j^i ® CS_l^k denotes rendezvous relation; $U(CS_j^i, CS_l^k)$ denotes that unification of the necessary type can be successfully applied; C(*one or more* CS_n^m *of conclusions*) denotes that CS_n^m are satisfiable. $R(CS_j^i \text{ or } CS_l^k)$ denotes that any parent *information_molecules* are retracted if necessary. The standard, e.g. PROLOG inferences are simple cases of the above definition. The above diagram will be abbreviated as $CS_j^i ; CS_l^k \xrightarrow{RPP} \sum_n CS_n^m$ without mentioning the retracted *information_molecules* given by $R(CS_j^i$ or $CS_l^k)$. In general, successful rendezvous can result in the "birth" of one or more child *information_molecules*. All of them must then fulfill a *C(...)* condition; otherwise they are aborted. It is difficult to find examples of direct rendezvous and inference between two CS_i^m *and* CS_j^n *if* $m, n \geq 1$ without an intermediary involved CS_k^0 $k = 1,2...$ (messages, pheromones, observation of behavior, etc.). Single beings like humans or ants can be represented as $CS_{individual}^1$. Such beings perform internal inferences (in their brains), independently of higher level, cooperative inferences inside CS_{main} and exchange of messages of the type CS^0. It will be allowable to have internal CS^k inside the main *CS*, but only as static ones (taking fixed positions) to define sub-structures such as streets, companies, villages, cities, etc. For simplicity, however, we will try to approximate beings as CS^0; otherwise, even statistical analysis would be too complicated. It is also important to assume that the results of inference are not allowed to infer between themselves after they are created. Products of inference must immediately disperse; however, later on, inferences between them are allowed (in [10] this is *refraction*). The two basic definitions for modeling and evaluating Collective Intelligence have the form:

DEFINITION 2: N-ELEMENT INFERENCE IN CS^N

There is a given CS at any level $CS = \left\{ CS_1^{a_1}, ..., CS_m^{a_m} \right\}$, and an allowed Set of Inferences SI of the form $\left\{ \text{set of premises } CS \right\} \xrightarrow{I_j} \left\{ \text{set of conclusions } CS \right\}$, and one or more CS_{goal} of a goal. We say that $\left\{ I_{a0}, \ldots, I_{a_{N-1}} \right\} \subseteq SI$ is an N-element inference in CS^n, if for all $I \in \left\{ I_{a0}, \ldots, I_{a_{N-1}} \right\}$ the premises $\in$ present state of CS^n at the moment of firing this inference, all $\left\{ I_{a0}, \ldots, I_{a_{N-1}} \right\}$ can be connected into one tree by common conclusions and premises, and $CS_{goal} \in \left\{ set \text{ of conclusions for } I_{a_{N-1}} \right\}$. ■

DEFINITION 3: *COLLECTIVE INTELLIGENCE* QUOTIENT (IQS)

IQS is measured by the probability P that after time t, the conclusion CM_{goal} will be reached from the starting *state of* CS^n, as a result of the assumed N-element inference. This is denoted $IQS = P(t, N)$. ■

The above two definitions fulfill all the basic observations underlying the *CI* formalization. The proposed theory of Collective Intelligence allows us surprisingly easily to give formal definitions of the properties of social structures, which are obvious in real life (see [15], [16]).

3. Comprehension and definition of life

Traditionally *Life* has been defined as a material organization, which fulfills certain lists of properties or requirements [13], [14]. The distinction between *alive* and *non-alive* has emerged as the result of "Cartesian "thought in science. Before that, all processes were considered as alive, e.g. clouds. This way of thinking is still observable in so-called "personification" processes, attributing them with human-like behavior. Despite progress in science, we have problems defining *Life* in an efficacious way. For a process to be attributed with *Life*, it must have the following basic properties: ***I) metabolism*****:** a complex of physical and chemical processes occurring within a living cell or organism that is necessary for the maintenance of *Life*; ***II) adaptability*****:** becoming suitable for a new use or situation; ***III) self-maintenance:*** autonomy; ***IV) self-repair***; ***V) growth*****:** development from lower/simpler to a higher (more complex form); or an increase, as in size/number/value/strength, extension or expansion; ***VI) replicability*****:** ability to reproduce or make an exact copy(s) of, e.g. genetic material, a cell, or an organism; ***VII) evolution*****:** the theory that groups of organisms change in time, mainly as a result of natural selection, so that descendants differ morphologically and physiologically from their ancestors **or** as the historical development of a related group of organisms, i.e. phylogeny. Other properties can also be sub-attributed to be properties of *Life*. Most living organisms adhere to these requirements; however, there are material systems which obey only a subset of these rules, e.g. viruses. There are also processes like candle flames, which fulfill most of them, but scientists do not attribute life to. As a result, we can say that *Life* is still a fuzzy concept. Even the properties listed above closely overlap. To help us understand how *Life* developing we should look at theory, e.g. the Proliferation Theory [5].

4. Ordering Collective Intelligence and Life

The hypothesis that *Collective Intelligence* emerged on Earth before *Life* will be demonstrated in the following way. First we will formally define the complexity order for computational spaces CS_i^j. Later, on a complexity axis, (see Fig. 1) we will order all possible CS_i^j which are interesting or could be turning points from a *CI* and/or *Life* point of view. Finally, looking back at properties I-VII required for attributing *Life*, we will point out that it is not probable that *Life* emerged directly, skipping various simple evolutionary steps where *CI* was present.

Definition 4: Strong[2] ordering of *computational spaces* CS^j.

Assume that there are given CS_i^j and CS_k^l composed of elements:

$$CS_i^j = \left\{ CS_{(...)}^{a_1}, ..., CS_{(...)}^{a_n}, \middle| \cdot \middle|_{(...)}^{p_1}, ..., \middle| \cdot \middle|_{(...)}^{p_m} \right\} \quad CS_k^l = \left\{ CS_{(...)}^{b_1}, ..., CS_{(...)}^{b_r}, \middle| \cdot \middle|_{(...)}^{q_1}, ..., \middle| \cdot \middle|_{(...)}^{q_s} \right\}$$

where (...) denotes an unspecified identification number for a given object and $a_{i,}, ..., b_i, ..., p_i, ..., q_i$ *are types*

The key problem is how to locate the point where the property *VI (Replicability)* could emerge. It is well known that many even simple chemical molecules can self-replicate in a favorable environment [9]. However we should remember that self-replicating molecules also take "building components" from their environment, absorbing and processing other molecules. Pure self-replication cannot happen in the real world; otherwise the fundamental principle of "constant mass" will be violated. Here we may find a turning point, i.e. computational space of the structure:

$$CS^1 = \{ | c_1, c_2, ... | \} \quad \textit{i.e. information\_molecules inside membrane.}$$

because according to inference processes, various types CS^1 can be also ordered by Definition 4 as to how they affect CS^1. An inference process can either reduce the number of c_i which automatically moves CS^1 down on the complexity scale (analog of natural selection), or stabilize or even expand it. *CI* as a computational process can also exist as a reduction process, but *Life* with *VI Replicability* cannot go beyond this point. **This validates our PRECEDENCE HYPOTHESIS given earlier.** However, the real *Replicability* can start as early as:

$$CS^2 = \{ | c_1, c_2, ..., CS_1^1, CS_2^1, ... | \} \quad \textit{i.e. first local computational spaces } CS_{(...)}^1 \textit{ emerge}$$

From this point on the complexity scale we can speak about gemmation and gamogenesis. At this time draft proofs of the HYPOTHESIS ON ORIGIN and the

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[2] The condition for ordering can be weakened, e.g. if we require only that elements of the same type must be used, not necessarily in the same quantity.

HYPOTHESIS ON CYCLES HAVE NOT BEEN COMPLETED. We consider them both as highly probable and as subjects for future discussion.

5. Conclusions

We have made an attempt to use the model of *CI* to formalize the relationship between the concepts of *Life* and *Intelligence*. We have proposed a draft proof on the basis of complexity of computational processes that a simple *CI* emerged before *Life* did on Earth. We have also proposed two hypotheses that *Life* is a logical consequence of of emerged *CI* in the environment of Earth. The second hypothesis states that since that time a cyclic development process has run where more and more complex forms of *Intelligence* and *Life* have propagated each other.

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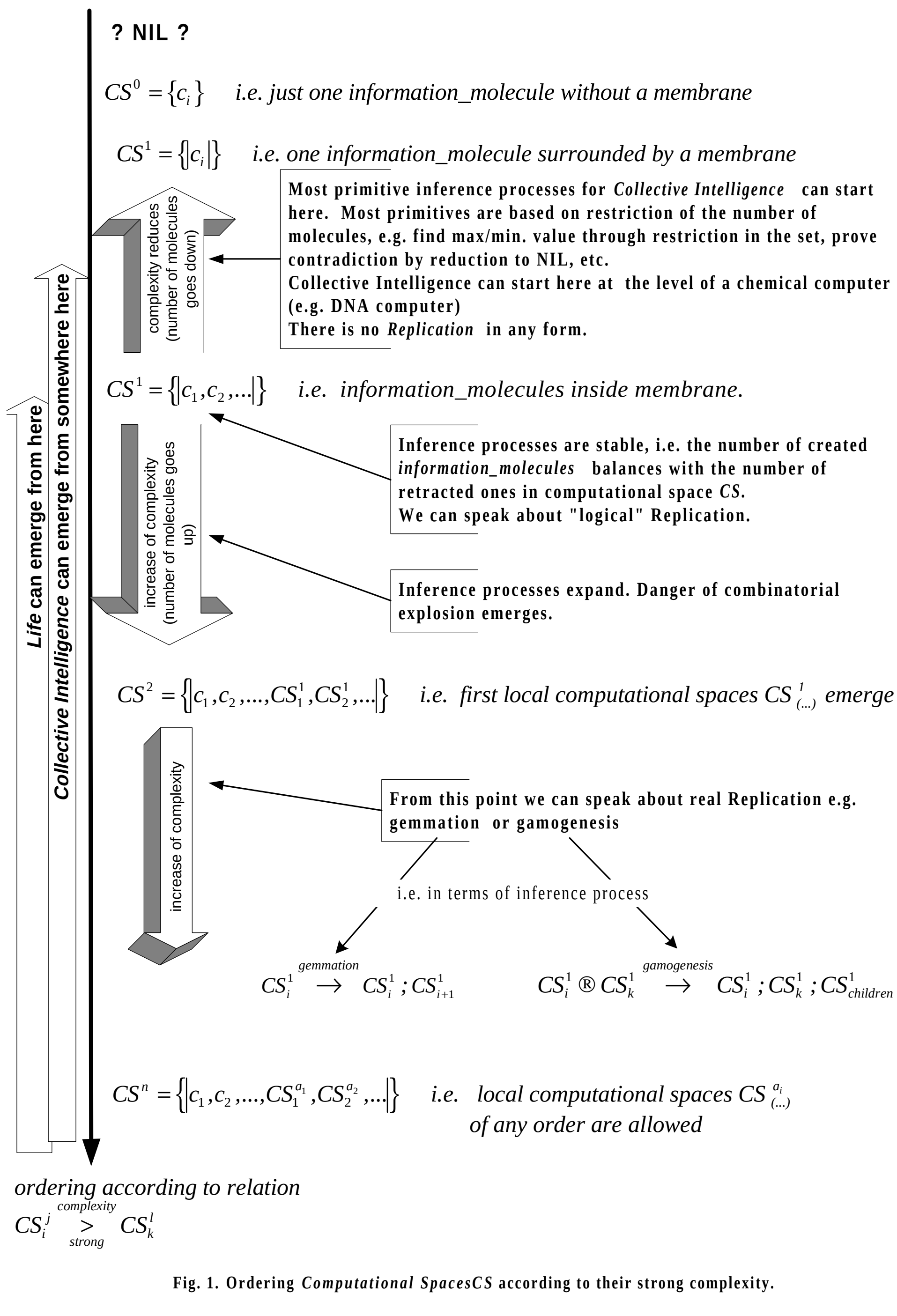

Fig. 1. Ordering *Computational SpacesCS* according to their strong complexity.