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A quest for an interface between information and action
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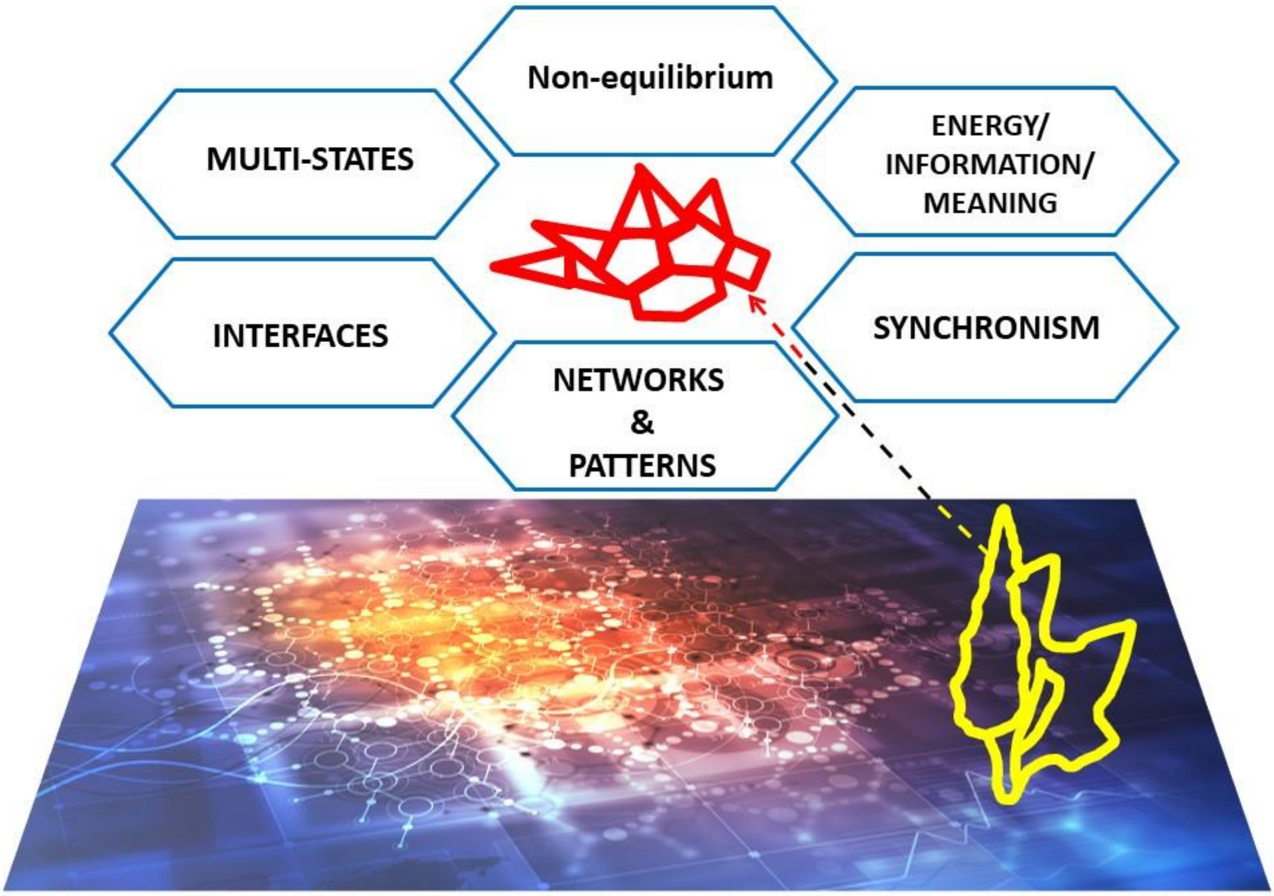

Schematic view of the concept of Stem Materials: understanding the functioning of living organisms and their interaction within the ecosystem (here represented in yellow as the marine gastropod mollusk named "pelican's foot") is approached through the integration of different aspects (in hexagons) which allows to identify building blocks (in red) to be assembled for a new generation of intelligent materials.

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A quest for an interface between information and action

Preface

The concept of Stem Materials

In nature, living organisms consist of a limited number of primary components and chemical bonds organized in complex systems capable to adapt to diversified environmental conditions. Materials are very rarely adaptable, and often require a large number of components to achieve high performances in specific functions. In this comparison between organisms and materials, the approach to their respective life-cycles are also largely different, the former renewing in a continuous interaction with the environment, the latter mainly preserving from alterations. Indeed, materials able to perform different functions and to respond to external inputs will become increasingly important. They will play a fundamental role in the additive production to the extent that these are designed and structured to perform specific operations and self-adapt to varying external conditions, without any additional device. This generation of materials can substitute robots in some applications, i.e. when communication and electronics are considered vulnerable aspects. Materials able to perform as sensors and actuators, accordingly to external environmental conditions for fulfilling different requirements, are still a challenge. These intelligent materials should be flexible in any context and condition, and possibly consist of primitive units, containing the minimal and sufficient number of components to perform a basic function, whose combinations can respond to specific requests of multi-functionality and adaptability. This is the concept of STEM (Sustainable Transformative Engeneered Multi-functional) Materials (http://www.foresight.cnr.it/working-groups/wg-materials).

The challenges

Many scientist already met to identify what scientific challenges are needed to tackle to implement the concept of Stem Materials (see cover figure and also https://bmcmaterials.biomedcentral.com/articles/10.1186/s42833-019-0004-4).

In this context, one of the main scientific challenges to understand the operational functioning of complex systems, such as biological systems, is the role/meaning of the information, its transport and interaction between the different agents. Despite the large amount of data which can be accumulated on the transfer of matter and energy, the rules and processes which structure and organize the system in real networks that dynamically modify their topology in relation to external inputs, are still a matter of research in different disciplines. Whether you want to call it "semantics" or a **functional analysis of the dynamics of topology** (in space and time), the need is to understand how the transport of **information can result into an action and in structure/organization**. Understanding how a signal is generated, propagates towards the 'target' and turns into a response has innumerable cross-cutting implications: from social communication, to robotics, to the synthesis of functional materials or medicines. This understanding is therefore embedded in many different concepts, from information in life sciences to network topology and ecosystem functionality. "*Languages of nature*" are still far to be framed in a mathematical formulation capable to infer a universal grammar including biotic and abiotic roles. Some theories are still at the level of hypothesis and far to be demonstrated: "*Proving Darwin*" is probably the key challenge for introducing a bridge between information and meaning towards understanding the fitness of different components in a complex system. What we are learning is that if we want to build STEM (Sustainable Transformative Engeneered Multi-functional) materials, we need to focus on the language of STEM (Space Time Energy Matter).

The context and the aim of these proceedings

One of the most unexplored aspects in the functioning of complex systems, are the understanding of how the information transfers within them, interact with the external environment, and realizes in a "meaning". Living organisms have been studied to understand their cognition processes, especially when the simulation of intelligence is required to be transferred in robots. In this context, promising results have been achieved in brain investigation and genetics too.

A large amount of data is usually accumulated to describe the distribution of matter and energy within many systems. These data are rarely analysed within a conceptual and operational mathematical framework aiming at identifying the meaning of the information when sensed by living organisms or supporting the sustainability of ecosystems at large.

The complete path to be investigated spans therefore *from* ***information*** *(analysis, evaluation, decision) to* ***action.***

In this context, a workshop was organized in collaboration by the National Research Council of Italy (CNR) with and Univeristè Libre de Bruxelles (ULB) to identify clues from different research activities, mainly focused on whatever can stimulate ideas to support a multi and inter-disciplinary cognitive path that can facilitate the understanding of the foundations of the functionality of signals in complex systems.

The main challenge was therefore to identify, invite, brief and guide experts from different disciplines to report salient contributions with a terminology that could allow the others to capture the main messages. Mathematicians, physicists, biologists, phylosophers…they often speak about the same concepts but with largely different languages and competences. They have been asked to prepare short abstracts to prepare the audience in advance, and to present their ideas. Questions and comments have been then collected and after two weeks a debate has been organized to reflect on the main aspects.

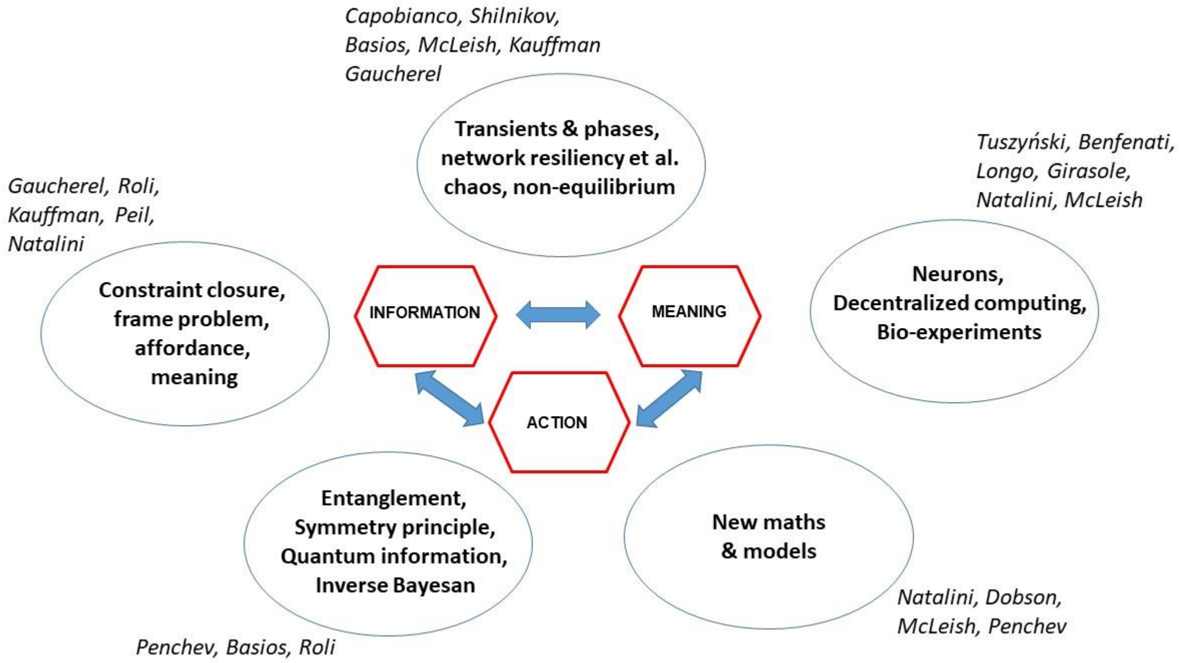
The design and the way to implement the workshop has introduced, on purpose, some chaos, noise and feedbacks in order to simulate a complex network to be self-organized, hopefully in the near future. Some participants were lost in the understanding of aspects so far from their backgrounds, many others interacted in restricted clubs to enter the details.

These proceedings report short articles and long abstracts, which have been asked to briefly focus on scientific results or questions and provide references for entering into the details. The contributions are aiming to support the development of an inter-disciplinary community and young researchers. We left some liberty to prepare the contributions, in lenght and format too.

The programme and the short bios of the first authors are included in this book.

Pier Francesco Moretti and Vasileios Basios

Brussels, November 2021



A sketch of the aspects that have been addressed when focusing on the process that links information to action, referring to the experts who participated.

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Chaos, rhythms and processes in structure and function: extending Bayesian Inference

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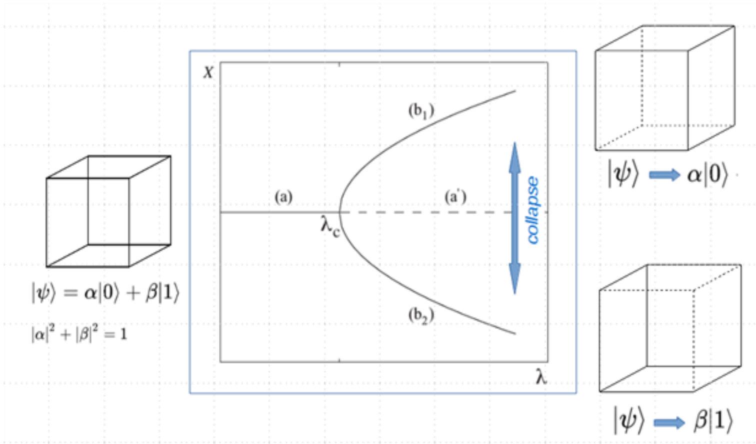
Keywords: Complexity, Information Processing, Bayesian Inference, Quantum Logic.

Abstract

From the early days of chaos theory and complexity it has been established, in contradistinction to artificial information processing systems, that a reliable biological information processor should be chaotic. By now, we clearly understand, and utilize to our benefit, certain aspects of the ability, and necessity, of biological processors to live and operate at the regime known as self-organized criticality or edge of chaos. Living systems posses information processing abilities far beyond any mechanical Turing-like scheme. They account for creativity, a synonym for life, reliance, resilience and flexibility. Moreover they are highly contextual and lavishly so. Their logic includes and surpasses Boolean logic. We review here some recent results on a recursive extended Bayesian inference scheme that incorporates these aspects. Moreover its underlying logic of orthomodular lattices is exactly as the one that underlies Quantum Logic and Quantum Cognition, known for its inherent contextuality. We also conjecture that such investigations might provide a gate to, and a bridge with, quantum biological processes in simple neural systems.



"The smallest biological information processor is the enzyme; the biggest is the (human) brain. They are separated by nine orders of magnitude. Yet their complexity is comparable"

– John S. Nicolis 'Chaos, Information Processing & Paradoxical Games'

Section I: Introduction.

Recalling the opening quote from the smallest biological information processor, the enzyme, to the biggest, (human brain) the span is about nine orders of magnitude. And their complexity is indeed comparable in the sense that at each level we deal with a complex system comprising of many interacting parts. For the enzyme it is clearer which subsystem can be considered quantum and which classical. For the neuron, or groups of neurons this is not unequivocally acceptable, the same goes, of course for, any group of cells or organs.

The nonlinear nature of the electrochemical and mechanochemical dynamics of the neuronal substrate can indeed elucidate why we witness such wide array of behaviours; ranging from simple and/or mix-mode oscillations, metastability, complex 'rythmogenesis', bifurarctions and chaos.

A biological information processor's intricate interactions produce also spatial and not only temporal phenomena. These too manifest in dynamic regimes that co-influence each other on a variety of scales and exhibit the characteristic patterns of elf-organization.

Finally another kind of patterns arise due to these complex interactions at coupled spatio-temporal scales, namely the patterns of information-flow that evolve during transmission, storage and retrieval. These information-flow patterns show both in their instantaneous phase and/or amplitude modulation as well as in stimulus-response relations in wide range of bandwidths.

At one hand on the larger scale view, when considering organs like the brain the heart etc and in general for information flows where classical chaos is detected, it is well known that we get order on the average and chaos and unpredictability in detail. This is due to the nonlinear features of their underlying dissipative structures; e.g. coexisting positive and negative feedback circuits are responsible for multistationarity. While coexisting attractors, dense periodic orbits, and scenaria rich in bifurcations are responsible for hysteresis, memory and chaotic itinerancy. All of which contribute to the appearance of super-selection rules presiding over and beyond Shannon's Theory hierarchy of the 'pragmatic-grammatical-syntactical' aspects of information. Actually it is this complex evolution of such an information flow that is driving the quest of semantics and an overarching context that reaches beyond Shannon's brilliant established framework.

At the other hand, on the smaller scale view, when considering enzymes, and in general for the information flow via and through molecular motors, microtubules, even via organelles we do observe order and predictability in detail and decoherence and disorder on the average. It seems that at this scale the factors moderating complexity are (among others?) orchestrated wavefunction reduction, quantum tunnelling, quantum decoherence /recoherence, entanglement, quantum-stochastic resonance and even the inverse quantum-Zeno effect. Evidently, complexity at the nano-molecular level is due to the coexistence of quantum and classical regimes and where to draw the line between them is one of the most sought after quests of our times. In this case the presence of contextuality is readily understood since it is well known that is the sine qua non of the quantum regime.

And in between these two extremes form the organism and the organs to the molecular machines in the cell and the enzymes there is a key factor that partially bridges these vastly distant spatio-temporal scales when seen as biological information processors at large.

For example a notable area of investigations is the so called "protein folding" problem. This is seen as a challenging problem because it defies any algorithmic 'Turing-like' information processing as its base for explanation. Yet, we see now that the polypeptide chains fold via partial nucleation pathways to scale-free network structures reminiscent of networks that are formed exactly in the `edge of chaos' criticality regime. So, the protein-folding concludes naturally an otherwise algorithmically inconclusive, or as it is also called NP-complete, problem by finding their optimal and hence natural final state. To use the language of materials' science these polypeptide or protein folding processes are characterized by 'frustrated multistability' and they evolve in 'ragged energy landscapes' towards their optimal / minimal energy state. In this case their energy minimization facilitates the overall ability of biological information processing rather than challenging or hindering it as it would have been in the case of artificial Turing-like algorithmic processing.

Moreover, very recently, supporting evidence of the role of chaos in biological processes has been discovered in the course of studies of a new nonlinear phenomena in microtubules vibrations. Detailed calculations suggest that "the energy released after the hydrolysation of guanosine triphosphate is converted to active turbulence leading to chaos". Such a phenomenon if directly observed would be consistent with the original theory that positive feedback from the hydrolysis process stimulates tulubin to explore by probing its environment and accumulate information (positive Lyapunov exponents in the dynamics). While negative feedback increases dissipation hindering the wave propagation in the microtubules, acting effectively as a storage and/or collector of information (negative Lyapunov exponents in the dynamics).

The above evidence is in accordance with our own investigations where we have revisited the subject of chaos and biological processing utilizing a novel implementation of an extended double aspected Bayesian inference. This novel approach also utilizes a positive-negative feedback scheme as we shall subsequently see.

Section II: A short overview of the state of the art in complex system modelling

In complex systems analysis the coupled variables, that typically spann a wide range of spatial and time scales, is pursued in two methodologically different approaches: (a) the model-based or parametric approach and (b) the probabilistic-statistical, model-free or non-parametric approach.

In case (a) we start by certain assumptions that are given 'a priori' from our knowledge of the phenomenology and/or the conceptual framework at hand. For example we write down the governing ordinary or partial differential equations of the laws that govern the system, either physical, chemical or biological. In general these equations model the known and assumed interactions between parts of the system. This is provides the evolution of the variables under investigation mainly using nonlinear dynamics, with its powerhouse of phase-space and state-space techniques. Then, in order to validate the model and its mechanisms, data from experiments have to be called in to determine, or 'fit', the parameters of the model. After a successful parameter and initial conditions determination one can extrapolate from the established values and propose predictions of properties and behaviours.

In case (b) the underlying detailed mechanism of the model is of no concern. Now the 'model' is understood as a probabilistic scheme that would give statistical measures of interdependence. This is usually called a model-free, model-independent or even 'equation-free' approach. Here no parameters are present, hence the name 'non-parametric' approach. That does not men that we start free of assumptions. But know given, or 'a priori' probability distributions are the ones that reflect the underlying physical, chemical or biological processes and the interactions of the parts of the system. Here the powerhouse is that of Fourier-type spectral analysis, 'hidden-Markov' modelling, causality analysis and Bayesian statistics. The validation with experimental data is via their probability density functions and their statistical properties. Again prediction is accessible via extrapolation from the given features of the 'a priori' probability distribution.

Both approaches work perfectly well in the linear regime of the phenomena under study no matter how complicated they are. But the linear methods will certainly fail if the phenomena are inherently nonlinear and irreducibly complex. Here we have to stress that complicated is different than complex. A complex system cannot be reduced to the sum of its parts due to its nonlinear interactions; a complicated system can be reduced to the sum of its parts as its interactiosn can be resolved to linear ones.

For example, the oscillations in a system of neurons, like the one in "COMA-SAN" running experiments on sensing biological communication (see the entry by Giovanni Longo et al. in this volume) can be studied according to: (a) by modelling via a set of coupled nonlinear ordinary differential equations and its observed oscillations can be analysed and compared with similar models that exhibit rythmogenesis such as the ones by A. Shilnikov and his group, for example. Or at a microscopic level their communications via signals can be analysed with models for their detailed cytological and sub-cytological macromolecular interactions as Tuzinski and JULIA????N propose for similar systems.

Or, they can be studied according to (b) by analysing their frequency data via Fourier-type transform methods. To this is included the Wavelet analysis which is particularly useful when one deals with couplings over many scales in time and frequency domains and even recurrence diagrams. A 'hidden-Markov' scheme can also aid causality analysis. Moreover from the time-series data one can measure various informational theoretical measures –such as cross-entropy, block-Shannon entropy as well as well established probability-distributions divergence/distance measures– that correlate with and reveal the nonlinear dependencies present in the system. This methodology is apt at discovering the presence of semantic dependencies and global dynamical constrains in the dynamics of the flow of information in complex systems. Bayesian inference is another important and well established theoretical instrument of investigation and we would like no to visit a quite recent and novel idea that adds value to the classical, standard, Bayesian methodology by extending its scope.

Subsection II b. Expanding the Scope of Bayesian Inference

In standard Bayesian inference an a priori hypothesis given by a certain initial guess/estimation of the probability density function is tested against data. By applying Bayes' rule one then updates the initial hypothesis based on the data that are present at each time step. It is like the data driving the navigation through an array of hypotheses rejecting at each step the ones that do not adequately fit the experimental observations.

So we can sketch the formalism of Bayesian inference as follows: We have a set of hypotheses, say h = {h1, h2, h3, … , hM }, indexed by m=1..M, and a dataset from experimental observations, say d={d1, d2, d3, … , dN }, indexed by n=1...N. Then we have: the probability of a hypothesis being valid, as P(h); the probability of data to be recorded as P(d); and the conditional probability of hypothesis, h, to be valid given data, d, is P(h|d). And the other way around, i.e. the likelihood of a data set, d, appearing if hypothesis, h, holds, that is the probability-distribution of data, d, given h, and is denoted as P(d|h).

Simply by the definition of conditional probability, we immediately have that: P(h|d) = P(h, d)/P(d) ; P(d|h) = P(d, h)/P(h), and since the overall probabilities are P(h, d) = P(d, h) by Bayes' Theorem (or "Bayes Rule"): P(h|d) = P(P(h|d)P(d) = P(d|h)P(h). Now, since the conservation of probability over all possibly considered hypotheses is the sum over all hypothesis indexed by k:

$$P[t](d|h) = P(d) = \Sigma k\ P[t](d \mid hk) \text{ at each instant of time t,}$$

The index t, indicates the time step at time t. So P[t](hk) represents the probability of hk at the tth step, because the probability.

Therefore Bayes' theorem reads at each step, t:

$$P[t](d|h) = P[t](d|h)P[t](h) / (\Sigma k\ [P[t](d \mid hk)\ )$$

We call this Bayesian-inference, for short B-inference. As usual, the probability of hypothesis under a given data, P(h|d), is called the 'a posteriori probability' and P(d) is the called the 'a priori probability', e.i. the hypothesis not conditioned of hypothesis by the obtained data.

A simple iteration produces an inference process: At each step the preceding a posteriori probability is updated by the subsequent to a priori probability. This iterative inference updates 'preceding', P[t](h), from 'subsequent', P[t+1](h), probability of a hypothesis at each time step, t.

hypothesis at tth step is represented by P[t](h), so we have: P[t+1](h) = P[t](h|d).

This specifically chosen hypothesis, hs, can be chosen in a variety of ways. It is not an deterministic update. It might be the least optimal hypothesis with a given or even the highest probability. There is a certain formal symmetry between B- and IB- inferences but the similarity stops here. B-inference is algorithmic in the sense of a deterministic process. IB-inference is not deterministic it can be heuristic, based on an 'oracle', or on a semantic or 'super-selection' rule, or it can well be probabilistic and/or depending on a global emerging property of the system. It might even be driven by a subsystem or another system. It can serve as model of a non-algorithmic creative instant, or a model for innovation.

In standard Bayesian-inference the likelihood of a hypothesis is invariant,

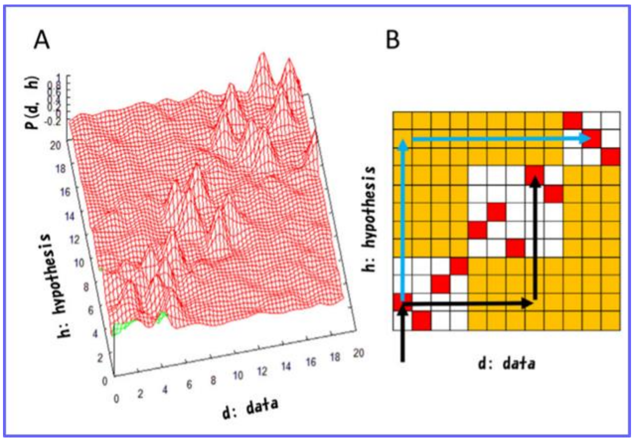
which reads: P[t+1](d|h) = P[t](d|h).

That does not mean that the distribution of the probability or likelihood does not change as data are considered, what it means is that the hypothesis itself, h, remains the same.

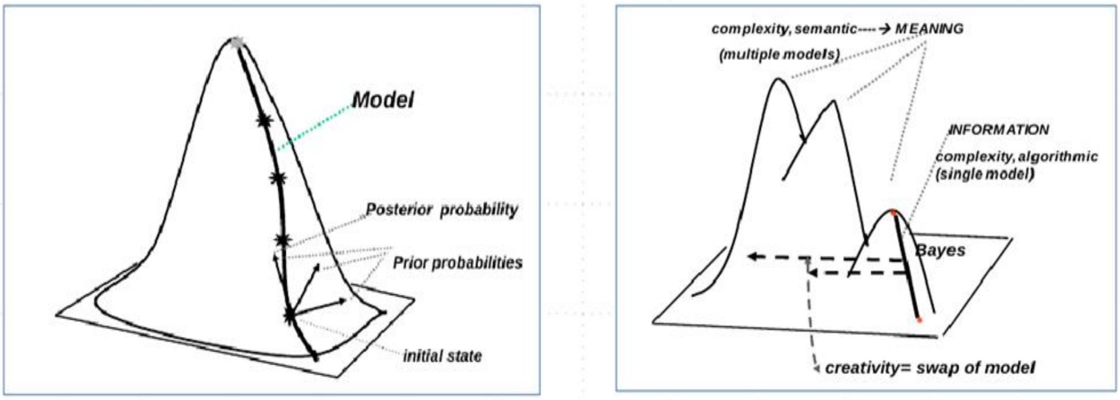
And here is the distinguishing step between B-inference and Inverse Bayesian inference, or as we call it for short IB-inference: IB-inference changes the likelihood of a specifically chosen hypothesis, call it hs, in the following way:

P[t+1]= P(d| hs) = f[t](d)

where f[t](d) represents a normalized frequency of the occurrence of data or the the temporal probability of data, d, at the time interval from start to instant [t+1].



The picture above, on the left (panel, A) shows the distribution of the joint probability P(d,h) plotted against the complete dataset, d, and the set of hypotheses, h. On the right (panel B) depicts the matrix representation of the joint probability-data landscape. Each red or white cell is a diagonal matrix area while the orange cells are noisy, unstructured, areas. The probabilistic transition from attractor to attractor on this complex landscape i.e. the iterative BIB-inference, is denoted by the arrows.



*Bayes and Gödel**:** One way of understanding the essential innovation of BIB has been proposed by Prof. Fortunato Arecchi employing the picture above (adopted from his presentation named 'Fiat Lux' of 2015 also discussed in [JSN]. On the left hand side we have the B-inference. The feedback loop between between prior and posterior probabilities climb up the mountain towards optimal likelihood of a fixed hypothesis adapting parameters of the probability distribution on the way.*

On the right hand side the information landscape has a lot of optima, shown as mountain peaks, representing changing hypotheses as we attempt to find the optimum optimorum. To arrive at the highest peak we need BIB-inference; we need to employ a non-algorithmic route reminiscent of a Gödelian jump to avoid getting stuck in one hypothesis. These non-algorithmic 'creative' jumps are the traces of the inherent semantic complexity and contextuality of the system.

If a system employs both B-inference and IB-inference, we have been calling it a "BIB inference". system. A BIB-inference system, consists of two nonlinearly closed feedback loops, one that explores by expanding the probability space, of prior hypotheses, and the other that restricts by selecting parts of it.

Bayes and Gödel: One way of understanding the essential innovation of BIB has been proposed by Prof. Fortunato Arecchi employing the picture above (adopted from his presentation named 'Fiat Lux' of 2015 also discussed in [JSN]. On the left hand side we have the B-inference. The feedback loop between between prior and posterior probabilities climb up the mountain towards optimal likelihood of a fixed hypothesis adapting parameters of the probability distribution on the way.

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It is an iterative -but non-algorithmic- process that captures the essential requirement for expanding (positive Lyapunov exponent) coexisting with contracting dynamics (negative Lyapunov exponents). Of course, we have put our scheme to the test in various cases and it has passed with flying colours. It suffices here to refer to two cases directly relevant to biological systems. The first was by confronting the data from the cognition of ambiguous stimuli. The second was to use it as a predictor for the collective dynamics of swarm intelligence, using data from migrating blue-warrior-crabs.

What comes as a surprise, apart of its remarkably increased efficacy, is that its underlying logical structure always turned out to be an extended, non-Boolean, logic of orthomodular lattices exactly as the ones that underlie Quantum Logic and Quantum Cognition models; which both are well known for their inherent contextuality.

Section III: Reflections Suggestions & Conclusions.

Of course in confronting key research questions about complex systems and especially if the aim is at understanding their information flows which translate information and signal processing to action one has to enrol both methodologies that we called (a) & (b) at the start. Recall that (a) is the traditional model-based or parametric approach and (b) is the more recent, 'data-driven', probabilistic-statistical and 'model-free' or non-parametric approach.

Both parametric modelling via differential equations and non-parametric modelling via a probabilistic approach have their merits and challenges. The rational thing to do is to see them as complementary rather than in antagonistic. The most promising and fruitful research program would ideally combine the top-notch methods of coming from nonlinear dynamics and chaos methodology with advanced Bayesian and Fourier-type analyses.

Moreover, the BIB-inference scheme provides a drastically different picture for the pathway that carries information to action especially in biological or complex highly nonlinear systems. Classical systems or even artificially engineered information processors operating in linear regimes are essentially covered by Shannon theory. In all three structures necessary for information processing –information storage (memory), information transfer (signalling), and information modification (computation)– we observe qualitatively different functions present in living organisms than the ones present in our machines. The former not reducible to the latter. The former also surpasses the conceptual framework of Shannon theory. Their associated rhythms are also qualitatively different. For information processing machines we seek stable periodicity and linear response, for the clocks necessary to control their information flow. In the living realm information processing happens on the edge of chaos and their information flows demonstrate complex patterns and geniuine nonlinear response.

It is only natural then to propose the extension of deterministic-chaotic models by including quantum or quantum-like components in order to investigate the substratum upon or through which biological information takes place. And we believe the results from COMA-SAN experiments will shed more light towards such a daring endeavour.

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Dynamic information in complex networks

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Introductory remarks

A biological system is complex when its units or subsystems share relationships and induce dynamics of unknown spatio-temporal nature and time scales. From such conditions, emergent and self-organizing behavior may generate which is difficult to predict so that only probabilistic laws may be proposed. These complex systems evolve over time by changing both internal structure and dynamics as a result of changes in their endogenous governing laws and exogenous (environmentally caused) adaptations.

Recent advances in the understanding of cancer show them as perfect examples of complex adaptive systems. Many emergent properties of cancer are currently explored, for instance heterogeneous clonal expansion, replicative immortality, rewired metabolic pathways, altered reactive oxygen species (ROS) homeostasis, evasion of death signals, hijacked immune system, growth signaling and metastatic invasion (Hanahan and Weinberg, 2011). Usually, the reconstruction of cancer networks enables a systems view of such properties starting from measurements like gene expression data. In turn, this task becomes a computational complexity problem.

The study of network dynamics involves an understanding of what topology can represent the relationships between bio-entities and what nonlinear/stochastic influences may justify the observed structural associations for then providing effective analysis and improve the diagnostic, predictive, prognostic performance at systems level. The main challenges are solving the often large-sized problems with incomplete information and obtaining scalable solutions. More specifically, the following aspects are considered relevant to the study of dynamic networks: stability, robustness, fragility, controllability, synchronization.

Especially the control problem has gained an increasing research interest as complex systems usually contain a variety of nonlinear factors affecting the achievable performance in practical applications. The unknown nonlinear functions generated in the control design can be analytically approximated in various ways, but the most exciting aspect comes from the role played by Big Data solutions (data integrations requiring network ensemble models, varieties of data types feeding heterotypic networks, structured and unstructured information calling for machine and deep learning).

How to deal with dynamics?

Biological systems can be investigated with respect to the reconstruction of the phase space of the generating dynamical process. Here, a dynamical system is assumed to perform a trajectory in a state-space, for instance spanned by variables such as the gene expression levels (or mRNA concentrations). A gene profile can thus be considered dynamic through the involved temporal dimension, i.e., gene expression levels detected at each phase and concatenated to form measurable quantities.

In cancer, phenotypes may be found to match some regions of the gene expression signatures in the state-space. In such case, the signature becomes a specific feature, and the multidimensional landscape includes examples from each phenotype. The identified features should reflect dysregulated pathways and depending on the type of perturbation, persistent versus transient profiles can be obtained from the gene sets that enrich for those pathways. With *n* observed states, an ensemble allows for consideration of steady dynamics, and before steady-state dynamics, transient dynamics can be observed under non-equilibrium conditions. Cancer dynamics are particularly significant under such conditions and require suitably conceived network configurations to infer the mechanisms behind such dynamics. This cancer landscape is hard to walk in terms of challenges and complexities concerning bottlenecks like problem indeterminacy, inaccuracy of measurements, unknown uncertainty, etc. These call for new integrative inference approaches.

Biomedical networks are measured in both physical and functional terms, and often embed "targets" to be identified. However, networks are static representations of the associations (links) between biological variables (nodes). When causative associations are present, then regulatory dynamics can be inferred (from genes). Instead, when the associations can only establish the presence of communication without defined directionality, then interactive dynamics are represented (from proteins). Node-entities determine edge-based relationships that allow the investigation of both temporal and spatial information. Spatiotemporal dynamics are usually lacking in network maps, replaced by averages taken over conditions or time points. This limitation reduces the inherent potential of networks to emphasize roles and functions of co-existing entities through their causal relationships, while monitoring the information transmission mechanisms, including phenotypic alterations, that signaling processes activate at systems' level. A dynamic network approach is thus based on the study of coordinated spatiotemporal signaling networks and pathways activation.

Dynamic networks are useful for the analysis of disease processes (Barabasi et al., 2011). Pathways work as functional modules in networks and can be used for target identification. Differential network analysis (Ideker and Krogan, 2012) may compare topological architectures and modular structures in health versus disease states, or between two different disease states, often with the support of expression, genetic, and clinical information The expected variation may reflect the distinctiveness in molecular signatures of gene expression. Once such signatures are assigned to network nodes, topological and biological features may elucidate interactions and causal relationships. Targeting altered signaling networks can shift the focus from individual targets to combined/combinatorial target dynamics.
The dynamic property of networks cannot be isolated from gene expression and pathway activation. Even if the correlation between transcriptional and network profiles is not completely predictable due to the action of control/regulation mechanisms at both levels, these complexities may be monitored by looking at the changes in network configurations at both module and pathway scales. Systems assessments can be enabled by monitoring the transfer of network dynamics into new associations (aggregation of separate interactions) and dissociations (break down) of modular structures. One could qualify such changes in transient or permanent terms. Intuitively, a natural quantity to monitor is the degree of participation in network dynamics from its constituent entities, the modules, with a significant (i.e., biologically relevant) role. Thus, one objective is to check how differential conditions affect the participation of key bio-entities to modules, which in topological terms means that properties such as betweenness should tell about how the dynamics induce a localized or global re-positioning of nodes in the network depending on conditions, perturbations, etc.

Inference through Networks
Some of the problems that cancer networks face, are listed below:

• Quantifying the system's robustness. The solutions are quite elusive when their applicability is beyond single nodal scale. In particular, therapy effects are usually hard to predict.

• Identifying vulnerabilities of network measures. Entropy, for instance, is not a measure independent of a particular network representation and cannot capture the properties of the underlying generative process. Shannon entropy is of quite limited utility in dealing with complexity, information content, and causation and temporal information. Other entropy-based measures of network require focus on particular graph properties (adjacency matrix, degree sequence, etc.).

• Dealing with loss of information. The landscape of bio-interactions is only marginally covered, thus the approximation that one can reach depends on the context of study (cancer type), the type of data (experimental biology, omics, clinical, etc.) and on the overall uncertainty that can be managed at systems level.

Some of the relevant properties emerging from networks, are summarized below (Bertolero et al., 2017):

• High connectivity in the network is known to exert effects on its structure. The high-degree central nodes tend to form a so-called 'rich club' supporting global network communication. An example comes from the brain regions in which such nodes tend to be pathological. If these nodes are removed, the global efficiency of the network decreases. Therefore, the rich club is considered a stable core of brain regions coordinating the transmission of information.

• High-participation nodes have effects on functions. These nodes exhibit diverse connectivity and are called 'diverse clubs' and are more consistent with the development of integration functions. For instance, in the brain these nodes belong to different communities and some are physically proximal. Also, they control functionally connected regions (those more predictive of changes). Finally, it was demonstrated that their activity increases in complex tasks requiring specialization and more communities involved that need to be integrated. Therefore, removing these nodes would likely damage the overall functionality as they govern modularly the local processing of information.

• Controllability In highly non-linear systems is hard to reach due to the occurrence of conditions of non-equilibrium and the effects of critical transitions between unstable and stable points. A system is by definition controllable when it can be driven from any initial state to any final state within finite time. In practice, this tends to be not common. The typical control strategy involves efficient guidance of a system's behavior towards a desired state through only a few input variables. Finding these few points is challenging and refers to a key question: what is necessary to control a network? In general, knowledge from two domains is need: system's architecture, i.e., network structure/configuration, and dynamical rules that are observed through time-dependent interactions.

• Transittability of complex networks of another useful property (Wu et al, 2014). Here the goal is to steer the regulatory network to transit from abnormal to healthy phenotype, thus enabling a phenotype transitions (complex disease progression, p53-mediated DNA damage response network, T helper cells differentiation, epithelial to mesenchymal transition). Usually, the cellular phenotypes can be studied by the network states collectively, i.e., considering all molecular expressions. Also, phenotypic changes work as dynamic transitions between states of the network cellular reprogramming. Thus, one phenotype can be transited to another by overexpressing a few transcription factors. In drug designs, a few drug targets can achieve a disease-to-healthy state transition for many complex diseases. A steering node is where an input control signal is directly acted. A steering kernel is a minimal set of steering nodes network transiting from one state to another (much less than minimum set of driver nodes). Notably, transittability is less requiring than complete controllability for cellular phenotype transitions. Controllability is computationally prohibitive even for moderate-size networks. As a note, the minimal number of driver nodes is about 80% of nodes in a regulatory biomolecular network. Therefore, complete controllability affects the full state space in the network.

Lessons learned

The presence of redundancy in complex biological systems suggests that the influence of biological mechanisms is devoted to maximize the diversity of the interaction landscape.

Some properties of a more exploratory nature are highly desirable. An example is susceptibility (Manik et al., 2017), which quantifies the change of the systems' state in response to a change in an external field. This induces the so-called collective dynamics, depending on topology in networked systems and where the perturbation hits (local properties). The main problems refer to the fact that it is unclear how to define susceptibilities in networked systems and it is also unclear what susceptibilities tell about collective dynamics.

A clear distinction is needed between influence and flow. Network components like nodes, links, pathways, are ranked according to their dynamic impact on the network, e.g., seeking the most influential nodes, (impact captured by the magnitude of the response of the system to perturbations). However, network components are not just the source of information but also mediators. When a single gene is perturbed, that gene is the only source of information, whereas the role of all remaining genes is to propagate the signal and support the flow as mediators, not as sources (Morone and Makse, 2015). In other words, localizing optimal/minimal set of structural nodes that act as influencers is the problem, however a hard one as weakly connected nodes tend to emerge among the optimal influencers. Collective Influence (CI) methods that perform collective influence maximization are therefore needed (Teng et al, 2016).

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“From information to action” means “from encoding to decoding”

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Introduction

Devices and materials we daily use, have a definite function and can usually not modify it or extend it. We would dream about adaptable materials, performing several functions or possibly shifting from one to another, and sometimes called “stem materials” (Moretti et al. 2019). We have not yet produced such objects, and we still do not know how to proceed. We may certainly learn from living systems, often exhibiting multifunctionality and even creating new functions according to their environment changes (Holland 1975, Maynard Smith and Szathmáry 1995). How do they proceed? I hypothesize here that they use a kind of *language* (Gaucherel 2019) to decode information from their environment and ultimately produce an action.

As stem cells are able to differentiate and adapt, some scientists have proposed to build stem materials which may change and perform new functions. The idea behind this proposal is not to recreate life, a dream still unachievable, rather than to build material autonomous enough to respond to their environment without additional components (Tibbits 2017). Is it only possible? If it becomes possible one day, we can wager it will be by mimicking life. Living systems appear capable to extract some kind of information from their close surroundings, through sensors, and to occasionally produce some (new) actions necessary for their survival (Holland 1975, Maynard Smith and Szathmáry 1995). This required information seems not yet to be an action. Is it a kind of semantics or even semiotics (Peirce 1994, Trifonov 2008, Tournebize and Gaucherel 2017)? I propose that we need to *decode* the language involved in such events to answer the previous questions.

In the most recent theories, life may be understood with the help of specific processes operating the whole living system as well as maintaining it in the long run. Life is usually defined as a metabolism process or an evolution process, and often both (Bersini and Reisse 2007, Gaucherel et al. 2019). Recently, it has been proposed that a *closure of constraints*, depending to each other and closing a functional loop, is necessary and sufficient to maintain such a living whole (Montévil and Mossio 2015). Complementarily, the “It’s the song not the singers” theory proposes that living systems maintain through some evolutionary processes independently to their material components (Doolittle and Inkpen 2018). Finally, in a similar yet slightly more synthetic spirit, the *linguistic theory of life* (LTL) proposes that living systems have developed some languages allowing them to reading their environment and potentially responding to it (Gaucherel 2019).

The reaction of a (living) system to its environment has been called an *affordance* and is defined as a set of variable values that are sensed and then used into concrete consequences (Gibson 1979). Another solution is conceivable. The LTL suggests that any living system is “decoding” its environment and then “encoding” it with concrete actions, and this paper intends to show it. Such transformations may belong to different processes, but they all appear to be a new process which did not come to exist before. This view is close to process philosophy propositions (Whitehead 1929 (revised ed., 1978), Hustwit 2019). According to this philosophy, our world is not made up of lasting material components, rather than of processes responsible for any change. Then only are such changes reified into transitory (and illusory) materials. The LTL highlights our need of both, material objects and immaterial processes to interpret the dynamics and stabilities around us. Here, I would like to illustrate this point of view in more details.

The linguistic theory of life

The *affordance* concept seems highly relevant in this context, but it not yet explains the connections between immaterial information (reaching the sensed objects) and the tangible emerging action produced by it. I propose here that affordances are the results of linguistic events. For this purpose, we need to define the so-called *system network* which is the known interaction network gathering the studied system components at play (Gaucherel et al. 2020). In a sense, this system network forms the "skeleton" or the structural backbone of the living system. By definition, the LTL proposes that information is precisely the topology of this system network (Gaucherel 2019). This information definition should not be confused with any other, such as those of information theory and computer sciences (Brillouin 1956, Tournebize and Gaucherel 2017). This inner structure of the living system is not contained into any other component of this Kantian whole (Kauffman 2013).

For example, any ecosystem is made up of material components as well as of immaterial processes connecting them (Fig. 1a). The material environment (E1) embedding a prey population (P) and a predator population (S1) can be represented by a qualitative graph combining these three components. By definition, any present (respectively absent) material component, denoted as + (or - resp.), is a node of the graph, while any process making them interacting is a (possibly oriented) edge connecting the nodes. Such a representation assumes components to be either functionally present or not. In this ecosystem, P and S1 populations depend on their common environment E1, thus the two corresponding edges (Fig. 1a). Here, the system does not welcome any other action than both populations preexisting in the same space.

To handle such an (eco)system, we could use a qualitative and discrete event model of our own, and rigorously compute its whole dynamics. These models belong to a family of models coming from the formal linguistic studying human languages (Chomsky 1963) and then developed by computer sciences (Cassandras and Lafortune 2008). They are used in biology among other domains (e.g., Reisig 2013, Fages et al. 2018), but are almost absent in environmental sciences. We recently proposed to use these models in ecology and related domains to compute social-ecological system dynamics thank to their *possibilistic* properties (Gaucherel and Pommereau 2019, Mao et al. 2021). With such algorithmic models, we are able to formalize any (social-eco)system network and to compute all its possible trajectories from a given initial state. See some recent papers for more details on the model (Gaucherel and Pommereau 2019, Gaucherel et al. 2020).

Now, let's assume that both populations P and S1 become in close contact. The trophic rule of this simplistic ecosystem will make them interacting (through signals and information), and likely provoking some predation events (Fig. 1b, red edge). If we wait a time long enough, it could even deplete the prey population P in environment E1, and let alone the predator population S1. Quantitative changes are occurring, but the qualitative model is blind to these changes. In this drastic and long term event, predation actions have pushed the ecosystem network to qualitatively change toward a network with a new topology (Fig. 1c). The system information has changed in terms of present interactions due to the corresponding action of predation (red edge). In a way, material components of the system responded to its whole structure, by reading (decoding) it and then writing (encoding) it into a new topology (Gaucherel et al. 2019).

Conceptually, the overall phenomenon can be decomposed into a set of events commonly represented by computer scientists as a state space (Fig. 1d), the set of reachable system states from the initial state and according to the set of rules (Table 1) described in the previous paragraph (Gaucherel and Pommereau 2019). In a possibilistic scheme, all these events *may* occur and, thus, the system may change according to the system network (skeleton) carrying it. The phenomenon is equivalent to reading (decoding) the network by some system's components themselves, and then to writing (encoding) the network by the components according to the actions potentially occurring (Gaucherel 2019). This proposal suggests identifying the components and the processes making them interacting each time a living system seems to maintain itself and its inner interaction network. In other words, we need to look for the syntax and semantics composing the system languages and handling system networks (Trifonov 2008, Tournebize and Gaucherel 2017).

The ever changing living network

Some may object that such a simplistic ecosystem is not exactly alive. Possibly, yes. The previous model would be convincing if it would mimic evolution, such as a clearly visible speciation process (Maynard Smith and Szathmáry 1995). Whatever the system, this will not change our understanding of affordance in linguistic terms, but we should try to model "new" (adaptable) affordance in the system. For this purpose, let's imagine that the neighboring environment of E1 is changing in such a way that a new environment E2 appears nearby (according to a new formalized rule and a new state space, Fig. 2a). Such an event could possibly push species S1 to speciate (or not) into a new species S2, adapted to this new environment E2. As the new species S2 is a predator population quite similar to the original one S1, it could also feed on prey population P. We can assume without impact on the demonstration that preys can rapidly spread without speciation into the second environment E2 too.

The new biological system network has now increased and has gained new material components as well as new immaterial processes (Fig. 2b). The processes related to the system evolution (blue edges) can possibly draw a completely new state space (Fig. 2c), shifting from the initial four-state dynamics (Fig. 1d and 2c, in blue) into a new eight-state dynamics (E1 + E2, Fig. 2c, in red). These colors highlight the fact that each set of states are qualitatively stable: by definition, each state of a qualitative stability is reachable by any other state belonging to it (Gaucherel and Pommereau 2019). In the second stability, both environment E1 and E2 are present, and their embedding species may be occasionally present or absent, depending on the predation events and the species appearance and extinctions (Fig. 2c). In such "cycling" dynamics, the system is continuously writing and reading the whole system network and species are regularly affording preys (and predators).

This view could apply to stem materials in a similar way to that of living systems. Stem materials should learn to change their inner *interaction network*, in order to consequently modify their possible state space and potentially reach new states and *new trajectories*. This would happen in three successive steps: first, the system environment changes and put a pressure on it (Fig. 2a); then, the system needs to adapt and "afford" a new process from a new interaction (or several) between existing components (Fig. 2b); and finally, this interaction consequently generates the arrival or departure of a material component in the system (actions of predation, Fig. 2c). Such a macro-event (of affordance) is in good agreement with the process philosophy, insisting on the predominance of processes changing our world, and giving the illusion that lasting materials are populating it (Whitehead 1929 (revised ed., 1978), Hustwit 2019).

In brief, I propose here that the action is not decoupled from the information acquired by the system: action *is* the information, in the sense that it directly modifies the system network by adding a process (edge). This change in the system network starts by an immaterial change, as in the process philosophy principles, which in turn modifies the material surroundings and generates (the illusion of) an action occurrence. Every action acts as an encoding of the system's structure which is, by its topology, the inner information carrying the system (Gaucherel 2019). Hence, may affordance become an illusory point of view due to our human perception (Gibson 1979)? It may be that the affordance concept would artificially split the world in two parts, information and action, while such a representation is not necessary for interpreting life. Both actions and information are perhaps two sides of the same coin and respond to each other in each new event of the world.

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Tables

Table1. Lists of the complete (evolutionary) system components (a) and system processes (b), here called constraints if they are mandatory and rules if not.

Nodes	**Acronym (and initial state)**	**Description**
	E1+	First environment
	E2-	Second environment (change)
	S1-	First species (adapted to E1)
	S2-	Second species (adapted to E2 and speciate from S1)
	P-	Prey population for both predator species (S2 and S1)
Constraints		
	E1- >> S1-	Selection of the second species
	E2- >> S2-	Selection of the first species
	E1-, E2- >> S1-, S2-, P-	Without environment, no species survive
	P- >> S1-, S2-	Without prey species both S1 and S2 disappear
Rules		
	E1+ >> E2+	Appearing second Environment
	S1+, E2+, P+ >> S2+	Speciation from S1, adaptation to E2
	P-, E1+ >> P+	Prey population may spontaneously reappear (autotroph) in E1
	P-, E2+ >> P+	Prey population may spontaneously reappear (autotroph) in E2
	P+, E1+ >> S1+	With enough Preys, predator species S1 may reappear
	P+, E2+ >> S2+	With enough Preys, predator species S2 may reappear
	S1+ >> P-	Predator species S1 may deplete the prey population (action)
	S2+ >> P-	Predator species S2 may deplete the prey population (action)

Figures

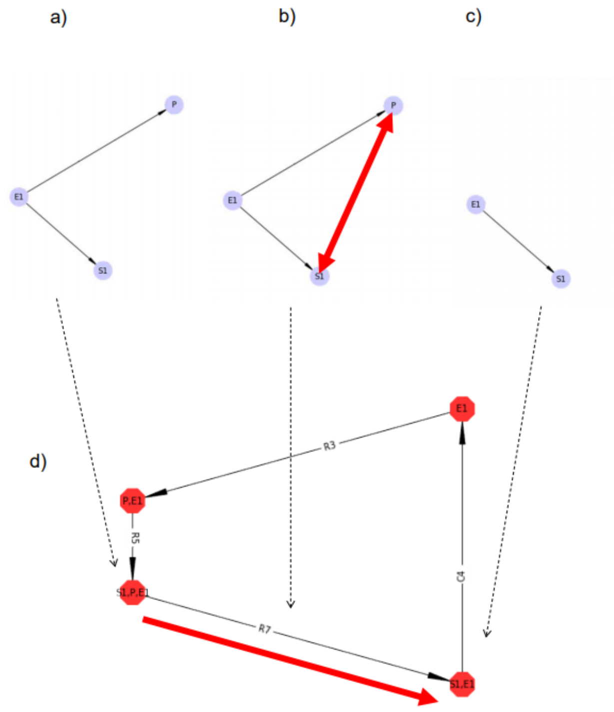

Figure1. Example of a simplistic and qualitative ecosystem with its changing system network (a-c) and corresponding state space (d). In a qualitative and discrete model, a simple ecosystem may be represented by three nodes (a, the environment E1 with species P and S1) and their interactions of various natures (a, edges). Possibly, a predation event may happen (b, red edge) and push the prey population to extinction, thus reducing the system network to a simplified graph (c). These successive states reach by the ecosystem may be represented with a state space (d) linking the system states (composed of present nodes) through transitions (d, edges with rule numbers Rx labels). Dashed arrows link the system network topologies to specific system states.

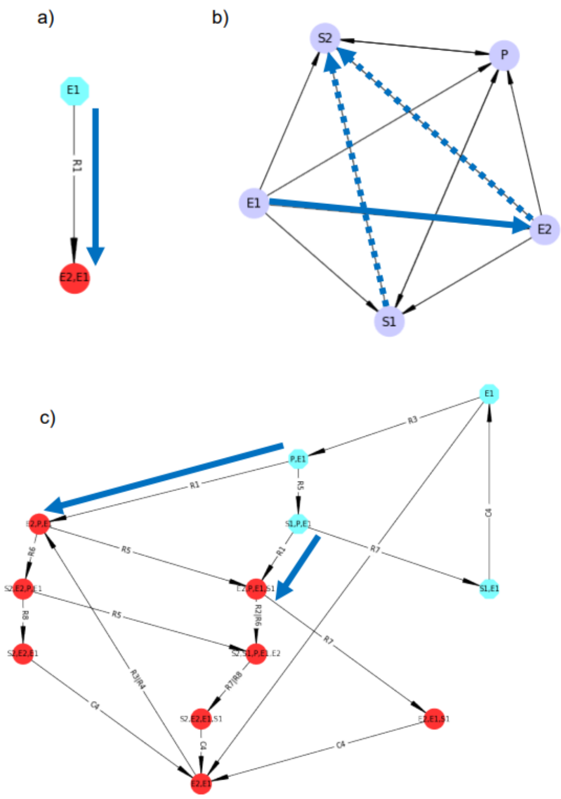

Figure 2. Improvement of the previous toy-model with evolutionary dynamics and speciation (a), with the whole system network (b) and its corresponding state space (c). In case the environment of the system locally changes, it may split into two environments (a, blue edge). The changing rule is visible in the system network too (b), associated to the speciation event from species S1 to S2 (b, dashed blue edges). The new model easily computes the new state space (c) highlighting two qualitative stabilities (c, colors) cycling between reachable states, and link through the same environment changing rule (c, blue edges).

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Cognition and communication in different evolutionary levels: some reflections

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Abstract

Information exchange is at the core of organisms' lives. In order to simplify the problem, we could look at cognition and communication. Originally, the concept of "cognition" involved the idea of the need for a complex brain and neural system. Therefore, we were prone to believe that organisms considered simple were not able to use cognition. However, more recent studies show that organisms in various evolutionary levels have this ability. The organisms can sense if there are changes in their habitat and can develop adaptation techniques to it. Communication is found in various contexts, and it depends also on the interlocutors. For example, plants have been shown to communicate with their neighbors using acoustic and electrical cues and detect insects' sound frequencies and increase nectar response. They can distinguish between antagonists and useful interactions. Moreover, protozoans can vary behaviors, adapting to specific experiences. As a more complex example for communication, Humpback whale (*Megaptera novaeangliae)* songs can be used as models to understand and quantify the structure and the complexity of vocal communication in mammals. In fact, studying the hierarchical structures of their vocalizations can help to understand the context of the conversation history and the behavior. How could this be important? To monitor biodiversity and understand the connection between living organisms and their habitat. In fact, by monitoring biodiversity, scientists can identify the most vulnerable ecosystems and define hotspots where conservation measures must be taken.

Introduction

Life is built on information that moves from one organism to another. Free-ranging organisms explore their environment and modify their behavior in order to accomplish biological functions. They must understand their surroundings to fit well into them by making choices, remembering, learning, and solving problems (Parise et al., 2020). A classic definition of cognition combines the brain with the complexity of the neural system (Parise et al., 2020). Therefore, we do not believe that plants and organisms considered unevolved could use cognition. However, lately, new experimental evidence has been less focused on the brain as a core component of cognition and proposes alternative ways of exploring cognitive processes (Parise et al., 2020; Calvo, 2009; Calvo et al., 2011; Segundo-Ortin and Calvo, 2019).

Communication involves the transfer of information from one individual to another (Gagliano et al., 2012). Vocal communication occurs in a social context: speakers reason about interlocutors' intentions, adapt style, content and duration of the message to the audience. Receiving and assessing the energy that has propagated through the environment requires that organisms evolve specialized hearing structures in order to perceive sound and vibrations (Gagliano et al., 2012).

Communication is present in many species. However, our interest is piqued more by some species than others and we usually have an anthropocentric view of the problem. Wilks et al., 2021 present two studies in which children prioritize saving groups of animals over single humans. The authors postulate that the idea that human life is more important than animals on a moral level is not so eradicated in children but appears later, and it is probably induced by society.

Can we learn from mechanisms at the base of what we consider less evolved organisms? This paper presents some reflections on the topic, starting from some examples of cognition and communication in plants and bacteria and moving to some more complex ones regarding cultural complexity and semantics in cetaceans.

Building from simplest to most complex levels of evolution - cognition

2 **Plants**

Cognition involves perception and action. The organisms sense the modification introduced by the environment and can evolve the ability to adapt to it (Parise et al., 2020).

Research and public opinion focus on animals rather than plants because of the higher degree of empathy, especially towards mammals (Karaffa et al., 2012; Serpel, 2004). Moving gives animals the great advantage of being able to decide which individuals to be close to and the ability to avoid predators (Baluška et al., 2009). On the other hand, plants can move but at a much different time scale. Therefore, they can be stuck next to threatening neighbors that steal resources (Bilas et al., 2021; Parise et al., 2020).

Plants are sensitive organisms that process and use the surroundings' information to assess neighbors' behavior and resource availability. For example, they are able to recognize competitors and choose some favorable interactions over others (Gagliano et al., 2012). Are cues rather than signals exchanged between plants? Interactions between these organisms have not been linked to intentional behavior, making it difficult to deduce implementing an action or strategy (Bilas et al., 2021; Gagliano et al., 2012). Moreover, some researchers have been studying plants' abilities to detect insects' sound frequencies and unharness spores or increase nectar response (De Luca & Vallejo-Marin, 2013; Veits et al., 2019). This research area is still in expansion. Some criticisms have been raised with regards to the so-called "extended cognition" connected to this topic. In fact, it has been maintained that an organism is not necessarily crucial for the constitution of its environment ('coupling-constitution fallacy', Adams and Aizawa, 2001; Japyassú and Laland, 2017). The relevance of an organism to its environment can be understood through the mutual manipulability criterion (Craver, 2007).

Amoebas and molds

The mold Physarum is able to distinguish between various food sources, choosing the best dietary options (Bonner, 2010). They can find the best path to reach food in a maze (Nakagaki et al., 2000), and when harmed with a frequency, they can recognize it and foresee the next hit (Ball, 2008; Trewavas and Baluška, 2011).

Moreover, from early studies in the 1920s, we know that protozoans like *Stentor*, *Didinium*, and *Amoebas* display the ability to modify the behavior after a particular experience (Jennings, 1923). Some protists build protective cases from gathered material and some Amoeba exploits cooperative behavior also during hunting (Walker, 2005). They are able to discriminate through chemical distinctions, make informed decisions, and learn new aspects of their behavior (Jennings, 1923). Recognition of other individuals would indicate that amoebae are self-aware: minimal consciousness would be biologically advantageous (Calvo et al., 2020).

Building from simplest to most complex levels of evolution - Communication

Plants

Some authors (e.g., Gagliano, Mancuso, & Robert, 2012) state that plants communicate with their neighbors using acoustic and electrical cues. They can discriminate between neighbors, exchange data, and select convenient interactions, resulting in cooperation and altruism. In addition, they seem to be capable of exchanging information inside a group in order to solve a problem (i.e., root swarm intelligence) (Baluška et al., 2010). Moreover, there are examples of antagonist phenomena where plants can kill other plants releasing toxins from their root apices; therefore, shaping their biotic niche (Bais et al., 2006). A huge variety of compounds are used and can be released by plants, requiring complex apparatus sometimes defined as 'neuronal,' a system used for interpretation of received signals and to adapt to the surroundings, and to share information with other plants of the same species. These aspects of plant activity haven't nonetheless been extensively investigated (Karban, 2008; Baluška, 2006; Baluška and Mancuso, 2009).

Self and non-self recognition have not been confirmed yet, and they have been considered a very controversial theory that has been postulated since different species release different molecules. However, it is not clear how plants from the same species can release different signals recognising other individuals and allowing discrimination of the origin of cues (Chen et al., 2012). Complex mechanisms involving internal oscillations and electric signals have been suggested to explain this phenomenon (Chen et al., 2012; Bilas et al., 2021).

Kin and non-kin recognition are even trickier, but, according to some authors, plants employ a mechanism that allows distinction between closely related neighbors (kin) from all other neighbors (non-kin) (Dudley, Murphy, & File, 2013; Callaway & Mahall, 2007; Chen et al., 2012). These interactions are carried out between the root systems of plants (Crepy & Casal, 2016; Karban et al., 2013; Bilas et al., 2021).

Bacteria

As reported by Allman (1999), "Some of the most basic properties of brains such as sensory integration, memory, decision-making and the control of behavior can all be found in these simple organisms." Over 50 signals have been identified involved in bacterial signal transduction, allowing for the creation of informed decisions and learning opportunities when the network is widened (Hellingwerf, 2005; Allmann, 1999). Microbes and hosts can communicate through chemical signals: bacteria can identify a suitable host nearby through chemical signals. Quorum sensing is the ability of single bacteria to adapt their behavior using chemical interactions. These interactions imply chemical exchanges, cue detections and might indicate a role in conflicts between organisms (Keller and Surette, 2006). In addition, the relationship between microbes and hosts could lead to the implementation of novel strategies for preventing or treating bacterial infections (Freestone, 2013).

Information theory applied to acoustical repertoire - Cetaceans

Information can be defined as the degree to which data are non-compressible. While the word 'meet' can be compressed without losing information, 'meat' has more statistical or entropic information (Ruiz, 2013). Information theory is generally used to objectively examine the unknown structure and acoustic repertoire communication systems (Shannon, 1948; Shannon & Weaver, 1949; Zipf, 1949, 1968; McCowan et al., 1999). For example, if the source is a singing humpback whale (*Megaptera novaeangliae*), entropy measures the amount of uncertainty and unpredictability in the output

(Miksis-Olds et al., 2008). Highly structured songs have a reduced entropy. On the other hand, songs made up of the same units, but less complex are less predictable, resulting in higher entropies (Payne et al., 1983; Handel et al., 2012). If predictability remains consistent over time, songs are likely easier to be learnt, increasing the chances for their spread among individuals.

Zipf's statistics can express the capacity for an optimized transfer of information in an acoustic repertoire quantitatively. Animal repertoires often depart from linearity, creating what is called ad the Zipf–Mandelbrot curve. With an increase in the departure from the linear trend, the repertoire becomes more redundant, transferring less information. Therefore, units provide metrics information for systems' potential capacity for complex communication (Suzuki et al., 2005). Shannon higher-order entropies can also be used to examine levels of informational complexity of the communication system. Contrary to Shannon's, Zipf's statistic does not recognize language as a 'noisy' channel. Moreover, it cannot examine the interaction between signals and repertoires organization.

Looking at another example, Zipf plots of humans and bottlenose dolphins have a similar tendency for complexity. They show similar slope trends with age. During babyhood, both species show higher negative Zipf slopes, becoming more repetitive (McCowan et al., 1999). A balanced and complex communication system would follow the "Principle of Least Effort" in which both speaker and listener achieve an optimal balance between ensuring accurate reception of the message and a least effort transmission (Doyle et al., 2011).

Chaos and Communication using Nonlinear Phenomena in cetaceans

Subharmonics, biphonation (a series of non-parallel bands related to two independent pitches), and chaos are widely recognized and common in mammal vocalizations. In cetacean's vast acoustic repertoires, between phonation and air turbulence, other observed phenomena are: intermittent subharmonic episodes, the appearance of a second independent frequency, and sudden transitions to chaotic dynamics (Wilden et al., 1998). It has been postulated that these acoustical characteristics can develop and evolve, diversifying the repertoire to be understood using nonlinear dynamics. Nonlinear phenomena might be acoustic indicators of individuality (Tooze et al., 1990), motivation (Nikolskij, 1975), status (Fitch and Hauser, 1995).

Signal analysis is performed in the time or the spectral domain. In contrast, nonlinear dynamics are built on "phase space." If we look at the problem from a biomechanical perspective, the key variables are the elongations of the vocal folds and the glottal airflow, amplitudes and velocities of tissues and pressure. In linear systems, only damped oscillations are possible, whereas nonlinear behavior can manifest itself as vibrations of the vocal folds, leading to complex signals such as subharmonics or chaos. Two coupled nonlinear oscillators display complex dynamics with various modulations, including subharmonic regimes and deterministic chaos (Berge et al., 1986; Glass and Mackey, 1988).

Slight variations in parameters can cause changes to non-periodic oscillations. Deterministic chaos can be separated from turbulent noise through sudden changes to a chaotic segment with residual harmonic structures, tori, and subharmonic bifurcations (Owren and Linker, 1995; Brown and Cannito, 1995).

Some examples: Cultural complexities in cetaceans

Dolphins live in pods with developed bonds and complex relationships, exhibiting self-awareness and self-consciousness. Bottlenose dolphins (*Tursiops*), killer whales (*Orcinus orca*), sperm whales (*Physeter macrocephalus*), and humpback whales (*Megaptera novaeangliae*) exhibit cultural evolutionary traits (Allen et al., 2018; Krützen et al., 2005; Riesch et al., 2012; Whitehead, 2003).

Individuals can recognize their relationships with other dolphins and can adapt the relationship, adjusting the behavior to the new ecological niche (Marino et al., 2007).

Humpback whale songs provide a model to understand the evolution of complex vocal communication in mammals by quantifying the complexity hidden in their vocalizations. High complexity shows male fitness. Moreover, increased song complexity and acoustic repertoire may also be correlated to an increased learning capacity (Allen et al., 2018). Therefore, highly complex songs might indicate more developed cognitive abilities of female selection to males with more complex songs (Allen et al., 2018). These songs have a hierarchical structure: 'units' are arranged into a 'phrase,' and phrases form 'themes.' Multiple themes create a 'song' (Mercado et al., 2005). Usually, songs change each year; they become more complex and individually different (Allen et al., 2019). Complexity scores can be calculated to reflect the song's hierarchical structure: number of units, number of themes, and a combination of song-level and theme-level. Complexity can be evaluated in pattern predictability and individual-level variation. Modifications at any level of the structure contribute to changes in complexity.

As an example: humpback whales of Southeast Alaska hunt herring using bubble nets. These whales use vocalizations to make prey go in a specific direction and coordinate the group of hunters. With the absence of boat noise, the vocal behavior is mostly focused on feeding, with vocalizations used in communication a more negative Zipf slope. On the other hand, during the presence of ship noise, the negative Zipf slope becomes less steep: this might point to the fact that, in this situation, the vocalizations used for communication might be prioritized over the ones used for hunting. One type of message is chosen over another (Doyle et al., 2011).

If a repertoire is too unified, a message is represented by only a few signals, conveying less communication complexity. If a repertoire is too random, the same message can be represented in different ways; therefore, less potential for communication is conveyed. A system exhibiting a balance between less and more distributed signals has a high potential capacity for transferring information. However, some acoustic repertoires are more able than others to information related to communication; higher-order entropies drop in values across entropic orders, less entropy, while a redundant system will begin to lose complexity (Suzuki et al., 2006).

Semantics: inferring meaning in cetaceans communication

In order to find meaning in communications, the short-term and long-term structure should be investigated, starting from the smallest vocalization units. For example, individual codas produced by sperm whales carry information about the individual, the family, and the clan identity; however, the function and the variability of many codas and the variability in structure and individual clicks is still unknown (Andreas et al., 2021). Studying hierarchical structures can help understand structures of conversations needed to build models capable of generating probable vocalizations given a conversation history, behavioral, and environmental context (Andreas et al., 2021). Fault tolerance mechanisms are sometimes built into the communication system at different levels. Animal known fault tolerance mechanisms allow them to backup communication signals or adapt the communication to various situations (Andreas et al., 2021).

Conclusions

Communication underlies the concept of life. As researchers focus on a wider range of studied species, a broader body of research becomes available to justify the knowledge supporting the idea that many species use cognition - the interactions with the environment - and communication among individuals and groups. Even though contemporary research focused on animal cognition is clearly linked with Charles Darwin's theory of evolution, recent perspectives on the matter are now changing. In *The Descent of Man* (1874), he compared abilities among species, defining more and less clever animals, with men being on top. On the other hand, he bestowed human characteristics on animals such as emotion, memory, imagination, and reasoning.

In this paper, some examples are provided, leading to higher degrees of complexity in syntax and semantics. Cognition and communication are linked. While cognition implies that an organism senses and perceives the environment, communication adds a layer of complexity, implying also the need for a receiver. Communication between organisms somehow changes the ecosystem, effecting the perception across the whole foodweb.

How could this be important? To monitor biodiversity. Anthropogenic stressors are impacting global biodiversity and the extinction rate is one thousand times higher than the natural one (Pimm et al., 2014). The scenario is shifting greatly and it is profoundly linked to ecosystem processes and human exploitation of natural resources (Sala et al., 2000). By monitoring biodiversity, scientists can identify the most vulnerable ecosystems and define hotspots where conservation measures must be taken. Biodiversity conservation is also linked to ecosystem services provided to humans, thus critically connecting conservation of natural resources with health and economic development (Turner et al., 2007).

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Emergence of organisms: An exploration of the boundaries between living organisms and robots

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Abstract

Can one formulate broad principles for evolving proto-cells, single cell organisms, perhaps multi-celled organisms and even robots, that live in their complex worlds, adapt and survive, can grow more complex and diverse in an abiotic or biotic environment co-evolving with one another? In this contribution we try to identify a minimal set of properties that are likely to characterize living organisms that adapt and evolve in open environments. This enables us to formulate hypotheses on the boundaries between living organisms and artificial machines.

Introduction

Since early cybernetics studies, such as the ones by Ashby [1] and Wiener [65], the properties of living systems are subject to deep investigations. The goals of this endeavour are both understanding and building: abstract models and general principles are sought for describing organisms, their dynamics and their ability to produce adaptive behavior. This research achieved prominent results in fields such as artificial intelligence and artificial life. For example, today we have robots capable of exploring hostile environments with high level of self-sufficiency, planning capabilities and able to learn. Nevertheless, the discrepancy between the emergence and evolution of life and artificial systems is still huge. Here we try to identify and we discuss core elements characterizing organisms able to adapt and evolve.[1]

Our journey starts from a rocky extrasolar planet in which we suppose that a community of humans has established a colony. There are also robots that extract minerals and work in factories producing several materials and goods; moreover, by executing specific programs, they build and assemble the components to produce new robots. One day, a robot named Patrizio,[2] failing to decrease its speed fast enough after a declivity because a wheel accidentally slid on the flat ground instead of rotating, stumbles onto a sharp and pointed rock and gets a dent on its aluminium side. The rock turns out to be made of obsidian, very useful material to the community. This accident has no consequences on robot's functions, but opens up the possibility for Patrizio to detect rocks containing obsidian, which protrudes from the rock trunk, because the dent fits rather well with obsidian extrusions. The dent *affords* the robot to identify obsidian rocks more efficiently, because it can immediately go to the robot base and call the robots specialized in collecting rocks,[3] instead of extracting a sample to bring to the lab for the analysis. The dent has become an "obsidian detector" and has now a *meaning* in this particular environmental niche and can be formally named. As a consequence, the control program of Patrizio can be changed in such a way that this new opportunity is exploited.[4] Not only

[1] This contribution is a revisitation of a previous paper by the same authors [54].

[2] Patrizio is the Italian name for Patrick, one of the characters of an interlude in chap. 8 of [31].

[3] In this planet, electromagnetic interferences make it impossible to send radio signals to communicate.

[4] A question may arise regarding whom is going to actually change the control program and how. Let's assume that there are some agents in the colony, either humans or robots, capable of doing this.

the control program, but also a new robot line can be deployed: the "Patrizio model" capable of efficiently identifying obsidian.

Now that a more efficient way to detect obsidian has been found, a larger quantity of this rock can be collected. Therefore, robots equipped with special actuators for processing obsidian can be built. By an accident, one of these robots, Roberto[5] has been built with an error in the assemblage procedure and gets a bump on its aluminium side. The cause of the error is an impurity in the aluminium sheet that deceptively recursively attracted the accumulation of more aluminum in a small area of the chassis. This characteristic can be exploited as a means to detect dents in objects but also in other robots. As a consequence, robot Roberto can easily identify the robot that is more efficient in finding obsidian and follow it, just by matching its bump with the other robot's dent. Roberto has now a new sensor, which can serve as a "dent detector". Therefore, the two special robots can recognize each other and form a specialized team extracting and processing obsidian even more efficiently. Again, a brand new robot model can be put in production with this "dent detector". And all Patrizio and Roberto robots can reciprocally recognize themselves by using their "bump" and "dent" detectors.

Bumps and dents, and bump and dent detectors, did not exist prior to the accidents and they could not even be predicted. The accidental sliding of a wheel and the impurity in the aluminium opened up the possibility of dents and bumps. These accidents *enabled* new forms of behavior and cooperation in the niche where the robots operate. It is also worth observing that bumps and dents, along with their detectors, have acquired a meaning because they are useful for a robot to do something, to be more efficient in accomplishing a task. They have a meaning only in this specific niche and for these robots. Now that they have a meaning, the robots can name and use them inside their control programs, which we assume to be adaptive to some extent.

The events simplistically and metaphorically illustrated in the robot story ceaselessly occur in the evolution of the biosphere: organisms adapt and evolve by exploiting new opportunities in their environmental niche—either by heritable variation and selection or by identifying new ways to achieve their goals. We are surely amazed by the continuous blooming of forms and varieties in the biosphere and we may wonder what are the core elements characterizing this process. We may also ask ourselves whether and to what extent this process can be reproduced in an artificial environment.

A first property we can identify is the ability of discriminating what is beneficial or disadvantageous for the organism, "what's good or bad", in Ashby's terms. This discrimination capability consists in being able to classify relevant information from the environment, and it leans on *sensors* that can capture the relevant information for categorizing external stimuli. The detection of relevant information is a way of *meaning creation*: what is important for the survival of the organism in its environmental niche shapes the evolution of specialized sensors, so the patterns and the correlations they capture come to exist and get a name. Not just data streams collected by sensors, but semantic information.

Besides the capability of capturing relevant information from the environment, for surviving the organism must be able to use this information properly. As a consequence, also mechanisms and means for acting in the world should be developed. In robotic terms, we may speak of *actuators* [40], but we also include here the ability of taking decisions and act, i.e. having a *control policy*—that should also be adapted and changed.

Finally, organisms are *Kantian wholes*, i.e. organized beings having the property that the parts exist for and by means of the whole [25, 32] and they are *critical* [57], i.e. their dynamical regime is at the boundary between order and disorder.

[5] Italian for Rupert, another character in [31].

In the following we introduce these elements and we briefly discuss some implications for artificial systems.

The evaluation function

In robotics, adaptive mechanisms such as learning and evolution require the definition of a merit factor that is used as a feedback for the adaptive process, e.g. a fitness function in evolutionary computation techniques [45]. These functions are externally defined, but their implicit purpose is to provide a value system to the robot, such that it is able to take decisions that are beneficial to its self-sufficiency and goals. Indeed, living organisms need to answer the question "what is good or bad for me": on the one hand, they act so as to take what is good for their survival and goal achievement, and, on the other hand, by acting in this way they are likely to survive longer and thus spread their genetic material to the next generations. In essence, if they are endowed with a suitable value system and act accordingly, they attain both an individual advantage, as they keep homeostasis and achieve their goals, and a phylogenetic one. In this context, emotions have a primary role, as they are involved in the self-regulatory sensory system of organisms and category formation [48]. Along this line, task-agnostic merit factors are currently used in robotics, with the aim of providing internal motivation-inspired evaluation functions [2, 55].

Ashby [1] suggests to formalize this concept by considering essential variables: if essential variables are kept in a given range, then the system is fine, i.e. if the system is able to act so that its essential variables are within the given range, then it survives. This notion can be easily generalized to include in survival not just self-sustainability, but also the achievement of goals [62, 4]. A dynamical systems perspective of agents and environment [3] provides a suitable formal framework for this generalization.

A fundamental issue here that discriminates between natural and (current) artificial systems concerns whom defines the goals and evaluation function: while in artificial systems the initial setting is provided by the designers, biological organisms appear to be fully autonomous in this respect, exhibiting a property called *agency* [64]. The debate as to whether artificial systems will in the future be endowed by the same kind of autonomy as natural organisms is quite active at the present time.

Sensors and actuators

If robots are equipped *ab initio* with sensors that acquire the information that is necessary for their survival, then the boundary conditions for their adaptation and evolution are already set and cannot change. Therefore, in order to avoid to inject *ad hoc* knowledge, we would need to set up mechanisms enabling robots to extract and/or create useful information from the environment. To this purpose we need either an evolutionary mechanism acting on populations of systems (primarily by heritable variation and selection) or providing the systems the capability of adaptively evolving and/or constructing sensors, or both. Cybernetics scholars have indeed explored the evolution of sensors, starting from the pioneer work by Pask [47] to more recent works [46, 51, 61]. As remarked by Cariani [9] rephrasing Ashby, "in order to achieve better performance over its initial specification, a device must be informationally open, capable of interacting with the world independently of its designer, the device must have some degree of epistemic autonomy in order to improve itself, but epistemic autonomy is not achievable without some degree of structural autonomy". In other terms, no improvement is possible if the organism is not able to change something in its structure so as to autonomously find ways to profit from useful correlations in its environment. For example, if energy sockets are under light bulbs, a robot could detect and reach them faster if it is capable of developing an electromagnetic sensor for the visible spectrum. In biology we have plenty of notable examples of sensor evolution, from the capability of bacteria of measuring food concentration [23], to the various forms of eyes [12].

Sensors are the way organisms and robots acquire useful information that is used to act in the world through actuators. We assume a wide definition of actuator as a tool or mechanism that the robot can control to change something in the world (e.g. grasping an object, moving, lighting up a LED). Sensors and actuators are the information channels between the organism and the environment and their combined use produces what in robotics is called *sensory-motor loop* [49], referring to the fact that sensors readings affect actuator commands and conversely the results of actions affect sensor readings. Therefore, it is no surprise that the evolution of sensors and actuators is intertwined in Nature. Hence, in an artificial setting we also need to set up a mechanism enabling the organism to act properly and choose what is good for it. Again, we need either an evolutionary mechanism acting on populations of organisms or providing the organisms the capability of adaptively constructing actuators, or both. *En passant*, we observe that, while the subject of sensor evolution has received attention from the cybernetic community, the evolution of actuators has not been discussed so in depth [46]. We believe the reason is to be found in the fact that, rather than actuator evolution, the interest has been often focused on tool development.

Affordance

Sensor and actuator construction essentially consists in identifying *affordances* so as to make use of something that is "useful to me". Informally speaking, an affordance is a possible use of X to do Y [30, 32]. This term has been introduced by Gibson [17] to capture the fact that objects afford observers possible actions. Jamone and co-authors [24] emphasize two aspects of affordances that are relevant for our discussion:

- affordances are not properties of the environment alone, but they depend on sensing and actuating capabilities of the robot;

- affordance perception suggests action possibilities to the robot through the activation of sensory-motor patterns [50], and it also provides a mean to predict the consequences of actions.

Therefore, without the possibility of evolving its own sensors and actuators, a robot cannot identify affordances and so there are no ways for it to explore possible information acquisition and actions, and so improve.

The controller

The missing piece in the design of an organism is a mechanism for converting the information sensed by the robot, and possibly its state, into actions (i.e. the "controller" or the "control software"). Succinctly, we can say that the system needs a behavior policy that maps perceptions and internal states to actions. If states and actions can be formally modeled and are time invariant, then any formalism defining a policy is sufficient to provide a functioning controller (e.g. a Markov system), to be trained by a learning technique. Nevertheless, here we are considering the case in which sensors and actuators can evolve in time, so both the sets of states and actions can change, and new states should be added to the policy and also new actions. In general, acting properly requires dynamics and choice. Therefore, a viable formalism for accommodating such requirements is that of dynamical systems, provided that they can be subject to structural changes (e.g. new variables can be added). Memory might not be strictly required, even if for non-trivial tasks it is often needed, especially considering changing environments. Note that memory can be a stable structure but can also be alternative attractors.

In order for the robot to exploit a feature of the environment to improve its performance, the action policy has to be adjusted with respect to this feature and possibly other relevant features of the environment such that the robot can reach its goals. Some questions arise as to what are these relevant features, what is the role of affordances, how do policies emerge and improve. In addition, we also may ask the fundamental questions concerning the nature of computation: are policies calculated in an analogue calculation by a physical system? What is the character of the computation and improvements of policy? How is the policy carried out physically? For these latter questions, we can provide an answer by observing that from recent studies Hebbian and anti-Hebbian learning mechanisms have been discovered in biochemical networks of single-cell organisms [10]. These mechanisms involve protein translocation, signaling cascades, and chromatin memory, among the others. In abstract terms, these systems can have dynamical attractors, can alter they attractors by synapses alterations, can evolve, and can store information in old and new attractors.

Changes in sensors, actuators or the controller affect in general the phase space of the robot, therefore it can move to the *adjacent possible* [28], i.e. the space of opportunities that can be reached starting from the actual condition. As a consequence, a policy update mechanism is needed to add new states and actions to the current policy. The new states and actions are new symbols associated to meanings.

Semantic information

The possibility of developing sensors and actuators, and consistently adapting the behavior policy, enables the organisms to identify affordances and create constraints that stabilize these features, thus expanding to the adjacent realm of possibilities. Affordances are continuously created and can be exploited, constraints are created, and so forth.

Creating affordances is creating information, which is in fact *semantic information* [35], as opposed to Shannon-based information which propagates already existing syntactic information. Semantic information characterizes correlations in the environment that are useful for an agent as they carry significant knowledge. Affordances are carved out of a continuum, e.g. bumps and dents become new relevant variables in a formal representation of the world. After the relevant variables have co-created themselves, we "can name them" and new meanings come to exist. The presence or absence of a bump, the presence or absence of a dent can now be represented by variables. As a consequence, semantics comes first and syntax comes later: first the bump means something for me (good or bad), later it gets named and the corresponding symbol can be used. In digital computers the computations operate on the syntax (bits) but there is no semantics. Theorems are operations on bits, i.e. symbols, and are not the world: the world is the bumps and dents. For these reasons, the notion of affordance is a key concept in biosemiotics, where it has been discussed and extended since its original formulation [17]. Particularly suitable to the perspective taken in this paper is the definition of affordance provided by Campbell et al. [7], who propose to define "*affordances* as *potential semiotic resources* that an organism enacts (detects, reads, uses, engages) to channel *learning-as-choice* in its environment.".

Let's now return to the robotic scenario we illustrated in the Introduction: bumps and dents, and bump and dent detectors, evolve in the world so organisms can collectively coordinate their behaviors to get what they need [31]. This becomes a construction of mutually consistent biosemiotic systems [15, 52, 63]. In the biosphere organisms have evolved to mutually create mutually consistent affordances: the evolution of life is the evolution of myriads of meanings. Finding the principles governing the emergence of the organisms is therefore the foundation of biosemiotics [37, 21, 38].

This creation of meanings through new emerging functions and dynamical patterns that turn out to be useful to some organisms is also at the roots of the *symbol grounding problem* [18], which concerns the way symbols are intrinsically represented in systems. This problem has been thoroughly discussed inside the community of artificial intelligence and artificial life [59, 60, 8, 43] and we believe that our perspective puts the problem in a more general context, related also to constructive biology [44]. Strictly related to the grounding problem is the *frame problem*, that deals with how an embodied and situated system can represent and interact with the world it lives in [11, 19, 16]. Note that the viewpoint of evolving and maintaining mutually consistent meanings provides a unified way for dealing both with the grounding and the frame problem.

The continuous identification of affordances and the construction of constraints change the phase space of the organisms and expand it to the adjacent possible. We remark that it is not possible to prestate new functions emerging in this open condition. Let's take the case of the use of an engine block as a chassis for the tractor: it is also possible to use the engine block as a paper weight or to crack a coconut on one of its corners. These are alternative possible uses of the same physical object and in evolution none, one, some or all of these uses may come to exist, for example by Darwinian preadaptation. Because there is no deductive relation between the use of the engine block as a chassis and the use of the engine block to crack open coconuts, there can be no deductive theory of the evolution of biospheres. We are beyond deductively entailing laws: evolving biospheres are radically free [31, 32]. Therefore, the possible uses of an engine block are indefinite and so are its affordances [28].

We remark here that evolved systems are built of physical parts which have multiple causal features: some of them might be selected for performing a specific function useful to the organism. For example, we say that the heart pumps blood because we identify in this feature a property functional to the survival of an animal and we discard other irrelevant features (e.g. the heart also produces sounds). Not only the emergence of these functions is non-deducible, but it is typical of a *bricolage* process, in which causal features of objects that turn out to be useful are exploited. Note that the segmentation of an organism into separated parts is often just a convenient simplification of our description [13, 27]. Conversely, in engineered robotic systems, each part has its own identity and is optimized for one specific function: here the interactions among parts are precisely modeled and there is no space for affording new functions nor new emerging relations.[6]

Organisms are critical *Kantian wholes*

From an abstract viewpoint, we can state that surviving means keeping organismal individuality, i.e. the property enjoyed by *dynamically critical Kantian wholes that achieve constraint closures and construct themselves, mutually critical among the organisms in order that they can cooperate to survive*.

A *Kantian whole* is an organized being that has the property that the parts exist for and by means of the whole [25, 32]. An individual is a Kantian whole that achieves constraint closure, whereby each of a closed set of non-equilibrium processes constructs constraints that enable other processes to construct further constraints, in a circular way. Constraints enable a process to do *work*, which is the constrained release of energy into a few degrees of freedom [41, 31]. Constraint closure, plus the other things that constraints closed systems can build, define the boundaries of the individual. The individual lives in its abiotic and biotic world, defining its niche. The niche of an individual is what Von Uexküll calls *Umwelt* [63], i.e. the subjective world of an organism, and cannot be defined non-circularly.

The organisms in the evolving biosphere are very likely to be critical, i.e. their dynamical regime is at the boundary between order and disorder [26, 29]. This conjecture has found strong support in biology, neuroscience as well as computer science [57, 42] and can be expressed as the combination of two statements:

i. critical systems are more evolvable than systems in other dynamical conditions as they attain an optimal trade-off between mutational robustness (i.e., mutations moderately perturb the phenotype, without introducing dramatic changes) and phenotypic innovation (i.e., mutations can introduce significant novelty in the phenotypes);

[6] And if this, for some serendipitous and very limited conditions happens, it is called a "design error"!

ii. critical systems have advantages over ordered or disordered ones, because they optimally balance information storage, modification and transfer, and achieve the best trade-off between the repertoire of their possible actions and their reliability.

The property of being critical is therefore very likely to be found in Kantian wholes that identify and exploit affordances in their environment and furthermore they cooperate among each other to survive. If organisms are critical, their parts are not necessarily so. The advantage of being critical comes from the necessity of interacting with other systems in a changing and dynamic environment [20]. Being critical is anyway an advantage in evolution and because it's easier to find an advantageous coupling with the environment [5]. Therefore, we expect to find Kantian wholes critical, but their parts may or may not be critical, depending on the evolutionary path that occurred and the way they are coupled with the other constituents. As a consequence, in a scenario with the evolution of artificial organisms, criticality should play an important role and systems should be designed in such a way that critical dynamical regimes are favored. Notably, dynamical models such as Boolean networks have been shown to maximize mutual information [53], basin entropy [36] and transfer entropy [58] when poised at the critical regime; both measures are correlated with the capability of discriminating percept categories and act accordingly. This property is crucial for evolving organisms, because as the number of sensors that come to exist increases and organisms use those sensors, the number of possible combinations of percepts increases exponentially in the number of sensors. For example, if the sensors return binary values and the number of sensors N increases in time, the number of possible percept patterns increases as 2^N. This is just a lower bound, as we are assuming binary percepts; organisms in Nature are rather analogical and this means they are able to deal with a huge number of "worlds" they can sense.

Conclusions

The ability of knowing "what's good or bad for me", the possibility of developing sensors and actuators and the capability of adapting their own behavior policy are properties that enable organisms to evolve in an ever expanding phase space. The astonishing evolution of the biosphere is beyond physics: critical co-evolving Kantian wholes develop by following paths for which there are no entailing laws. The question now arises as to what extent artificial systems can be built such that they are endowed with the properties listed above and is if these properties are sufficient for the emergence of artificial organisms.

Current advances in AI and robotics suggest a positive answer to the first part of the question [14]. Promising attempts to the online embodied evolution of robots have been proposed [6, 22]. Soft robotics [39] and unconventional computing systems [66, 56, 5] may provide a viable approach to the evolution of sensors and actuators, along with self-improvement of behavior policies (which, of course, may greatly benefit from current machine learning and AI techniques). By setting up experiments with artificial systems in an open-ended evolution, we are looking for the boundary between what can be achieved through the properties listed above without consciousness, and what can be achieved with free will and *qualia*.

Implications for the so-called *General AI* can be drawn from our analysis. The possible uses of an object are indefinite, they are in a nominal scale and there is no deductive procedure to predict them [31, 34, 33]. Organisms seize affordances by heritable variation and selection. But we find affordances all the times: can an AI based on Universal Turing Machines (UTMs) also do it? We are persuaded that UTMs cannot find affordances because *(i)* algorithms are deductive, and *(ii)* learning just does statistical summaries and does not create new representations. Therefore, robots, as embodied UTMs, cannot find affordances either—at least, in reasonable time. However, this subject is out of the scope of this contribution and will be further developed, with emphasis on consciousness, in a further contribution by the same authors.

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COMA-SAN:
COMplexity Analysis in the Simplest Alive Neuronal network

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Keywords: AFM, nanomotion detection, cell viability, collective behaviour.

Abstract

Complexity is a concept embedding many different phenomena in nature. Brain functioning is one of these, where a multitude of neurons are interconnected. We designed an experiment focused on few neurons to study the interaction between the simplest configuration of a complex system, consisting of three units. We present the first results of experiments based on the Atomic Force Microscopy, where the nanomotion of the cells is acquired, demonstrating the capacity of the set-up to detect the activity of a system composed by neuroblastomes down to few units.

Introduction

There is a strong correlation between movement and life, between energy consumption and large or small-scale motions or vibrations. Remarkably, complex organisms perform many vital functions through movement: searching for food, reproduction, defence from predators and other important activities, and all these functions require the movement or vibration of the cells of a system. Performing a function that involves movement requires a sophisticate coordination and information transfer between several parts of the organism and this collective behaviour is paramount in understanding the status and response of the biological system as a whole.

The importance of movement does not fade even at much smaller scales, such as molecules and macromolecules. At this level, the importance of molecule dynamics in the emergence and in the modulation of chemical-physical and biological properties is well known and many tools are available for their modelling and characterization [1, 2]. Just to name few, experimental approaches based on IR and X-ray spectroscopy as well as molecular dynamics or ab initio calculations for theoretical analyses and modelling are widely used[3-5].

It must be noted that the movements of even the simplest living specimens are inherently complex, influenced by the combination of many endocrine and behavioural parameters, as well as by contextual or environmental variables and are, in general, difficult to evaluate in terms of the information they can provide on the status of the biological system. The complexity increases even more when multiple specimens interact in multi-cellular systems, and knowledge of the micro and nano-scale behaviour of such complex biological systems is much scarcer.

Recently, with the aim of investigating the movements and vibrations of small, but complex, biological systems both at the micro and at the nanoscale, we have introduced a new nanosensor: the nanomotion sensor (NMS)[6]. The idea is to make use of the intimate link between life and motion, to monitor the metabolism of living biological systems by measuring the fluctuations of flexible cantilevers that act as solid support for the microorganisms.[7] The NMS allows real-time measurement of the movement of any compatible biological sample within physiological or culture medium, with displacement sensitivity in the Angstrom-to-micron range.[8] The nanoscale movements of the viable specimens will induce dynamic deflections of the sensor, which are collected in the form of a time-dependent chart of its vertical movements. If the specimens are exposed to a stimulus that modifies their activity, the sensor's oscillations are altered accordingly, providing a fast and reliable tool to characterize the relationship between stimulus and response.

This methodology has the potential to highlight the insurgence of peculiar oscillatory signatures in the motion of microorganisms to be associated to collective behaviour, self-triggering or other mechanisms through which a cluster of biosystems can communicate and develop a synchronous response to an external stimulus. This approach opens the way to the use of these nanosensors to estimate the communication and interactions between microorganisms, which is the underlying phenomenon to the more multifaceted behaviour of cells in complex organisms.

Here we present the first steps of this endeavour: the NMS study of a neuronal−like cell model in small clusters (COMA-SAN, COMplexity Analysis in the Simplest Alive Neuronal network). These pioneering analyses is designed to shed light on the unexplored world of the communication-mediated group behaviour of neuronal cells, studying also how the observed patterns are altered by changes in environmental conditions. Overall, these studies open a path to produce a new means to understand the interactions between cells and possibly evidencing the complexity of group dynamics in cells.

Detection of nanomotion in molecules and living organisms

The very first example of AFM cantilevers used to sense biological phenomena was carried out by Radmacher et al in 1994.[9] In this seminal work, the authors adsorbed lysozyme molecules onto a mica surface and approached an AFM tip above the proteins. Upon exposure of the lysozyme to one of its substrates (e.g oligoglycoside), the cantilever oscillated. It was speculated that the oscillations were caused by the lysozyme conformational changes. Several years later, a similar experiment was carried out by Alonso et al. by coating an AFM cantilever with topoisomerase II, a protein which changes conformation by oxidizing ATP and that is involved in mitotic chromosomes scaffold as well as DNA unfolding. Comparing the cantilever's oscillations before and after addition of ATP, a drastic increase in the cantilever oscillation magnitude was evidenced and this was associated to the conformational changes of Topoisomerase II induced by ATP hydrolyzation.[8]

Nanoscale vibrations were exploited also to evaluate the viability of different microorganisms. The first report on this phenomenon is by Pelling et al., in 2004, who demonstrated how living yeast cells produce a measurable vibration.[10] In this study, an AFM tip was brought in close contact with the cell wall of *Saccaromices cerevisiae*, which induced nanoscale oscillations of the cantilever at relatively high frequency. Further characterizations were employed to ensure that the recorded signal was not due to Brownian motion or noise but had, in fact, a biological origin.

In 2013, some of us demonstrated that microorganisms attached onto an AFM cantilever can produce oscillations of the sensor that are directly correlated to the metabolic state of the organisms.[11] The time-dependent chart of the vertical movements of the sensor form a coloured noise signal, a nanomotion pattern, whose amplitude can provide a real-time determination of the metabolic status of the specimens as a function of different physico-chemical stimuli, and can therefore be used to determine almost instantaneously the viability of a biological system. Importantly, the very same observations were reproduced by different groups working on bacteria[12-15] and on other biological systems [7, 8, 16, 17], validating the nanomotion sensor in the research laboratory and highlighting the robustness of the detection methodology.

The experimental procedure of a nanomotion analysis is quite simple: first, the organism of interest is attached onto an AFM cantilever, which was preliminarily functionalized using a molecule that promotes adhesion such as fibronectin, poly-lysine APTES or glutaraldehyde. The choice of the compound depends on the organisms as well as the surface of the cantilever following optimized protocols[18]. The cell-loaded cantilever is then immersed into the analysis chamber containing medium promoting cell growth. Finally, the oscillations of the cantilever are recorded under different conditions such as medium containing a molecule that compromises or that enhances the metabolism or the viability of the organism.

According to previous works using FEM and studying conformational changes in quaternary proteins structures [8, 11], the energy of two ATP molecules is sufficient to produce a 1 nm oscillation in a cantilever. Thus, the number of cells needed to detect oscillations is very small and depends on their size and strength[7]. A single yeast or mammalian cell is enough to obtain exploitable signals whereas hundreds of bacteria are necessary for an equivalent signal to noise ratio. (Figure 1)

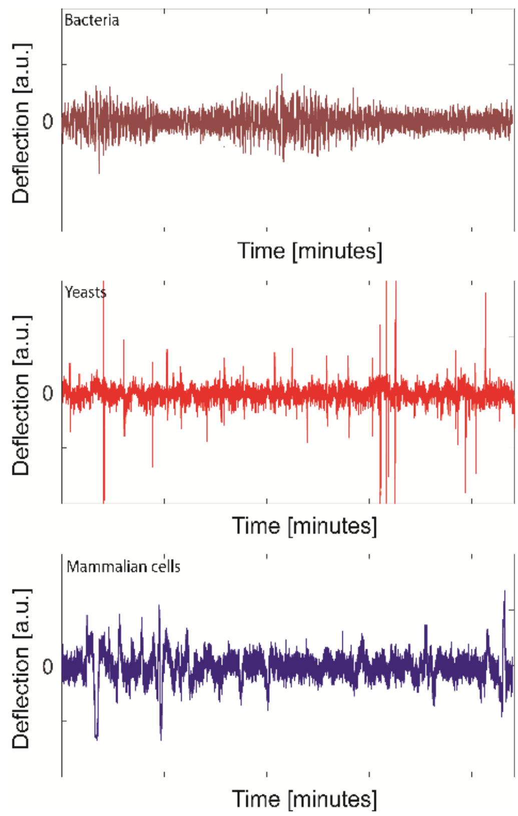

Figure 1. Examples of nanomotion signals collected using Bacteria (Staphylococcus aureus, Top), Yeasts (Candida albicans, Middle) and Mammalian cells (Osteoblasts, Bottom)

Overall, the nanomotion sensor provides a robust and sensitive platform to translate a variety of biological mechanisms into a measurable signal. Its high-energy sensitivity provides a great opportunity to detect very small responses even when these are embedded in a potentially very complex landscape. These aspects will be discussed in the next paragraph

Possible cellular mechanisms as sources of nanomotion

Despite the aforementioned studies demonstrating that cantilever deflection is induced by nanomotion of living organism, its origin remains not fully understood. Several hypotheses have been proposed to explain this phenomenon. Indeed, the nanomotion signal comprises vibrations arising from many metabolically-related sources that combine energy consumption with local movement or molecule redistribution. These include protein cytoskeleton reorganization, movements of focal adhesion proteins, metabolically active organelles (such as mitochondria in animals and chloroplast in plants), vesicles production and trafficking, opening of ionic channels, membrane interaction with the sensor or conformational changes of individual proteins.[8] All these biological signals are collected by the nanomechanical oscillator in the form of coloured noise, which could provide clues about the underpinning involved processes. These characteristics highlights the complexity of understanding the molecular and cellular mechanism behind nanomotion of cells.

With the premise that additional experiments need to be performed to unravel this phenomenon, the next section discusses some aspects of the signal transduction.

A first hypothesis to explain cellular nanomotion involves the most external cellular component: the cell membrane for mammalian cells or the cell wall for plant cells and microorganisms. Cell membranes are highly dynamic entities composed of a lipid bilayer whose role is to give flexibility to the membrane and proteins [19]. For several decades now, cell membrane has been showed to be a dynamic entity [20, 21]. Even early stages of cytotoxicity causes a change in the viscosity of the cell membrane and morphology, both affecting their adhesion to the cantilever and the membrane's ability to transduce the innermost vibrations.[15] Furthermore, as evidenced in mammalian cells, if actin-depolymerization drugs are used, some components of the nanomotion signal are affected, and this shows the correlation between the actin reorganization and the nanomotion signal.[7] Recently, it has been confirmed by Long-Range Surface Plasmon Resonance (LRSPR) that cell membrane nanomotion exists and that it extends within a range of nanometers.[22] This finding suggests a potential link between the dynamics of cantilever deflection and the cell membrane motion.

Another potential origin of nanomotion could involve the activity of the membrane ion channels. Many organisms including bacteria, yeast and plant cells possess thick and rigid cell walls that are less motile than the cell membrane of mammalian cells. Ion channels are proteins located in the cell walls as well as in cell membranes. Their function is to maintain a concentration gradient of specific ions across the membrane. Opening and closing of an ion channel requires conformational changes from the ion channel itself [23], which, as previously mentioned, induce detectable oscillations of the cantilever.[8] Furthermore, the channel opening/closing is often associated to lysis of ATP molecules. Taken together, these considerations suggest that ionic channels could contribute in some of the nanomotion signal in cells.

Other factors that could affect the nanomotion include extra- and intracellular organelles such as flagella and mitochondria respectively. Some prokaryotes and eukaryotes possess flagella, pili or cilia, motile organelles that allow cells to move. This could transfer a momentum to the cantilever either directly or via liquid turbulences. For instance, it has been demonstrated that the inhibition of the movement of flagella in *E. coli* can be detected as a reduction of the nanomotion signal, indicating that a component of the signal can be originated by these structures.[7] This mechanism, thus, could also be used to partially explain the cantilever oscillations.

Previous experiments have shown that the insurgence of a measurable nanomotion signal requires movement associated to energy consumption. Thus, Stupar and coworkers studied the nanomotion arising from mitochondria, intracellular organelles that are involved in the energy generation [24, 25]. Preliminary experiments demonstrated that active mitochondria can induce cantilever oscillations, with characteristics that change upon exposure to different molecules (malate, pyruvate).[25] As consequence, this mechanism should also be taken into account as a constitutive part of the overall nanomotion of cells.

Considering that mammalian cells can range from 5 to 100 µm, and possess multiple organelles in their cytoplasm, the complex, coloured noise comprising the nanomotion signal will probably be the superposition of several of the aforementioned components.

The COMASAN experiment

Following the works of Kasas's group, subsequently confirmed by Wu's group, we employed nanomotion sensors to monitor the response of neuroblastoma cells over time [16, 26]. Our goal is to determine the vibration patterns of single or small groups of cells in order to pave the way for a new methodology towards the study of brain communication, complex biological systems and response to drugs.

Figure X depicts the oscillations of the nanomotion sensor before and after the immobilization of three neuroblastoma cells on its surface.

Human neuroblastomas (SH-SY5Y cell line) were grown at 70 % confluence in DMEM low glucose (Euroclone Spa, Pero, MI, Italy) supplemented with 10% fetal bovine serum (FBS, Gibco), 2 mmol/L l-glutamin (Euroclone Spa, Pero, MI, Italy) and 100 g/mL penicillin-streptomycin (Euroclone Spa, Pero, MI, Italy). Cells were maintained at 37°C in a 5% (v/v) CO_2 humidified incubator and confirmed negative for mycoplasma by routine testing performed once every month. For nanomotion characterization cells were detached from culture flask using Trypsin-EDTA for 2 minutes at 37°C, centrifuged at 1500 rpm for 10 minutes, resuspended in culture medium and then transferred in a Petri dish.

The experiments were carried out using a Flex-AFM microscope (Nanosurf, Zurich, CH). The microscope was mounted on top of an IX 50 Olympus inverted microscope (Olympus, Tokio, JP) using a Progres MFCool digital camera (Jenoptik, Germany) for optical imaging. The entire AFM+optical microscope system was placed in an environmental control chamber (a biological incubator) that ensured the maintenance of optimal temperature and CO_2 conditions throughout each experiment. All the optical images were collected using a standard 40x objective in the phase-contrast modality. The nanomotion sensors were commercial silicon nitride, micro-cantilevers, with a nominal spring constant of 0.12 N/m (DNP-10 Bruker). The sensors were preliminarily treated with poly-D-lysine (20 µg/ml, from Sigma-Aldrich) for 15 minutes, followed by thorough rinsing in ultrapure water).

The time-dependent fluctuations of the sensor, linked to the metabolic activity of the biological specimens, were recorded using a NI USB-4431 card (National Instruments, USA) and through a custom LabView software. The data analysis was carried out using a custom LabView software. The cantilever fluctuations were recorded with a sampling rate of 20 kHz.

The immobilization of the cells on the sensor was performed using a technique mirrored from the single cell force spectroscopy preparation protocol and detailed in [27, 28]. The cantilever is brought on top of a cell and gently pressed over it in order to ensure its attachment. When the tip is retracted, the cell remains attached to its functionalized surface.

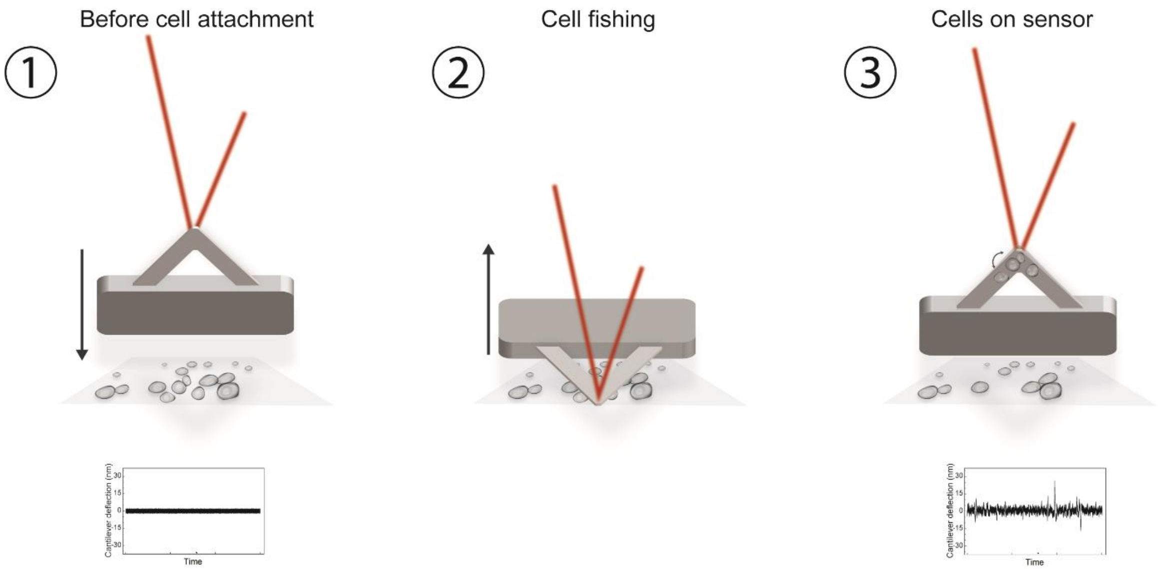

Figure 2. Schematics of the cell attachment protocol

After several cells had attached to the sensor, we retracted the sensor and started monitoring their oscillatory movements for hours. (Figure 2) The fluctuations of the sensor were used to investigate the nanometer-scale movements of the adhering cells, while the optical images showed their micron-sized evolution on the cantilever surface. These measurements reflected the basal metabolic activity of the cells. While collecting the nanomotion signal, we recorded time-lapse videos of the cells on the sensor (collecting an optical image every 20 seconds), to assess their attachment, their healthiness and to monitor at the micrometer-scale the individual cell movements during the time of the experiment.

To evaluate all the experimental results, we analysed statistically the fluctuations by calculating their variance and we repeated each experiment at least 3 times to ensure a good repeatability of the results.

We showed that for more than 5-6 hours, the nanomotion activity of the cells was uniform and the cells were alive and fully attached to the surface (Figure 3, Movie 1). These control experiments indicated that the nanomotion experimental setup allows a controlled analysis of the cell's metabolic activity for several hours and that its results can be compared directly with the conventional biological assays. The signal was also compared to the one obtained when no cells are attached to the sensor, which we used as baseline.

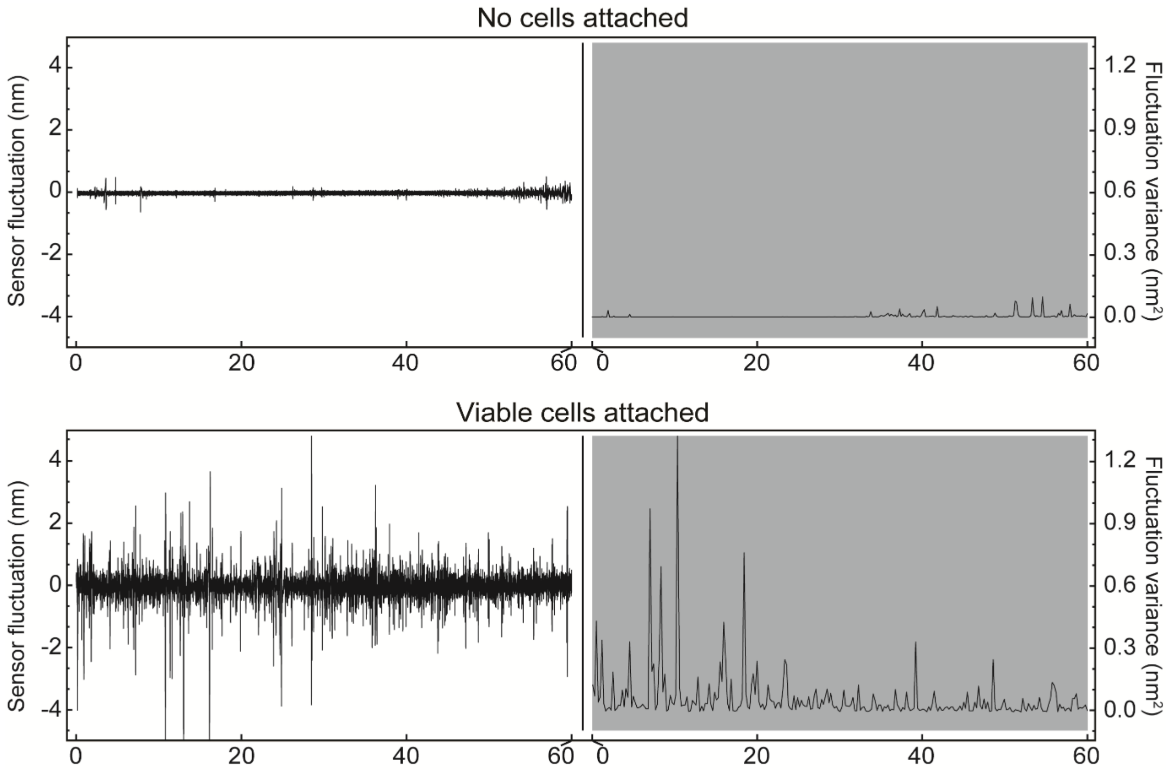

Figure 3. Comparison between the nanomotion signal and variance before (top) and after the immobilization of neuroblastomas (bottom)

Conclusions and future perspectives

We demonstrated for the first time that the nanomechanical fluctuations of a microcantilever sensor are sensitive enough to detect the dynamics of one neuroblastoma cell. The COMASAN experiment aims at investigating the nanomotion collective behaviour in different environmental condition, in order to pave the way for AFM to be used in studying brain communication, complex biological systems and response to drugs. The sensitivity of the technique enables downscaling the experiments to the simplest complex system, consisting of three individual cells, and with simple stimuli. This approach will allow to focus on the signatures of basic biological processes before upscaling to thousands of interlinked cells embedded in multiple sensing scenarios.

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Boomerang and Hologram - two examples of information in motion

The exploration of physical kinetic and structural information

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Abstract

This work is presenting a possibility how physical information processing can be seen as the predecessor of all information processing which descended in the course of evolution of systems which grew in capacity to relate observations and actions to drives. The example of the returning boomerang is chosen to present basic physical relations between structurally stored geometries plus matter (charge) distributions and their kinetic effect on flow patterns and forces from the surrounding medium air. The necessity for media in motion to transfer the structural information into the motion of excitations in the medium is further explored in the example of images from interference as in Lippmann photography and holograms. The two examples – one for on object which directly is affected in its motion by the alterations which its structure caused moving in the field and the other – for a structured surface which is inert to the microscopic forces which are generated by transferring its information as an image in form of an intensity distribution pattern are used to explore the idea of Stonier that there exist two types of information which are connected to transformations in energy, respectively between the complementary kinetic and potential energies in mechanics. A possible connection between physical information and the principle of stationary action is explored to conclude the presentation of educated guesses.

Introduction

Information is mainly experienced in everyday life as a (mental) construct which holds collected, memorized experiences about things in the world and allows deciding on categorization and estimation of quantity and quality. Information is employed in the form of knowledge –which can be seen as an individual´s capacity to direct energy [2]- or to influence an individual´s view of something [3]. There are many publications on the theory of information (for a review see e.g. [4]). Many of them focus on analysis of semiosis in language information, (differentiating between syntactic, semantic and pragmatic application). Almost all of them view the evolution of life as a precondition for information-based effects in the course of evolution and the genetically encoded[7] information as the first occurrence of information "physics" in the course of evolution. Only few discuss the possible action of prebiotic, physical information (e.g. [6,7]).

On a more basic, analytic level information is also defined in science. The term is often used technically on the very limited basis of having a counter for binary decision events in sequences, as it was initiated with the mathematical theory of communication [8]. Another publication which contributed an important aspect to information theory and got widely acknowledged is Bateson´s book on the ecology of mind, which contains the famous quote *"What we mean by information — the elementary unit of information — is a difference which makes a difference, and it is able to make a difference because the neural pathways along which it travels and is continually transformed are themselves provided with energy. The pathways are ready to be triggered. We may even say that the question is already implicit in them."* [3]. This nevertheless clearly is a description of information limited to human communication and neuronal language processing. The formulation "elementary unit of information" already suggests a broader applicability of the idea, though. It is claimed here that if the term information is being limited to the equations of the theory of communication or –a bit further but still strongly constrained – to describe a transfer function in human communication, even if genetic information is accepted as first basis for information processing, the scientific use of the term does not fully serve the intuitive, broader understanding.

The coupling between motion inside a potential landscape or a field like the electromagnetic field on the one side and density as well as distribution of charges in material structure on the other side is a fascinating topic. It will be introduced here in which way this coupling can be understood as physical basis of information. First an example of a macroscopic, mechanical system which is influenced in its motion by the interaction of its structure and form with the surrounding environment is analysed, the returning boomerang. Then an example of a system which holds information for a pattern in intensity distribution microscopically in optical form will be discussed, the hologram as an interference recorded image.

1. The boomerang, an example for mechanical structural information affecting the airy medium

Boomerangs are manmade objects with flying properties that are astonishing, given the first visual impressions of the seemingly simple formed artifact, when it is at rest. The physical basis for realizing their highly improbable trajectory – given the right throwing technique as an important initial condition – is "encoded" in their material structure and "decoded" in motion. Normally when throwing a massive, rigid body, one expects a trajectory more or less in the form of a parabola. Boomerangs are designed to largely deviate from this standard. The most well known type of boomerang trajectory is the one associated with a so called returning boomerang. For a right handed thrower, a returning boomerang fitting in handedness[8] in many cases will take a trajectory like the

[7] Although the results of genetic analyses for more than two decades increasingly show that genetic information processing cannot be easily equated to encoding as it is done in human languages [5].

[8] A boomerang at least in the classic asymmetric design is designed for only one direction of rotation. "By carefully shaping a boomerang to give it a symmetrical cross section it is possible to make it "double-handed" so that it will perform equally well either way [9].

following: After having left the right hand and having acquired forward- as well as rotational acceleration, the boomerang at first flies away slightly to the right, but soon its path will curve to the left, describe a wide, more or less circular loop, tending slightly upwards, to then come down hovering to somewhere near the thrower, i.e. it returns. Interestingly as fascinating and improbable as the returning trajectory for a thrown object might seem, it is the more probable trajectory of a “throwstick” or kylie, a boomerang-like object which is used for hunting. The typical trajectory of kylies in motion is a long-range hovering straight flight at ground level altitude for distances to at least 150 meters. Experienced kylie-hunters just have to aim the throwstick directly at the game (short or low-range) and it glides straight towards it. They transmit a strong impact force onto targets in 80m range (enough to break bones) but they do not return. Throwsticks as well as returning boomerangs owe their unusual flight behavior to their spinning motion (gyration). As long as they maintain sufficient speed and rotation, boomerangs can generate a restoring force to gravity´s pull. Since there exists more scientific literature on the aerodynamics of returning boomerangs than on that of kylies, the focus for the discussion of its physics will be put on the returning boomerang, its structure and the stages in its above described return trajectory. The structure of a returning boomerang is either that of two wings jointed at an angle between 80° and 120°(classic V-shape), or that of a symmetric distribution of more than two wings around a central rotational axis (symmetric boomerangs, cross boomerangs [10,11]). V-shaped boomerangs are a nice example for the fact that the centre of mass (COM) of an object can be located anywhere in space, not necessarily on the object itself. Having isosceles-triangle symmetry, the COM can be found slightly above the geometric centroid of its defining triangle. In rotation, one arm precedes the COM, whereas the other arm follows it. Interestingly although the V-shaped boomerang´s curve is said to prevent it from rolling, maximizes its speed of rotation and stabilizes its point of rotation [12], symmetric boomerangs return well and also a straight boomerang has proven to be usable for generating a returning trajectory [13]. Usually returning boomerangs are significantly less massive than throwsticks. A large surface area in relation to the boomerang's mass gives it a greater capacity to stay in the air and the surface shape of its arms [12] is essential. The unifying characteristic of shape in boomerangs is that its wings are effectively a pair of or three and more airfoils following each other in sequence during the rotation through the air.

Let us describe the most notable stages in the above trajectory of a returning V-shaped boomerang according to what models agree on [1,9,14–19]:

1) The nearly vertical throw

2) Centripetal aerodynamic lift

3) Precession into a circularly curved path

4) Lying down to hovering flight at the end of the trajectory

To 1): Different from a ballistically moved object, a boomerang generates lift from rotating air blades. Lift force is being generated by a rigid body turning a moving fluid. Based on Newton's Third Law, *Action is equal and opposite to reaction*, fluid flow is turned in one direction and lift force is generated in the opposite direction. In the case of a boomerang which is thrown almost completely vertically, lift is directed horizontally to the left (for a right handed boomerang, respectively to the right for a left-handed one). The angle of attack of an airfoil to the stream of air has to be positive to create lift; that is, the leading edge (front) of the airfoil has to be positioned slightly higher than its trailing edge (back). The shape of most boomerangs has positive camber (convexity of the outline curve) at its leading edges to enable lift at zero angle of attack and thus dynamic stability. Another possibility for reaching a positive angle of attack is arms with flat edges on both sides but twisted as to deflect the air. In any case, the boomerang should never be thrown horizontally (see 4) for more details) and the vertical axis of rotation should be adjusted by an initial inclination angle (5-15°) to the right (left in the mirrored case) to get ideal centripetal aerodynamic lift. A boomerang with only a rough airfoil structure might allow larger inclination angles up to 20° and more. In the vertical direction only a little lift is being generated, so this may not exactly balance the boomerang´s weight. To compensate for the imbalance between lift force and weight, the thrower needs to aim upward at five degrees. If the inclination angle (or the angle of attack) is too large at the start, increased air drag outweighs possible increases of lift. To impart maximum possible angular velocity (ω), it is important to raise the arm and throw quickly.

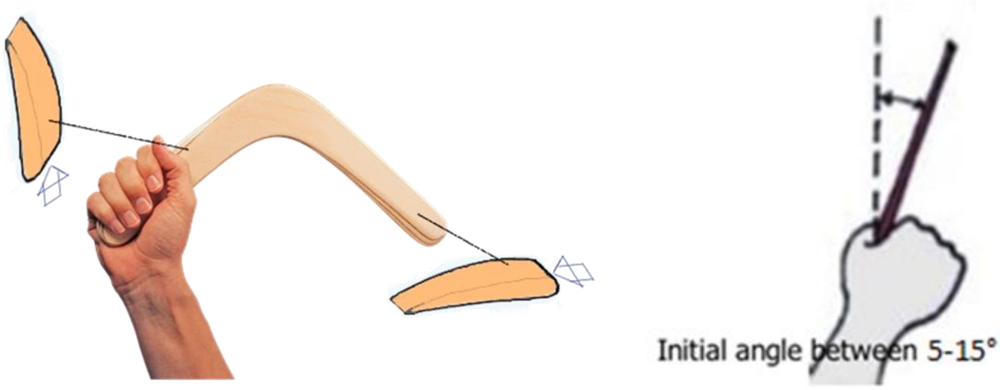

Figure A: Throw of a classically V-shaped returning boomerang with the right hand. The initial inclination angle for the throw should be between 5-15°. The shape of the boomerang on the left can be seen as consisting of two consecutively following airfoils, each with leading edge and trailing edge. Photograph of the throwing hand modified based on image by Alexander Lesnitsky [20]

To 2): The lift force of a spinning boomerang is directed mostly towards the centre of its circular flight path. Generation of aerodynamic lift is a complex process, the relationship between pressure and velocity being reciprocal and not observably ordered in time. In a steady flow, the medium air moves as a continuous material, deforming and changing its motion structure to flow around obstacles. Solid surfaces which might appear perfectly smooth are rough on the scale of air molecules. Apart from angle of attack and Newton´s Third Law, circulation and Bernoulli's principle are important to understand the generation of lift [21]. For more details, an excellent roundup written by Denker is quoted here amongst other references for further reading. *"The wing produces circulation in proportion to its angle of attack (and its airspeed). This circulation means the air above the wing is moving faster. This in turn produces low pressure in accordance with Bernoulli's principle. The low pressure pulls up on the wing and pulls down on the air in accordance with all of Newton's laws"* [21,22]. For the present study, it is more important to understand the medium character and the medium as an origin for a "pushback"- or restoring force against disturbances. As a parcel of air is accelerated by pressure difference, in accordance with Newton's second law, the parcel's neighbours exert a net force on the parcel. This means inertial forces due to viscosity effects provide a restoring capacity for pressure differences. Creating aerodynamic lift depends on converting viscosity properties into inertia effects by moving rigid bodies with certain form through air, affecting local density. This is why the property of having mass of air is important. As we will be discussing below, air is the necessary medium for a boomerang to achieve its flight pattern. A boomerang manages to fly a returning trajectory in a 0G environment like the International Space Station (ISS) in free fall[9], but it couldn´t do it in the vacuum of space.

[9] Watch [23] with Astronaut Takao Doi (accessed on 12 August 2021).

To 3): In its vertical rotation, the upper arm of the boomerang moves faster because its speed comprises translational forward motion plus the speed of rotation. The lower arm moves more slowly in relation, for it moves with the speed of forward motion less the speed of rotation. This difference in velocity becomes strongest each time when the upper arm reaches its most forward, almost horizontal position, i.e. it changes periodically. Lift force is proportional to the square of velocity. Thus the periodically recurring superposition of "forward (backward) directing" rotational movement vector and forward (forward) directing translational movement vector produces an imbalance of lift forces between the sides in the motion almost as a constructive (destructive) interference between amplitudes of an oscillation around a zero line. Alternatively put, differences in angular momentum (due to the differences in effective angular velocity), L, per time increment (dt) create torque. The centripetal lift force connects perpendicular to the plane of rotation and thus is a torque. The axis of rotation of the torque is again perpendicular to the spinning axis of the boomerang. It is perpendicular to the vector of the lift force that is the boomerang tilts around the x-axis due to force but due to its rotation does not tilt over and instead turns around the vertical axis (z-axis). This turning of a gyrating body is called precession. In Fig. 1 the vector for the angular velocity $\mathbf{\Omega}_1$ of this precession which rotates counterclockwise around the z-axis (resulting in the turning- left cyclic motion) can be seen in its location relative to the boomerang[10]. The rate with which the turning occurs is depending on both, the torque and the angular momentum (absolute mass, m, and mass distribution relative to the center of rotation[11] in motion). If it's too heavy for the achieved rotational speed, the torque will not be sufficient to make the boomerang turn into the circular returning path. The most important aspect for the present study is to be able to view complex motion structures like the one of a successfully returning boomerang as a superposition of rotational and translational modes of motion which need to be modulated in relation to each other, to form in their characteristic pattern. Forming on the other hand is supported by a rigid structure which by itself already has a certain surface roughness (scaling of regular and irregular bumps in relation to the size of elements of the interacting medium) and distribution of potentials (mass, charge,...) for the interaction with a medium and a sensible medium which is moving relative to the rigid structure. The rate of precession relative to the rate of progressing along the trajectory is of course defining for the form of the trajectory. As can be observed, successfully triggering a returning trajectory by creating initial conditions given a certain environmental context (weather conditions, especially wind,...) in a boomerang throw is dependent on many parameters, like inclination angle, aiming relative to the sky, or relations between translational and angular velocities [15]. Nevertheless once the trajectory is triggered, there are only few parameters of the throw which influence the form of the trajectory and which flight pattern will be generated is mostly inherent in structural properties of the rigid body; i.e. if one wishes e.g. to change the size of the circle, he/she must alter the moment of inertia of the boomerang (by adding weight, drilling holes) or use another boomerang. The behaviour discussed next is another important mode of the motion predisposed in the structure of a returning boomerang.

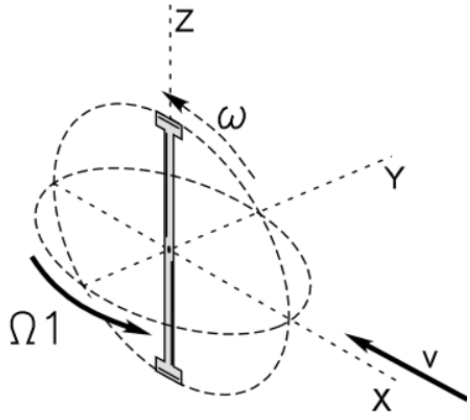

Figure 1 by Saulius Pakalnis [1]. Showing the angular velocity vector Ω_1 of the torque in relation to the other coordinates and ω. The vector of translation is **v**.

[10] Here it is modelled as a 180° connecting angle blade element with bolded leading edges and elaborated blades at the tips (more about the blades at the tips, the "arc blades" in the following). The boomerang is moving in the x-direction and tilts with an angle of rotation around x due to its net angular momentum, L.

[11] Inertial mass, $I = mr^2$ [kgm^2].

To 4): The horizontal hovering flight itself is not always observable at the end of a returning trajectory, nevertheless the tendency of returning boomerangs to “lie-down” their axis of rotation from almost vertical to near horizontal is evident [9,14,16]. There must be an additional tilting of the boomerang around the z-axis which – due to spinning - results in the precession of the rotating plane clockwise along the x axis. Hess described this behaviour somewhat tentatively compared to the detailed analyses of the rest of the aerodynamics of boomerangs in [9], not making the connection to another precession while in his later dissertation he completed his analysis . There he states that the lying down indicates that “(...) the axis of the torque T is not exactly horizontal (...) but tilted a bit upwards” [14] perpendicular to the vector of translation, **v**. At the end of the boomerang´s returning trajectory, its forward velocity reaches the local minimum and it becomes relatively easy to catch or lands on the ground softly. Due to the discontinuation of the translational motion and the loss of this dimension/those degrees of freedom of motion, the amount of motion-information is less compared to the begin of the trajectory and thus the superposition of different modes of motional information is reduced, too. One could construe that the resulting motion structure is consisting of fewer modes and in analogy to multiple resonances of wave-fields in complex, formed cavity structures that the externally excited modes approach the resonance frequency of lowest energy. Of course this rough analogy is only made to assist imagination in spotting the similarities between lowest energy mode of structurally disposed, externally excitable motion and easily excitable oscillatory frequency of a resonant cavity. Returning to the discussion about what is the possible structurally disposed reason for lying down in returning boomerangs in the first place. There needs to be a reason for a second torque with angular velocity Ω_2 which is rotating around the x-axis, clockwise. Hess explains this for a cross boomerang by “wake effects” respectively by drafting: The air is disturbed by the leading arm so that the respective trailing arm generates less lift than it could without disturbance. Air acquires an induced rightward velocity [14]. This torque type – which will be called “drafting-torque” in the following – is contributing to Ω_2 in boomerangs with axial as well as with eccentric COM. Another possible source for the torque would be the differences in location of the COM and the center of rotation in boomerang types with an eccentricity as described for the v-shaped type. As stated above: In rotation, one arm precedes the COM, whereas the other arm follows it. The centre of lift for the preceding arm would be away from the vertical axis (and the COM) as far in the forward direction as the centre of lift of the following arm the vertical axis (and the COM), compensating for differences in lift. But if in such a boomerang the dissimilarity in location of arms relative to the COM in rotation becomes enforced, e.g. by giving more or less lifting property to one of the arms, torque due to eccentricity would result, “eccentricity torque” [16]. The latter type of torque and the effect of inducing (enhancing) dissimilarities between wings is exploited in tuning boomerangs adjusting the trajectory of return [24]. The drafting-torque is always generated, since in rotation the preceding blades generally induce vortices and disturb the medium for the following ones. As mentioned in footnote 4, the blades at the tips of the boomerang model, the arc blades, which drawn by Pakalnis in direction of the x-axis in the sketch shown in Fig. 2, certainly play an important role in producing this torque, too. Apparently prior to Pakalnis, the effect of arc blades in boomerangs was ignored, while the boomerang model on his homepage became a reference. The arc blades become most active parallel to the direction of flight, as sketched in the figure. The tips of a boomerang wing mostly are slightly bend up, that is they have positive dihedral at 10°-15° and positive angle of attack. If the dihedral is increased by bending the arms upwards, the trajectory gets higher, but shorter, since lying down then is happening earlier. On the

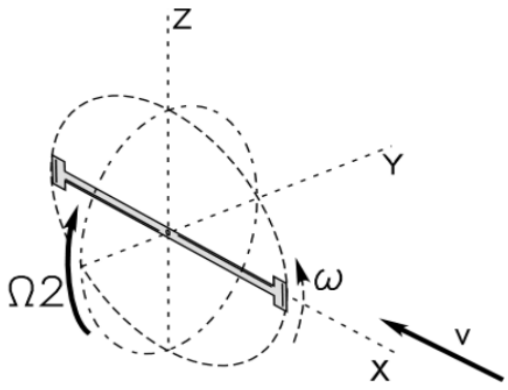

Figure 2: by Saulius Pakalnis (Pakalnis 2006). Showing the angular velocity vector Ω_2 of the torque in relation to the other coordinates and ω. The vector of translation is **v**.

contrary if the dihedral is decreased, the trajectory is relatively lower, but with more distance and lying down happening late in the flight. Thus the hovering phase will be reduced and instead a deviant, figure-eight formed trajectory is likely to occur; there the boomerang passes near the point of launching and then slowly flies a second small loop to the opposite side before finally landing near the launching position [1]. If the boomerang is thrown from a horizontal or almost horizontal position it rises very high, usually more than 10m and accelerates during its straight descend, hitting the ground (or accidently a person near the thrower) hard and possibly with enough power to break. This form of throw is forbidden because of danger of accidents.

What is most interesting regarding the boomerang behaviour when accelerated by a thrower against air medium, is that it can be confirmed in experiment as well as in calculations, that neither the rotational nor the translational velocity with which the boomerang is launched is contributing to the form of the trajectory. Moreover the structurally manifested properties of the boomerang, its COM and mass distribution, the angle between the airfoils (especially in the v-shaped type), its surface bumpiness and the form of the airfoils are decisive; together with other "structural" parameters like the angle of the launch and the height which the boomerang is given at the start, inertial and aerodynamic properties determine the characteristics of the trajectory.

The claim of this paper is that this is an example for the physical basis for information. This physical information (or if preferred: proto-type of information or latent information [7] from which later types of information like genetically coded information or symbolic language information descend can be found in two complementary types. The idea of two type physical information was first described by Stonier [25].

2. Parametric interaction between rigid structures and motion structures in lower dimensions

Any (complex) continuous, closed-on-itself trajectory can be modelled by coupled rotations with different frequencies and amplitude (radius). For example the continuous one dimensional outline of a Homer Simpson figure can be modelled as a complex time-domain representation of a continuous signal. As such it can be analyzed into a two dimensional superposition of a finite number of cycles with different frequencies and amplitudes in a certain phase relationship. To achieve this, the time-domain representation of the Homer-Simpson-outline-signal needs to be transformed into its frequency-domain representation using Fourier transformation (Used in [26] and published on YouTube as [27]; discussed by [28] and [29] and others).

When additional translations – straight paths with a beginning and an end some distance away as connections between the curved envelopes - are allowed, any complex trajectory of motion can be described by rotation and translation "elements". In an image or picture of a trajectory this is a well known fact used widely in theoretical and applied sciences. Parametric equations are describing surface curvature in one dimensional lines or in two dimensional areas. The geometrical point on a trajectory of a form which can be expressed by an epicyclic coupling between rotating circles of certain parameters (radius, rotational speed, phase relations), parameters which cannot independently be altered, can thus be given by a new parameter like time. In the example of the epicycle representation of the Homer Simpson envelope above, this means that e.g. the pupil of his right eyeball will be painted at 1 minute and 49 seconds (start at 1:06, end at 1:59), i.e. at the time when 43seconds of the 53 second period for the whole trajectory have passed. Given the frame rate of the images per second in the video is kept constant, not only people watching the same video, but also people reproducing the method of encoding by epicycles with the parameters used by [27] will be able finding the point in the picture by applying the parameter of time. If the frame rate is altered, the relative temporal position of the point will nevertheless stay the same, since the time of reaching the eyeball in relation to the time for one complete cycle will be conserved (43s of 53s, $43/53 \approx 0.8$ or at 80% of total duration). The important point for parameterization being possible is that all the other potentially varying quantities or rates are non moving (rigidly fixed) or ineffective (irrelevant) for the one quality (quantity, rate, complex property) which is adjusted by a known parameter or set of parameters which are mutually coupled to be adjustable as one cluster.

Very similarly, electromagnetic radiation scattering from any periodic structure which is suitably scaled in relation to the wavelengths of visible light, like a photonic crystal, a diffraction grating or a multilayer thin film in structural colouring, will produce the reciprocal lattice of the structure that is equivalent to its Fourier transform. The inverse Fourier transform of the reciprocal lattice will reconstruct the crystal lattice [30]. For example a lens structure in glass can create an image of a point light source (intensity patterned as an "Airy disc" central spot surrounded by annular bright and dark fringes) but also perform a Fourier transform of a largely more complex periodic intensity distribution pattern in real-time; this depends on coherence [31].

The returning boomerang is an extreme example of how much of a complex motion can actually be pre-disposed (for an experienced thrower even stored and retrieved from (!)) inside a rigid material structure. Material structures have the property of keeping potentially varying quantities like size of a cavity or distance between gridlines rigidly fixed. This is what forms rigid, invariant (to the motion induced by the field) surfaces from which images or patterned fields can be retrieved. In the example of the boomerang however, not the structuring of the reflected field is of primary importance[12]. The boomerang is dynamically affected by the forces which it by itself excites in the surrounding medium, while the holographic image is just selectively reflecting photons with no force transmission on itself which could overcome its inertia. The boomerang is a really fascinating example, for it shows how a structural disposition of the object as a whole can feed back in a rather simple way, needing agency only for the adjustment of initial conditions of the motion.

If structures are produced under processes consisting of potentially independently variable but coupled "elements" of motions, it becomes possible to parametrically adapt potentially effective and feedbacking features of structures by adjusting e.g. the scale of the producing complex motion. In the boomerang one would not regularly speak of parametric equations of motion, since the factors which become translated into the simpler parameters of its motions which basically define the returning trajectory – angular velocity vectors Ω_1 and Ω_2 of the torque – are quite complex in their relation to the structural parameters – COM and mass distribution, symmetry, joining angle of the airfoils, angle of attack of air foil edges (in radial and arc blades), initial height and aiming angle as well as inclination angle of the launch etc. The parametric relation between structural and kinetic parameters is often well hidden and demands for observation- (differentiating-) capacity and experience (repetition) to become binary or symbolic.

In evolutionary processes observation capacity becomes very important [33] and it is proposed that viewing rigid structure – motion structure interactions as physical information processing can contribute a lot to better understand evolutionary processes. Physical information processing can then be viewed as a processing where the connection between (observable) kinetic effect and (observable) disposition in a rigid structure is yet far from symbolic since the meaningfulness of parameters is only beginning to become observable.

As has been shown for boomerang aerodynamics above, in the coupling of non-linear processes to linear interference, an image of spatio- temporal distribution of energy per period on a stricken surface can be transmitted via fields respectively, media, by wave dynamics. Another example of how the structurally based guidance of motion inside a (largely) rigid material structure is informative is an image.

[12] Although in a kylie the surface structure is more important for efficient production of lift force than in a returning boomerang. The mechanism is possibly related to the effect of regular dimple-structuring of the surface of a golf ball; there the drag is reduced by reduction of main flow separation via local flow separations: a closed-loop streamline is produced, consisting of separation and reattachment ([32]).

3. The structurally stored image, an example for optical structural information affecting the electromagnetic vacuum as its medium

In an image, motions of millions and billions of separate oscillating things in (the electromagnetic vacuum-) medium can represent structural imprints of a patterned surface. An image with colour can consist of pigments. In this case the process is more complicated to relate to a material structure, since chemical molecules with pigment character need to be of a certain minimum size and mostly have a pi electron system with charges delocalized over several atoms. It is possible to picture molecules as rigid structures in the science of chemistry, but one has always to keep in mind that the cavities and angles of molecules are inherently dynamic structures (unless the temperature of the material medium would reach absolute zero, 0 Kelvin). Additionally considering structures at the molecular scale it becomes impossible to differentiate the electromagnetic vacuum and the effects of e.g. heat radiation on the dynamics of atoms and molecules in material media. An image with colour can also be of non-pigment, more rigid structural origin. Holographic images usually are less colourful [34], but the principle of interferential image intensity generation from monochromatic rigid media can in principle also be used for colour photography with the help of a special photographic medium [35] and the method of Lippmann [36,37]. Unfortunately the enormous difficulties to fulfil the requirement of fine grains with a photographic medium which is subjected to disturbing influences during the phases of making it, sensitizing it and developing it, made the method inefficient for photography as soon as three-colour methods had been established [38]. In case of the Lippmann medium interference- recording of an image (intensity pattern), no recording of relative phase between photons is involved. Instead in holography, the phase information is actually recorded in the image, encoded inside the interference pattern which is created between the light reflected from the object and a coherent reference beam [37]. In the Lippmann interferential colour photography the recorded interference structure is instead the result of a phase-locking by reflecting the light backscattered from the object from a back mirror at the end of the emulsion directly back into the emulsion. Basically the Lippmann colour recording is a volume recording of a standing wave and it has the property to reproduce the spectral composition of the recorded light. Standing waves are always defined in their fundamental frequency as well as the subsequent harmonics by the length and dimensions of the cavity in which they are formed. A Lippmann interferential colour photography or a holography of any depictured object can be viewed as a store both inside a rigid and inside a dynamic medium and motion is needed to transmit the image. Interestingly the term "image" is actually used for the structured "surface" on which the image can be seen as well as for the interference pattern in the electromagnetic radiation which is triggering recognition of the depictured object in an observer. The more rigid medium is the layer of pigments or the silver halides of the photographic medium (fixed on a carrier like cardboard) which an observer is holding in his/her hand. The dynamic medium is the ray of sunlight and/or light from an artificial light source, which is the electromagnetic vacuum excited to consist of a spectrum of electromagnetic radiation in the region called visible, i.e. wavelengths of 380-750 nm and which is reflected, transmitted and absorbed by the rigid medium in a pattern accessible to the eyes as sensory organs. An (optical) image can be construed as a store for motions of bosonic excitations of the electromagnetic ("light") field. There exist other types of images, like acoustic images and even acoustic holograms [39]. In the process of generation of a holographic image, quite some aspects of the coupling between light and the structural information inside the holographic medium are already well understood [40]. Images in general and holograms in special can exist (theoretically) in 2D as a single (infinitely thin) layer of silver halides. But most of the time even macroscopically "thin" images in form of photographic pictures or print outs contain several layers of medium particles and thus are in fact a 3D structure[13]. How is an image a store of motions of things? More precisely, an

[13] There exists a heuristic differentiation between thick and thin holograms. The criterion for discrimination is the thickness of the medium layer in relation to the wavelength of the recording light. In a thin or area- hologram, the

image is the structural information stored in one more rigid medium for organized motions, i.e. kinetic information inside another, more dynamic medium. In light, the above mentioned moving or "oscillating things" which are transmitting the motion pattern reflected from the fine diffraction grating structure are photonic excitations and in the air, they travel almost with the undisturbed speed of their genuine "medium" (speed of light in vacuum, c=299792458 m/s). In media where the disturbance of their mean free path is stronger, their progress is slowed down in relation to c in vacuum and this relative slow down has to be calculated considering the logic at the quantum scale as a statistical and complex measure, the refractive index RI.

Although the scale is a lot different from our boomerang example and although the microscopic nature of the relevant interactions necessitates consideration of quantum physics instead of classicality, image microstructure in a holographic medium and rotating airfoil- form or macrostructure in the boomerang have in common that information given by inhomogeneities in a rigid medium causes formation of a motion structure inside a dynamic medium the elements of which can expand into and "feel" the inhomogeneities as obstructions. As can be seen in a boomerang which is tested in a wind tunnel, reading out information from the rigid structure needs motion, but whether the rigid structure itself is moving through still air by a throw or the dynamic medium is being moved against the resting boomerang does not matter. In the boomerang, motion relative to the air results in a changing angle of attack and a changing lift force from air medium which gets disturbed in density distribution, reacting with equalizing flows and turbulences. As has been stated, the boomerang is dynamically affected by the forces it excites in the surrounding medium. An example more similar to the passive non-feedback situation between rigid structure and dynamic medium to an holographic image would have been a resonator and resonant cavity as they exist in most musical instruments, but their diverse agency-dependent mechanisms make most of them appear quite more complex than a wooden boomerang. This is an underestimation of complexity in the returning boomerang and an overestimation of complexity in many musical instruments which in fact consists of variations in mechanisms for controlling oscillation excitation, selective resonance and dampening. Processing of physical information in musical instruments is in fact a fascinating topic for a paper in itself which will follow later. Since the embedding context of the paper is evolution of information processing systems, the boomerang is a more striking example of how the structurally stored influence on a dynamic medium can actually feed back mechanically on its carrier, defining its trajectory.

4. Structural and kinetic information, the two-type concept of basic physical information

Information in its most basic form must be processed—in a basic way—in physical processes, i.e., processes under energy transformations and changes in position. Information is not matter and not energy [41]. Information is not energy, it acts on energy. In this sense it is proposed in reference to STONIER [25] and earlier work [33,42,43] to consider physical information in connection with energy transformation processes.

Kinetic energy (E_{kin}) and potential energy (E_{pot}) in classical physics[14], in macroscopic mechanical motion, are complementary and sufficient to describe the organization of elementary physical variables with the help of the laws of motion and the awareness that energy is conserved only if friction is included. Some elementary physical parameters of energy [kgm^2/s^2], of kinetic as well as of potential energy, are mass [kg], distance [m], area [m^2], volume [m^3], time [s], frequency [1/s], progression rate in time as velocity [m/s], acceleration [m/s^2], momentum [kgm/s], action [kgm^2/s] as well as some constants like e.g. the spring constant [kg/s^2]. While kinetic energy is describing motion in a moving body, potential energy describes the derivation of an accelerating force from a

reconstruction of the image can be approximated by diffraction at a 2D layer, while in a thick or volume- hologram it has to be described as diffraction in a 3D structure – in the easiest case, a crystal lattice.

[14] Conservation of energy assumed since friction and dissipation can be masked out in the considered frame of reference.

potential which is accelerating a mass along a certain distance. Temporary potentials are usually caused by anisotropic distributions of charges or stress [kg/s^{2}m] on masses due to local changes in density [kg/m^3] as in compressions and rarefactions. Kinetic energy is often calculated by mass times the square of velocity or in microscopic systems by quanta of action, h (with the same dimension as momentum times distance or energy times time) per period or equivalently times a frequency. It can be said that potential energy only potentially becomes kinetic energy, when the motion along a certain distance inside the potential field is possible. Likewise kinetic energy only potentially becomes potential energy, if the inertial force of mass in motion causes displacement of other mass inside a local potential field in a collision[15]. The view that potential energy is potentially motion, potentially kinetic energy and thus a store of energy seems intuitive, but the opposite (or complementary) view that directed motion E_{kin} can also be a store or potential, namely a store for tensioning a spring or elastic object which after collision is loaded with E_{pot} which it did not have before is rather unfamiliar. In the generation of pattern imprint from a captured image (optical intensity distribution field) on the silver-halide-crystal state and -distribution inside a photo medium it is important to keep this reciprocity in mind. Nevertheless which one is a store for its respective complementary is just a matter of convention and context.

From considerations of boomerang aerodynamics, the organization of energy parameters could be described as transformations between E_{kin} and E_{pot} – keeping in mind friction fairly precisely. The main problem is that already in classical mechanics it is a challenge to switch between force based descriptions (mainly Newton´s 2nd Law of motion) and energy based descriptions (like Hamilton´s principle (see below)).

A difference that physically makes a difference is primarily something that can accelerate masses or charges; however, this alone is not information but force.

Kinetic information (I_{kin}) is connected to information contained in kinetic energy; it is acting on kinetic energy. Kinetic energy, as described above, is energy in motion, i.e. in mass carriers that have been accelerated by a force respectively in mass-less bosonic excitations as quanta of action with a certain frequency. Information as a difference that physically makes a difference in motion, i.e. that introduces a structure into things that move with a mixture of translational, rotational and vibrational motion could be represented by a stable phase coupling between oscillators, so that their cycles add up to a complex 1D or 2D trajectory (like the Homer figure in our example) which then can parametrically be scaled or step-wise adapted to generate images of intensity distributions that have effect as kinetic energy[16]. Kinetic information could also describe the correlation in motion of particles which stream to abolish a potential; a potential that occurred due to local density differences as they have been created by an airfoil (like of a boomerang blade). Most probably it can also describe correlations between vortices with different senses of rotation. In quanta of the electromagnetic field I_{kin} describes the differential (pattern encoded) enhancement of coherence between mutually independent oscillatory motions in phase space, that is, waves in a relative phase in a wave forming a motion structure with a (communicable) spatio-temporal pattern of interference "coded" intensity related values (like in a holographic image emerging from patterned differences in the medium RI). In motion of a single object, speed and direction of propagation are also given by kinetic information. Additionally since sensors like heat sensors can also react to changes in the *average* of kinetic energy in ensembles of particles, it is most probable that I_{kin} not only describes stable patterns of correlated motion "elements" but also stable averages in intensity. Maybe the stability in averages has to be thought together with some structural information in the environment which enables this invariance

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[15] A collision with the effect that for example a field of tensions and compressions tends to reorganize masses into a more isotopic distribution, an equipartition; or that inside an electric- respectively magnetic field charges are displaced thus leading to the generation of forces.

[16] Later in the course of evolution, when symbolic ways of information processing developed and the energy transmission rather excites a signal than an inertial force the observable effect can be a more complex but less energy demanding process like recognition.

(think for example of border line structures as they occur already in very simple chemical systems and their capacity to generate stable averages and invariance in dynamically interacting but enclosed charges and masses). This means that stability in dynamic ensemble quantities and qualities (temperature, intensity, average colour of a spectral mixture, steady state chemical concentration ...) is information-generated like directed kinetics of a single moving object´s direction and speed of propagation. If E_{kin} instead occurs without I_{kin}, it is thermalized and chaotically fluctuating. Thereby kinetic information is related to its complementary in a way analogous to the relationship between kinetic and potential energy.

Structural information[17] (I_{struc}) is connected to information contained in potential energy; it is acting on potential energy. Potential energy, as described above, is derivation of an accelerating force from a potential which accelerates a mass along a certain distance. Long-term potentials are fields between and through opposite electric charges or fields between and through concentrations of (gravitational) mass of a huge scale (astronomical scale like planets or suns), like chemical or gravitational potentials. Temporary potentials are usually caused by anisotropic local distributions of charges or masses in stress. As Stonier already said, the occurrence of a potential amounts to a change in organization and demands a rearrangement motion restoring a force free organization some day. Information as a difference that physically makes a difference in rigid structures alters speed via (positive or negative) acceleration inside a potential. I_{struc} changes speed via constraining free motion inside a cavity or between borders, so that the amplitude or frequency has to adapt to the constraint. Relative position in relation to accelerating influences from potentials organizes correlated densities of mass and correlated densities of charge into spatial networks of distinct geometry creating configuration as 3D "pattern" on the molecular scale. Accelerating potentials inside special geometries can then force the motion of penetrating media to adapt to the special geometries´ form. Thresholds for the destruction of spatial constraints are defined by topologically influenced restoring forces and local potentials. Sub-threshold impacts of energy are reversible due to restoring forces. Mass distribution influences motions not only via local densities in ensembles of massive particles, it also for a single massive object (like the boomerang) creates a kind of virtual dynamical potential field which defines forces associated with changes in relative angles and speeds as well as motion relative to the COM for any possible trajectories. Thus phase space paths obeying Hamilton´s principle[18] are not only constrained by external potentials, but also by internal motions like dislocations of the COM. E_{pot} without I_{struc} is hardly possible. Even the densest packing of mass or charge defines a spatial structure and threshold energies. Collapse into a point is forbidden by the Pauli principle. Stonier´s intuition of even going as far as equating E_{pot} with structural information makes sense when viewed in this classical context. However due to uncertainty in quantum scale motion (Heisenberg uncertainty principle) E_{kin} and E_{pot} cannot be locally differentiated and the reciprocal action of information- and energy types cannot be tested there.

In works by Euler, Lagrange, Hamilton, Landau & Lifshitz, E. F. Taylor and others the laws of motion were formulated in an energy-based view. This proved to be very useful for prediction of probabilities when several possible paths for a motion trajectory are possible. The principle of stationary action (PSA) especially in engineering disciplines where friction is often being neglected and conservation of energy can be assumed, allowed expression of motions and changes in configuration with transformations between E_{kin} and E_{pot} along the time integral of the Lagrangian functional. For more details on the PSA see earlier work and references therein [44]. What could be the basis for this success of predicting with the PSA? Most probably the strong influence of parameters on complex transformation processes between kinetic information in media excited by

[17] The author keeps the term structural information as proposed by Stonier to honour his work and also because the term potential information is already in use with a different definition. Stonier in ([25]) proposed equating I_{struk} with E_{pot}, which is not adopted, since his argument of thermodynamic improbability does not hold for potentials and E_{pot} in general ([43]).

[18] Hamilton´s principle is Hamilton´s formulation of the PSA as time integral of the Lagrangian functional

parametrically adjustable structural information in rigid structures. Just think about what has been discussed here about so different fields of parameter-based logics like the boomerang and a holographic image in how they show interactions between I_{kin} and I_{struc}:

	I_{struc}	I_{kin}
Returning Boomerang	• mass distribution & COM • air foil structure & angle of attack • differences in airfoil structures causing torque • Surface structure ○ surface symmetries and asymmetries ○ scaling of cavities in relation to possible resonances and wave structures in the air medium	• centripetal motion due to lift forces • rotation & torque in rotation due to asymmetry in edge distribution • precession due to asymmetry in lift forces • hovering at the end of trajectory, the point when rotational energy does not suffice to introduce new action • laminar & turbulent streams in air medium, vortices
Image	• diffraction grating form & scale relative to λ • angles of reflection • frequency enhancements by cavity resonances • frequency reductions by dampening	• Intensity distribution pattern • Interference pattern depending on initial spatial and temporal coherence and diffraction

Table 1: I_{kin} and I_{struc} in the returning boomerang and in an interference recorded image

5. The evolutionary view and the boomerang

When thinking about the evolutionary view exclusively as the view on a system or thing as it evolves according to its phenotypically grown and genotypically encoded structural information in a biological ecosystem environment, it is a limited view. Even Darwin himself in 1882 in a letter to G. C. Wallich wrote that "*(...) the principle of continuity renders it probable that the principle of life will hereafter be shown to be a part, or consequence of some general law; but this is only conjecture and not science [45].*" In Darwin's times, this was a daring conjecture indeed. Given today's scientific experience and knowledge, evolution even in physics where it simply refers to changes over time can be said to usually be connected to some kind of invariance or stability in a set plus a selective influence on that set or system from the surroundings.

As was elaborated in [43], the large advantage of an evolutionary view is that reductionism is "only" needed for finding the possible base of a structural disposition in a potential landscape or motion structure. As biology learned by the theory of evolutionary development (EvoDevo), derived states or variants of products can often be traced back to (reversible) changes in state of the generating microenvironment. These transitions in state are triggered by altered influences from the surrounding environment. Both products from the microenvironment are its relational functions, but depending on its initial condition, the state, the so-called wild type or the variant, is produced, i.e., is a stable outcome of ontogeny. With an evolutionary perspective, one is looking at evolving units inside selective regimes whose criteria of selection may themselves be subject to evolution. Different selection regimes can be treated modularly and in nested, recursive form. The coupling between units and environment is important as is the creation of new selective criteria. Structurally disposed properties become functional or not; all functionality is based on the basic one, the maintenance inside the selective environment. Any evolution – guided by internal information processing capacities and selective inputs from the environment (i.e. the surrounding selective regime) – is starting from there. The evolutionary view used here can be defined as a systemic, recursion and observation based approach to analogies in selective events; selective events are differential perpetuations of stability or a role inside an environment. A role outside the interpretation of the term in human cultural environments can be seen as a function interpreted as norm for what something should and should not do to be appreciated[19] in that role.

Applied to the boomerang, we could for example discuss how the modern boomerang trajectory was possibly discovered by man when tying to increase the distance of a throwstick (kylie) which can be thrown in a straight non-ballistic trajectory. A well developed feeling for the predecessor form of the tool, curiosity and a need for a certain role of the throwstick in man´s life must somehow have led to the random and surprising discovery of the returning trajectory by one or several individuals of a tribe. Those individuals then individually or in cooperation decided to further explore the new structurally disposed function in adapting throwing technique and structure in small steps. Most certainly they used man´s great advantage in evolution, namely discussing individual experiences and observations with a common language. This way from a non-ballistic distance weapon – which could easily be replaced owing to the discovery and design of bow and arrow and other long distance ballistic "throwing" tools as it happened outside of Australia [46,47]– developed a toy for sport and dexterity exercises with a mystifying, mesmerizing disposed trajectory that can be decoded by the right throwing technique.

But we have other uses for the evolutionary view. Here we apply it to understand the boomerang and its properties as described in section 1 from a focus on the coupling between structure and "function" in the sense of relational function f(x)[33]. Which (not only mechanical) properties of the boomerang structure relate to characteristic reactions inside the common (not only air[20] medium-) environment?

Structural information	Neutral or maintaining structurally disposed properties due to structural information	Environment for input of I_{kin} and energy[21] to read out motion characteristics	Potentially destructive input of I_{kin} and energy
• mass distribution & COM • air foil structure & angle of attack • differences in airfoil structures causing torque • Surface structure ○ surface symmetries and asymmetries ○ scaling of cavities in relation to possible resonances and wave structures in the air medium • appearance to sensitive observers (aesthetics)	• rotation • torque in rotation due to asymmetry in edge distribution • lift due to airfoil structure of blades • precession due to asymmetry in lift forces over airfoils in motion • hovering at the end of trajectory, the point when rotational energy does not suffice to introduce new action • laminar & turbulent streams in air medium, vortices • Subjective impression	• human cultural environment, knowledge in creating initial conditions for returning trajectories • human individual with knowledge and interest	• Self-destruct by horizontal throw with sufficient acceleration (see 1.4)) • breaking • burning

19 Maintained

20 The medium in which its evolution or culturally assisted development took place is air. In the vacuum of space the boomerang would most probably follow a parabola as any ballistic rigid body with mass does when outside the gravitational potential of Earth. In free fall conditions on the ISS, the boomerang is able to perform its returning trajectory as has been proven by experiment (see footnote 3).

21 E_{kin} and E_{pot}

Table 2: I_{sruc} in boomerangs, predisposed properties and possible effects on maintenance of the structure inside the environment.

Discussion

The thoughts presented here are all based on educated guesses given the complexity of scientific descriptions and parameters made available in largely different disciplines with different histories and different jargons. Literature from theoretic scientific as well as from applied engineering sciences has been considered. Why is the differentiating principle between kinetic and potential energy and furthermore structures in materials or in motion called information here? Basically because there has to be a third quality of nature – already in existence in physical processes – which interacts with energy, respectively matter and which is the predecessor of what we know as language- or semiotic information. It is proposed here (referring to Wiener´s insight and Stonier´s basic idea) that this quality is not matter, not energy, but is acting on energy, respectively distributions of mass and charge of material structure. As has been stated here, physical information processing can be viewed as a processing where the connection between (observable) kinetic effect and (observable) disposition in a rigid structure is yet far from symbolic since the meaningfulness of parameters is only beginning to become observable.

In a returning boomerang it can be observed that if a human thrower – in correlation with whose species´ selective regime the artefact culturally evolved – is inexperienced, there is only a small probability that the structurally disposed characteristic returning trajectory will be observable on the first throw. Nevertheless the probability is not zero. The returning, almost closed trajectory is a property of this type of boomerang when thrown. Many combinations of external environmental parameters and internally disposed structural- as well as coupling intermediate parameters of how the throwing motion is conducted, are contributing. With the throwing motion, the system of the boomerang inside its environment of weather conditions can be adapted by a more experienced thrower to (nearly) certainly retrieve the returning trajectory. Resembling a living system, the physical object boomerang in the system with the thrower and its environment can adapt its initial conditions of the launch to dynamic initial conditions like those of the environmental wind speed and direction to read out its structurally disposed sequence of influences on the trajectory form so that the returning trajectory is realized. Inside the parameters of the returning trajectory paths, physics alone is then "doing the processing" between the structural information of the configuration and form and the kinetic information of its surrounding air medium.

During literature research it was obvious that especially in a strongly application based view, quite different descriptions and equation variables are common for acoustical, optical or mechanical imprints in media, so that analogies in influences on basic physical variables like energy, local intensity, frequency, amplitude, period, etc. become easily obscured. But in the global process of evolution of information processing systems, "mind-blowing" analogies and their recognition have enabled finding structures and behaviours to position the structures to generate images or feedbacking force effects. As a concluding remark, just think about an example where trajectory forming effects (discussed here in the boomerang example) and image-effects (discussed here in the interference recorded image example) occur combined on one rigid structure and bear in mind that structures like that are a product of biological evolution in the framework of Natural Selection. The scales on a wing of a butterfly: Microscopic regular air cavities within the body of the scales ([30] and references therein) by the mechanism of coherent scattering generate beautiful structural colours by interference in the electromagnetic field of visible light on the one hand; on the other hand structuring on a larger scale, of the wing surface [48] due to the same scales, affects flight efficiency ([49] and references therein) due to effects on aerodynamics in the air. Thus structures on the same wing influence aerodynamic flow and lift forces for the flight of the butterfly as well as optical effects at the same time. Both can be construed as physical energy transformations with underlying physical information processing, where kinetic information is introduced into motion structures of the surrounding medium fields by structural information; both are energy transformations but occurring on different scales (pun not intended) of size. The kinetic information is measured in flight capacity, mobility as well as in conspicuity of the motion to predators and reproductive success. The overall parameter evolvability is the standard for evolutionary success and it is measured in application of all forms of differentiability.

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Appendix

Just a thought: The author did some research whether the capacity of physical information processing between types of energy could possibly be explained by the Lagrangian formulation of the laws of motion and the principle of stationary action. It seems that the principle – which in applied physics is said to be only valid for non-dissipative systems – could have validity to explain an example of adaptation to changes in the action which was found during research for the paper above. In [49] the case of an obviously aerodynamically relevant change of structural information in an organ of motion in a living being is described. To analyze the function of scales for the flight of Monarch butterflies a lack-of-function type experiment was conducted. The flight behaviour of butterflies deprived of their scales was compared to flight behaviour of the same individuals when they still had their scales. The flight behaviour was documented within a space with high density of recording cameras. Therefore it was possible to characterize the two differing flight behaviours - with normally scaled and scaleless wings – by frequency and amplitude of wing flapping and to observe these two cyclic parameters on the course of a flight. The flights have been documented from start to finish each, where one segment of the flight course which is decisive and highly repetitive, namely the ascending flight at the start was focused on to do the comparison. It was found that 1) de-scaled butterflies showed lower ascending efficiency compared to their natural body state by a statistical factor of 32.2%. 2) The frequency of wing flapping was stable despite the change while the amplitude of the flapping-wing cycle (which was defined to reach from 0π – wings clapped below the body to 2π – wings clapped together above the body). The authors hypothesized that the butterflies have a favourite frequency of flapping and that to maintain this frequency under the severe structural alteration of having de-scaled wings with altered aerodynamics they adapt in the amplitude of flapping. This hypothesis is interesting, since due to the sound observability of parameters by the chosen method, the altered efficiency and amplitude could be concluded to possibly be the result of a change in the Lagrangian integral of action, $\int_{v=0}^{v_{\text{ascended}}}(E_{\text{kin}} - E_{\text{pot}})$ * $\text{time}_{\text{ascension}}$. $\int_{v=0}^{v_{\text{ascended}}}$ is the time integral from the point in time where the butterfly is at rest (v=0) to the point in time where the butterfly reached a certain speed in its ascension ($v=v_{\text{ascension}}$) and $\text{time}_{\text{ascension}}$ is the duration for reaching $v_{ascension}$. The change in action is two-fold. One is happening through a change in efficiency to gaining E_{pot} due to adverse flow property of the wing structure. The change demands for an adaptation of kinematics which most naturally would be a change in the motion cycle time, i.e. a change in frequency of flapping. Since the animal probably feels the increased effort for gaining height it adapts, but not the frequency, instead the amplitude of the wing motion cycle is reduced. The consummation of energy from biochemical potentials is thus reduced with the demand for speed in gain. Think about it, the clear expression of parameters as structurally generated change in aerodynamic efficiency and kinetically generated change in consummation of fuelling bodily potentials makes a connection to the PSA possible in principle. It would make sense to assume the action as being the quality for measuring change, the quality representative of changes in relations between E_{kin} and E_{pot} and its accompanying information. This information about change has to be "felt" so that abiotic systems' statistically-based and biotic systems´ sensory-intelligence-based capacity to adapt parameters of motion to palpable (sufficiently slow?) changes might find a natural explanation. To make the PSA applicable, a system and its transformation between E_{kin} and E_{pot} needs to be observable in motion (change of configuration) along a trajectory from a starting position to a finishing position. It appears that periodicity in the motion like it occurs in oscillation or in motion cycles like the flapping of wings (i.e. a trajectory from start to finish inside the larger trajectory from a position of start to a final position) supports the adaptability of the PSA. This is supported by the interesting fact that

- cycle- or periodic-wave based motions like in the wave function used in Feynman´s path integral formulation of QED,
- closed (non-cyclic) paths from start to finish in mechanical systems with energy conservation (respectively stable endpoint states q_1 and q_2 and times t_1 and t_2) in Hamilton´s principle

have in common that I_{kin} defining influences of local I_{struc} and -possibly non-local- environmental structural influences at the quantum scale (like what Bohm described by the quantum potential (?)) can be calculated by applying the PSA. Changes in action respectively changes in phase then physically decide trajectories of motion or probability amplitude.

The generalization of the periodic table: the “periodic table” of “dark matter”

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Key words: dark matter, dark energy, entanglement, Periodic table, separable complex Hilbert space

Abstract. *The thesis is: the “periodic table” of “dark matter” is equivalent to the standard Periodic table of the visible matter once being entangled. Thus, it is to consist of all possible entangled states of the atoms of chemical elements as quantum systems. In other words, an atom of any chemical element and as a quantum system, i.e. as a wave function, should be represented as a non-orthogonal in general (i.e. entangled) subspace of the separable complex Hilbert space relevant to the system to which the atom at issue is related as a true part of it. The paper follows previous publications of mine stating that “dark matter” and “dark energy” are projections of arbitrarily entangled states on the “cognitive screen” of Einstein’s “Mach’s principle” in general relativity postulating that gravitational fields can be generated* only *by mass or energy. The “cosmological constant” introduced by Einstein additionally in 1918 is generalized to a “cosmological function” depending on space-time coordinates, and then to a “cosmological function of entanglement” being a quantum field and decomposable to two entangled subfields, correspondingly depending on space-time coordinates and energy-momentum ones. Entanglement is an additional source of gravitation and can be represented by equivalent mass and energy observable as dark ones. In fact, it violates or complements “Mach’s principle”, but is forced to be mapped only as mass and energy in virtue of the principle, being furthermore available implicitly in the structure of the Einstein field equation of general relativity.*

One can use the metaphor of Plato’s “cave” about dark matter, dark energy or entanglement: the people are chained and thus can observe only the wall and shadows on it, but not what causes the shadows. So, the shadows can be described only in terms of the wall though those terms are irrelevant to the shadows by themselves: i.e. as dark matter and energy or entanglement. All possible experience of humankind is temporal: thus, the “screen of time” is what that metaphor means as depicted by the “wall of the cave”. On the contrary, what causes the shadows is not temporal, nonetheless being visible only as shadows of the temporal screen. So, the “shadows of dark matter” can be observed only on the “screen” of the usual Periodic table of visible matter.

Anyway, one can question what the dark “Periodic table” by itself is (i.e. not as a projection onto the visible Periodic table). What becomes visible on the “screen of time” (i.e. the non-Hermitian operators projected as Hermitian ones) can be likened as incomplete quantum calculations. The “complete calculations of the universe” as a quantum computer are all Hermitian operators and thus physical quantities, only to which the concept of the Periodic table makes sense; or in other words, the dark Periodic table by itself is relevant to non-Hermitian operators distinguishable into classes, each of which corresponds to a single subclass of Hermitian operator as any chemical element of the Periodic table can be represented.

I CONTEXT AND FRAMEWORK: SYNOPSIS

The paper follows a presentation in Torino (2019 July 15) also a paper (Penchev 2019). It discusses a thought experiment in Einstein's manner to suggest a possible generalization of the invariance of physical laws to arbitrarily accelerated reference frames in general relativity further: in astrochemistry.

The conclusion claims the indistinguishability of two kinds of spectral lines of the same chemical substance: (1) due to redshift and originating from an arbitrarily distant astronomical object (such as a star, a galaxy, etc.), anywhere in the universe; and (2), after entanglement in experiments conducted on our planet; furthermore (3), a bijection exists between all possible redshifts and the spectral shifts due to entanglement:

As accelerated motion and gravity are indistinguishable after Einstein's "*Gedankenexperiment"* about elevators (Einstein 1956), as any accelerated motion, gravity, *and entanglement* are suggested to be indistinguishable under the conditions of the thought experiment in the previous paper and presentation.

The conclusion relies on an eventual conservation of quantum information (considered as the Noether correlate of the physical quantity of action) generalizing energy and matter conservation in physics and chemistry. A generalized Periodic table of entangled chemical elements can be put forward as identical to standard one but dispersed in any possible motion anywhere in the universe and accessible by spectral observations on our planet.

The article accepts the existence of "dark matter" (Peebles[22] 1984; Trimble 1987; Sciama 1993; Sanders 2010; He & Wang 2011; Majumdar 2014; Gramling 2018) and "dark energy" (Riess[23] et al. 1998, Perlmutter[2] 2000; 2003; 2012; Schmidt[2] 2003) as very well established experimentally and will state that the Periodic table of entangled chemical elements can be interpreted as the "Periodic table" of "dark matter": dark matter is due to entanglement since the pair of dark matter and dark energy is equivalent to entanglement in virtue of quantum information conservation[24]. Dark matter is "visible" only as entangled states of the standard matter (meant e.g. by the Standard model or the Periodic table); entanglement propagating "instantly" by quantum correlations is what adds dark matter and dark energy to the visible ones just "visible" after propagating any electromagnetic radiation therefore limited of the constant of light speed in a vacuum. Mass and energy can be divided unambiguously into visible or dark by the velocity of interaction either subluminal or superluminal respectively. Dark matter and dark energy available in advance due to the "instantaneous" entanglement are to be added to the visible ones.

Entanglement in turn is to be identified with gravity just as gravity is identified with relative acceleration in virtue of general relativity. Quantum information conservation admits the violation of energy conservation since the latter should be restricted only to the subluminal area unlike quantum correlations. Then, quantum correlations meant by quantum information conservation are "depicted on the screen" of visible matter and energy (e.g. in virtue of Einstein's (1918) "Mach's

[22] The Nobel Prize in Physics 2019 was awarded "for contributions to our understanding of the evolution of the universe and Earth's place in the cosmos" with one half to James Peebles "for theoretical discoveries in physical cosmology" (including for his research of dark matter) https://www.nobelprize.org/prizes/physics/2019/summary/ .

[23] The Nobel Prize in Physics 2011 was divided, one half awarded to Saul Perlmutter, the other half jointly to Brian P. Schmidt and Adam G. Riess "for the discovery of the accelerating expansion of the Universe through observations of distant supernovae." https://www.nobelprize.org/prizes/physics/2011/summary/

[24] The generalizing law of quantum information conservation and its proof are published in: *Penchev 2020 August 17*; the link to dark matter and energy, in: *Penchev 2020 August 31*.

principle") as invisible, or they are "dark" as far as are out of that "screen" by themselves and only projected on it (metaphorically, "shadows on the wall" of Plato's "cave").

"Mach's principle" was introduced by Einstein to justify the "cosmological constant"[25] in the field equation. It states that only mass and energy (both visible on the temporal "screen") can be the source of gravity in the framework of general relativity. If any other source of gravity exists (as this follows from the option of energy non-conservation within quantum-information conservation), it would project as dark matter and dark energy. Dark matter and dark energy would be observable only after gravitational phenomena and described by general relativity. No experiment in the framework of the Standard model referring only to visible matter and energy can establish any effect of dark matter or dark energy.

The generalization of energy conservation (e.g. as quantum information conservation here) would be necessary. Anyway, dark matter and dark energy might be interpreted "conservatively", i.e. in the framework of energy conservation therefore excluding any violations of it. As *neutrino* was discovered initially theoretically in virtue of energy conservation, any observed violation would mean the existence of yet unknown entity, but visible and confirmable by relevant experiments: some researches grant that the ostensible "darkness" is not more than an unrevealed yet "visibility" obeying the absolutely universal energy conservation.

The dilemma is: a new law in cognition versus new entities in nature. The former seems to be more revolutionary implying the reformation of many scientific areas; e.g. chemistry (Penchev 2020 June 15): though equivalent as to spectral lines, a chemical substance on a distant star only observable terrestrially and the same substance in an entangled state equivalent as to spectral lines keep to be fundamentally different as to their empirical or experimental properties. The substance being on the distant star cannot behave as the substance which it only depicts on Earth by identical spectral lines.

The entangled substance should behave just as the corresponding substance: if any substance is entangled so that its spectral lines turn out to be those of gold, for example, it would be indistinguishable from gold by itself. Entanglement changes the substance itself; gravity, only the signal of it: the generalized "periodic table" of "dark matter" should be related to the former, but not to the latter.

II THE STATE OF ART AND RESULTS: ENTANGLEMENT ON THE SCREEN OF "MACH'S PRINCIPLE": DARK MATTER & DARK ENERGY

Einstein's "Gedankenexperiment" (Einstein 1956; Norton 1984) about an accelerating elevator demonstrates his generalized principle of relativity by the indistinguishability of experience after observations in: (1) an arbitrary accelerated elevator; (2) the same elevator situated in a gravitational field. Gravitational field is equivalent to *relations* of accelerated reference frames in the general principle of *relativity*.

The following two groups of experiments can be suggested analogically to be indistinguishable as to entanglement and gravitational field:

(1) The redshift of spectral lines of a certain chemical substance in any point of the universe and observed from Earth.

(2) The redshift of spectral lines of the same substance being on Earth, but entangled relevantly for the redshift at issue.

[25] Einstein's main consideration referred to the universe to be static, which is not valid as to the initial equation (Einstein 1916). However, Einstein observed in Hubble's observatory (Topper 2013) that the universe expands and declared the cosmological constant to be his "biggest blunt" (Gamow 1970: 44). Anyway, "Mach's principle" in Einstein's interpretation is consistent with the expanding universe (Ghosh 2018; Ne'eman 2006).

The wave function of that chemical substance observed on Earth is modified by: (1.1) the geodesic line from any point in the universe to Earth in pseudo-Riemannian space due to the gravitational field of the universe, in the former case, (1.2) a second wave function entangled with that of the substance, in the latter case.

Einstein's "*Gedankenexperiment*" demonstrates the experimental indistinguishability of gravitational and force field causing the same acceleration. The intended thought experiment is to show an analogical, but generalized experimental indistinguishability of gravitational field and entanglement causing the same observed redshift. One extends the general principle of relativity (GPR): gravitational field is representable by two equivalent ways: (1) as a relation of two arbitrarily accelerated reference frames; (2) as a relation of two arbitrarily entangled wave functions.

That generalization of GPR postulates the equivalence of GPR and the quantum phenomena of entanglement. This implies a theory of quantum gravity (though nonstandard due to the *complementarity of the quantization* of the gravitational field unlike that of each of the three interactions of the Standard model). General relativity understood as a nonstandard theory of quantum gravity would state that it is a complementary, smooth description of entanglement, but equivalent to it after a relevant transformation, for which a new concept: "discrete (or external, or quantum) reference frame" seems to be relevant and generalizing GPR from smoothly accelerated reference frames, to discrete ones (i.e. non-continuous and thus, non-smooth).

"*Discrete* reference frame" needs a generalization of time as well: from the irreversible (though arbitrarily "curved") time of general relativity to the reversible time of coherent quantum state. This implies further a generalization of energy and matter, which is a particular case of energy due to Einstein's "$E = mc^2$": "dark matter" & "dark energy" describable whether as "atemporal" or as relevant to the reversible time of coherent state.

If that generalization is linked to "dark matter" and "dark energy" directly and explicitly, they can be explained as a projection on the "cognitive screen" of general relativity after "Mach's principle".

Einstein introduced "Mach's principle" only in 1918 to infer from it for the universe to be static adding the "cosmological constant" to the initial equation(s) of general relativity. However, "Mach's principle" is much more general, stating that the "only source of gravitational field can be matter and energy". In fact, "Mach's principle" is implicit even in the initial "Einstein field equation" for its structure: a space-time tensor (Ricci tensor) corresponding to mass is to be equated to an energy-momentum tensor for energy: if anything else generates a gravitational field, it would imply relevant mass and energy corrections in the Einstein field equation.

Both dark matter and dark energy can be established only after astronomical observations therefore based only on general relativity and thus, "switching on the cognitive screen of Mach's principle". Dark matter is necessary for the Milky Way and many other galaxies to rotate too fast and should disintegrate and scatter due to centrifugal force since their visible mass and energy including the dark holes within them are extremely insufficient to balance it. Dark energy explains the observed acceleration of the expansion of the universe: the universe is a closed system, but obtains some energy permanently, namely "dark energy" which accelerates its expansion.

Though the dark matter & energy in total are about 20 times more than the visible ones, they can be considered mathematically as corresponding corrections in the Einstein field equation. Also, they can be contained implicitly in a modified "cosmological constant" generalized as a "cosmological *function*". Meaning some hypothetical source only projectable on "Mach's screen" as dark matter and dark energy, it is identifiable as entanglement for the "still more general principle of relativity" demonstrated by the thought experiment in the beginning.

Dark matter is to be a "correction" in the space-time tensor, and dark energy, in that of energy-momenta accordingly. Both corrections can be separated in a "cosmological function" so that its variables would be two entangled wave functions, corresponding to the effective gravitational field caused by dark mass or dark energy.

The usual Einstein field equation would be a particular case of the generalized one if (1) both "fields" are zero; or (2): they are orthogonal (or complimentary as in the "classical" quantum mechanics) to each other, and thus their entanglement is zero.

The Einstein field equation can be represented conceptually so:

$$\{R_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}\} + \{\frac{R}{2} g_{\mu\nu}\}$$

Here $R_{\mu\nu}$ is the Ricci curvature tensor; G is the gravitational constant; c is the constant of light speed in a vacuum; R is the scalar curvature; $g_{\mu\nu}$ is the metric tensor; and $T_{\mu\nu}$ is the energy – momentum tensor. The sense is:

{The gravitational field due to mass = that due to energy} + + {a function due to the metric of pseudo-Riemannian space}

The former brackets surround the "screen of Mach's principle", and the latter brackets, what is to be "projected" on that screen as both dark matter and dark energy.

Einstein introduced the "cosmological constant" in the equation in 1918:

$$\{R_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}\} + \{\left(\frac{R}{2} - \Lambda\right) g_{\mu\nu}\}$$

The sense of adding the **"cosmological constant"** Λ is: there exists some unknown influence on the relation of the gravitational field due to mass and the gravitational field due to energy. Furthermore, that (today, "dark") influence changes the metric of pseudo-Riemannian space.

One can generalize the cosmological constant to a "cosmological *function*" $\Lambda(x, y, z, t)$:

$$\{R_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}\} + \left\{\left(\frac{R}{2} - \Lambda(x, y, z, t)\right) g_{\mu\nu}\right\}$$

The sense of the generalization is: that "dark influence" is not homogeneous, constant, but different in any space-time point (in general): the transformation of pseudo-Riemannian space is accomplished by an arbitrary operator, the action of which is experimentally observable as the additional "dark matter" and "dark energy".

The cosmological function can be interpreted as two entangled quantum fields, i.e. as the "cosmological *function of entanglement*":

$$\{R_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}\} + \left\{\left(\frac{R}{2} - \Lambda[\Psi(x, y, z, t), \Theta(p_x, p_y, p_z, E)]\right) g_{\mu\nu}\right\} \text{ (\textit{Equation A})}$$

That is: $\Lambda[\Psi(x, y, z, t), \Theta(p_x, p_y, p_z, E)]$ is the "function of entanglement" of two quantum fields: $\Psi(x, y, z, t)$ and $\Theta(p_x, p_y, p_z, E)$: the observable dark influence is due to entanglement being the *macroscopic* total effect of the microscopic quantum entanglement. The "cosmological function of entanglement" is projected on the "screen of mass and energy":

The structure of the Einstein field equation is:

"{GF due to mass = GF due to energy} + "**dark** GF" implies:

↙ ↘

*{GF due to mass visible + **dark**= GF due to energy visible + **dark**}*

Dark gravitational field GF = that of dark matter (mass) + that of dark energy

The dark GF is due to entanglement or even, only to entanglement. Entanglement by itself is only information, therefore invisible or "dark": it seems as both dark matter & dark energy only on the "screen" of the Einstein field equation by Mach's principle.

After Einstein's "$E = mc^2$", energy & matter are the same, but what is "the same" at issue? It should be *temporality*; "Mach's principle" can be paraphrased as "any physical process is temporal".

This is not valid as to entanglement: it is a physical process, but not in time since its time to occur is zero definitively, being furthermore another source of GF: the "screen of Mach's principle" and the "screen of temporality" are the same after energy is the universal physical quantity and implies time according to the first Noether (1918) theorem.

All physical quantities in quantum mechanics are Hermitian operators, which is consistent to the unitarity of the separable complex Hilbert space and to their general commutativity with the Hamiltonian of the system as the operator of energy. If time is the only physical quantity which is not an operator[26], but the conjugate of energy, it is universal not less than energy and valid to any quantity, which is a Hermitian operator. However, entanglement is equivalent to non-Hermitian operators and out of the temporal screen.

Quantum information is measured in units of qubits (where "qubit" is an orthonormal superposition of any two orthogonal subspaces of the Hilbert space of quantum mechanics). Quantum information: (1) unifies and describes uniformly Hermitian operators (i.e. all temporal physical quantities) and non-Hermitian operators (i.e. entanglement); (2) acts physically and is equivalent to a certain quantity of action.

Since quantum information can be represented as equivalent to the information of infinite series or sets (Penchev 2020 July 10), a qubit is an infinite set of bits, and the physical action of any finite sets of classical bits is zero (as it is commonly accepted).

Entanglement being by itself quantum information equivalent to physical action is, nonetheless, out of time. That physical action is out of time and conditions 95-96% of the total mass and energy of the universe in units of mass or energy.

The conclusion is: our scientific worldview is extremely incomplete for ignoring all physical out of time. Two metaphors of the "temporal screen" are possible: (1) as the "wall of Plato's cave"; (2) as the "screen of the quantum computer of the universe".

III REFLECTIONS, SUGGESTIONS AND CONCLUSIONS: MATER AND DARK MATTER IN CHEMISTRY AND QUANTUM CHEMISTRY, THE PERIODIC TABLE

The proven existence of dark matter restricts all chemical knowledge only within the scope of visible matter. The advocated hypothesis considers dark matter by itself as the *substance of quantum information* due to entanglement. Visible matter refers only to the particular case of quantum information on the "screen of time", on which it is distinguishable from visible energy.

Can the existent chemistry of visible matter be generalized as to an eventual chemistry of quantum information?

Though visible, plasma does not possess chemical properties in the usual meaning: so, chemical properties are defined standardly as to the non-plasma, low-energetic states. They refer to the electron

[26] That idea was suggested by Wolfgang Pauli in his debate with Niels Bohr about the "conservation of energy conservation" in quantum mechanics: if time were an operator as all the rest physical quantities in quantum mechanics, this would imply its variability after measurement and thus, a different value of energy in any single measurement, i.e. the violation of energy conservation in the final analysis.

shell of the atom divided into discrete energy levels (or layers and sublayers) and especially, to the top energy level of valence electrons. All atoms can be separated in classes according to their chemical properties into about 118 chemical elements (discovered or synthesized until now). Their chemical properties are altered discretely and correspond to the number of electrons in the shell constituting periodic groups of similar chemical properties because all electron shells obey rigorous quantitative laws of quantum physics.

All chemical elements can be visualized by the periodic groups of their chemical properties in a compact two-dimensional ordering known as the "Periodic table". Meaning the advocated hypothesis of dark matter as entangled states, that Periodic table of dark matter is interpreted as the meaning or relation of the Periodic table to entangled states. Obstacles for this are:

The Periodic table of visible matter is discrete, but entanglement is not. All chemical properties are defined only on the "screen of time". Thus, the concept of chemical property suggests the distinction of matter and energy, but entanglement implies their indistinguishability.

After dark matter, the Periodic table can be understood as a two-dimensional series of atomic states whether stable or radioactive, but only on the "temporal screen" (or that of energy, resp. matter conservation). One can figure quantum information as a mathematical function definable as by the variable of time (the case of the "classical" quantum mechanics) as independently of it (studying the phenomena of entanglement). Then, the chemical elements as all visible matter would be the "roots ("zeros") of the equation of quantum information" to the variable of time (i.e. the points in which the "function graphic of quantum information crosses the axis of time", and time makes sense).

The Periodic table was invented by the Russian scientist Mendeleev by generalizing the empirical experience of chemistry, but without any reason why the Periodic law exists. Only quantum chemistry after the Bohr model of the atom managed to reduce the Periodic law to quantum properties of the corresponding electron shells, their discrete energy levels and their filling by electrons following the principle of Pauli.

The quantum foundation of chemistry prefers the language of particles rather than the equivalent language of waves, but the theory of quantum information and entanglement uses the "wave language". The appearing quantum-information chemistry of entangled chemical substances needs wave-particle duality to synthesize quantum chemistry with quantum information. For example, the electron shell of the atom of a certain chemical element is to be represented by a single wave function for investigating its entanglement with any other wave function. The reverse approach, the translation of entanglement into the language of particles, is not less admissible, but seems to be more difficult technically.

The few principles of the translation of "particle language" into "wave language" are based on "quantum number" granting it to any quantum physical quantity whether continuous or discrete. Any physical quantity is described by a relevant Hilbert subspace: finitely dimensional for discrete quantities, but infinitely dimensional for continuous ones. Any quantum entity is described by a finite set of quantities therefore by that separable complex Hilbert space consisting of the same set of subspaces though some of them being infinitely dimensional. The shell properties (quantum numbers) relevant to chemistry refer only to finite Hilbert subspaces.

The "conservation of energy conservation" in quantum mechanics (Penchev 2020 August 17) is a postulate imposed initially by Pauli debating against Bohr[27], and now, as commonly accepted as underlying the Standard model and the language of quantum particles. If the separable complex Hilbert space unifying Heisenberg's matrix mechanics and Schrödinger's wave ("ondulatory")

[27] The "BKS theory" (Bohr, Kramers, Slater 1924) is meant. Hendry (1984) elucidates the dialogue of Bohr and Pauli to energy conservation in quantum mechanics and the BKS theory.

mechanics is given, its property of unitarity implies energy conservation as a necessary physical interpretation. The justification is: if the wave function of an entity is the same to all possible apparatuses, and the dual Hilbert spaces are idempotent, the former can be interpreted equivalently: any possible wave function of the same entity is the same (e.g. to a certain apparatus).

Entanglement needs a relevant generalized conservation therefore violating energy conservation: "quantum information conservation" meaning that the set of quantum numbers is predetermined and unchangeable and only namesake quantum numbers of two or more wave functions can be entangled. The violation of energy conservation consists in the direct transformation of quantum information into energy, but only under the condition of quantum information conservation.

Though energy and matter are equivalent after "$E = mc^2$", matter in chemistry is meant *only as "matter at rest" (having mass at rest) and being non-plasma (for electron shells to exist)*. One needs the *Ricci tensor* of the Einstein field equation and relevant to the *gravitational field of matter at rest* to be represented by the entanglement of two (or more) wave functions. This is very complicated technically, but not conceptually:

The Ricci tensor at issue is the Ricci tensor of the one of the two entangled quantum fields; namely: $\Psi(x, y, z, t)$ in relation to $\Lambda[\Psi(x, y, z, t), \Theta(p_x, p_y, p_z, E)]$. This means:

$$R_{\mu\nu} = \{R(\Psi(x, y, z, t), \Lambda[\Psi(x, y, z, t), \Theta(p_x, p_y, p_z, E)])g_{\mu\nu}\}$$

The result is inferred from *Equation A* above and where $R_{\mu\nu}$ is the Ricci tensor of $\Lambda[\Psi(x, y, z, t)$ to $\Lambda[\Psi(x, y, z, t), \Theta(p_x, p_y, p_z, E)]$.

Quantum information chemistry is to be defined as that quantum chemistry studying the influence of entanglement. As chemical properties are determined by electron shells, quantum information chemistry investigates entangled electron shells (since only namesake quantum numbers can be entangled according to quantum information conservation). Entanglement adds "dark matter" to the visible matter of chemical substances obeying the Periodic law and would modify the Periodic table of visible matter.

The Periodic law follows the successive filling of the admissible discrete energy levels of electron shells one by one in accordance with the serial numbers of the chemical elements. The second dimension of the Periodic table corresponds to the number of filled energy layers (or sublayers) of the electron shell.

Chemical elements in entangled states can remain the same, but energetically excited therefore radiating photons after decoherence. Furthermore, the entangled chemical element may be changed into another substance (not necessary element) due to the chemical properties of the entangled system. A few questions follow:

Can the Pauling (1960) chemical bond be interpreted as an entangled state of electrons belonging to different atoms?

Can "chemical compound" be generalized as to the entanglement (chemical bond) of non-valence electrons of the shell?

Can entanglement generate new chemical compounds, which cannot be a result of any classical chemical reaction?

Can entanglement explain the phenomena of *catalysis*?

One can generalize entangled electron shells by adding the entanglement of the corresponding nuclei. This means to investigate the influence of entanglement of the corresponding discrete quantum numbers of atomic nuclei. Analogically, the entangled atomic nucleus can remain the same, but energetically excited, or can change in another isotope or chemical element. Is nuclear fusion needing additional energy can be explained or generalized by entanglement?

Can any radioactive isotope be interpreted as an entangled state of the products of its decay? If yes, which is the reason for the process of decoherence after many radioactive isotopes to be so slow? That reason would be a key to creating huge, super-powerful and mass-available quantum computers. Can one influence the speed of radioactive decay by entanglement? For example, can the chemical element "118", Oganesson with the semi-decay of 700 microseconds for the isotope ^{294}Og to be stabilized by entanglement?

The only quantity which can be assigned to dark matter (as well as to dark energy) directly is quantum information, furthermore shared with visible matter and energy. All other quantities are the influence and change of the namesake quantities (quantum numbers) of visible matter and energy. One can speak of dark matter and dark energy only continuing the list of dark quantities as corresponding counterparts of the visible ones.

If one accepts the Periodic table only as a list of quantum numbers relevant to the electron shell, it will be valid to matter as visible as dark.

The influence of quantum information can be visualized by decomposing the relevant non-Hermitian operators into pairs of Hermitian one changing a certain quantum quantity and Hamiltonian changing energy accordingly. Entanglement can be interpreted also as an omnipresent physical interaction implying for any physical system not to be closed. Thus, entanglement is able to change the value of any quantum number (including those relevant to the Periodic table), but not to create new quantum numbers (forbidden by quantum information conservation).

Any scientific hypothesis is to offer new predictions.

The advocated one implies:

Energy can be transformed directly into quantum numbers relevant to a certain chemical substance by entanglement with another substance sharing the same quantum numbers as those undergone to change.

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What is consciousness?

Artificial intelligence, real intelligence, quantum mind, and qualia

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Abstract

We approach the question, "What is Consciousness?" in a new way, not as Descartes' "systematic doubt", but as how organisms find their way in their world. Finding one's way involves finding possible uses of features of the world that might be beneficial or avoiding those that might be harmful. "Possible uses of X to accomplish Y" are "Affordances". The number of uses of X is indefinite and the different uses are unordered and are not deducible from one another. All biological adaptations are either affordances seized by heritable variation and selection or, far faster, by the organism acting in its world finding uses of X to accomplish Y. Based on this, we reach rather astonishing conclusions: 1) Strong AI is not possible. Universal Turing Machines cannot "find" novel affordances. 2) Brain-mind is not purely classical physics for no classical physics system can be an analogue computer whose dynamical behavior can be isomorphic to "possible uses". 3) Brain mind must be partly quantum – supported by increasing evidence at 5.2 sigma to 7.3 Sigma. 4) Based on Heisenberg's interpretation of the quantum state as "Potentia" converted to "Actuals" by Measurement, a natural hypothesis is that mind actualizes potentia. Then Mind's actualization of entangled brain-mind-world states are experienced as qualia and allow "seeing" or perceiving" of uses of X to accomplish Y. We can and do jury-rig. Computers cannot.

I. Introducion: the issues

This short paper makes four major claims: 1) Strong AI is not possible 2) Brain-mind is not purely classical. 3) Brain-Mind Must be Partly Quantum. 4) Qualia are experienced and arise with our collapse of the wave function.

These are quite astonishing claims. Even the first claim is major. Artificial Intelligence has been with us since Turing invented his Universal Turing Machine that refigures the globe. We await replacement by Siri and Borgs.

We hope to show this first claim is wrong for wonderful and fundamental reasons. The becoming of any world with an evolving biosphere of philosophic zombies, let alone conscious free will agents, is, remarkably, beyond any mathematics we know.

The pathway to this insight depends upon a prior distinction between the degrees of freedom in physics and in an evolving biosphere. In physics, the degrees of freedom include position and momentum, energy and time, the U(3)U(2)U(1) group structure of particle physics, the Schrodinger equation, General Relativity and Dreams of a Final Theory.

Oddly, in the evolving biosphere, "affordances" are the degrees of freedom. An "Affordance" is "The possible use of X to accomplish Y." Gibson, (1), points out that a horizontal surface affords a place to sit. In evolution, an existing protein in a cell used to conduct electrons also affords a structure that can be used as a strut in the cytoskeleton or bind a ligand. Evolution proceeds by organisms "stumbling upon ever new affordances and 'seizing' them by heritable variation and natural selection". "Evolution tinkers together adaptive contraptions", as F. Jacob said, (2).

We humans do the same thing when we tinker and jury-rig. Given a leak in the ceiling, we cobble together a cork wrapped in a wax-soaked rag stuffed into the hole in the ceiling and held in place with duct tape, (3).

Jury-rigging uses subsets of the causal features of each object that articulate together to solve the problem at hand. Any physical object has alternative uses of diverse causal features.

An engine block can be used to drill holes to create cylinders and craft an engine, can be used as a chassis for a tractor, can be used as a paper weight, or its corners can be used to crack open coconuts, (4).

It is essential that there is *no deductive relation* between these uses. And there is, therefore, *no deductive theory of jury-rigging.(ibid).*

How many uses of a screwdriver alone or with other things exist? Is the number exactly 16? No. Is the number infinite? How would we know? How define? No, the number of uses of a screwdriver alone or with other things is *indefinite* (3,4).

Consider some uses of a screwdriver alone or with other things. Screw in a screw. Open a can of paint. Scratch your back. Wedge a door closed. Scrape putty off the window. Tie to a stick and spear a fish. Rent the spear and take 5% of the catch….

What is the relation between these different uses? There are four mathematical scales, nominal, partial order, interval, ratio. The different uses of a screwdriver are merely a *nominal* scale. There is *no ordering relation* between the different uses of a screwdriver (3,4).

II. We cannot use mathematical set theory **with respect to affordances:**

The Axiom of Extensionality: "Two sets are identical if and only if they have the same members." But we cannot prove that the indefinite uses of a screwdriver are identical to the indefinite uses of an engine block. No Axiom of Extensionality.

We cannot get numbers. One definition of the number "0" is "The set of all sets that have no element." This would be the set of all objects that have exactly 0 uses. Well, No. We cannot get the integers this way. We cannot get the number 1, or the number 17.

The alternative definition of numbers is via the *Peano axioms. Define a null set, and a successor relation, N and N+1.* But we cannot have a null set. And the uses of objects are *unordered*. There is *no successor relation*. We cannot get numbers from Peano. No integers, no rational numbers, no equations 2 + 3 = 5. No equations with variables 3 + x = 5. No irrational numbers. No real line. No equations at all. No imaginary numbers and no complex plane. No manifolds. No differential equations. No topology. No combinatorics and no first order predicate logic. No Quaternions, no Octonions. No "Well Ordering" so no "Axiom of Choice" so no taking limits, (4).

The implication is that *no Universal Turing Machine operating algorithmically,* hence *deductively* on 1 and 0, can find new affordances not already in its ontology of a finite set of objects and for each a fixed set of properties. The central reason is that there is *no deductive relation* between the indefinite uses of an engine block as a paperweight and to crack open coconuts.

If by Strong AI we mean the capacity of a universal Turing Machine to invent that which is not deductively derivable from its current ontology of objects and for each a fixed finite set of properties, Strong AI is ruled out.

Computers cannot jury-rig in novel ways. The evolving biosphere can and does jury rig in ever-creative ways by jury-rigged Darwinian Pre-adaptations such as the evolution of the swim bladder from the lungs of lungfish (3). Cells do thermodynamic work to *construct themselves*, (5). *The evolution of the biosphere is a progressive jury-rigged construction not an entailed deduction.(3, 4)* The evolution of hominid technology for the past 2.6 million years is also one of unending non-deductive jury rigging, ten stones 2.6 million years ago exploding to billions of goods including the space station today, (5).

Life and mind are not algorithms. Siri and cyborgs will not replace us.

We can *just see or perceive* affordances. We can see and laugh about using an engine block as a paper weight and also to crack open coconuts. *Thus, we are not merely disembodied Universal Turing Machines.*

Again, Strong AI, or General AI, is ruled out.

But we do perceive affordances? How can we possibly perceive or "see" Affordance?

III. **Perhaps we are classical analogue computers**?

These classical analogue computers can be embodied as robots. Analog computers compute by being isomorphic to that that which is modeled. But we cannot be classical analog computers. The reason is unexpected: Affordances are "possible uses of X to do Y". But these *Possibles are ontologically real.* Before the evolution of the swim bladder from the lungs of lungfish was it *possible* that such a preadaptation would occur? Of course, the swim bladder really did come to exist. But what is the ontological status of this *Possible*? *The possibility is ontologically real***,** *as demonstrated by the subsequent fact that the swim bladder did come to exist, but it might not have come to exist. To "exist or not exist" is surely ontological***!** C. S Pierce pointed out that *Actuals obey Aristotle's law of the Excluded Middle.* "X is simultaneously true and not true", is a contradiction. All of classical physics obeys the law of the excluded middle. *Possibles do not obey the law of the excluded middle*. "X is simultaneously possibly true and possibly false" is not a contradiction (3).

In evolution, affordances are about *ontologically real "possible uses of X to do Y*". This is also true in our seeing affordances in our immediate world. It is really true that it is possible to use the corners of an engine block to crack open coconuts. In technological evolution it is really true 5000 years ago that the cross bow might or might not come to exist.

Astonishingly, this implies that no classical system can be an analogue computer for affordances. Affordances do not obey the law of the excluded middle, but all classical systems do obey that law. Thus, *no classical system can be isomorphic to, hence model, affordances.*

The claim that no classical system can be an analogue model isomorphic to affordances seems to be new and must survive severe critique.

IV. Brain-Mind is Quantum

This hypothesis is widely discussed (6). We wish to pursue a different set of data. There are, at present, two lines of evidence that brain-mind is partly quantum.

First, there is growing and powerful evidence gathered independently over decades that *mind is quantum* seen in aberrant behavior of quantum random number generators, telepathy, and precognition. The publicly available data are confirmed at 7.3 sigma for quantum random number generators and above 6 sigma for telepathy and precognition (7). Are these physically possible? Yes, if mind is quantum, spatial nonlocality allows telepathy and psychokinesis. Temporal nonlocality, less well established, allows precognition (ibid).

Second, a particular interpretation of quantum mechanics was offered by Heisenberg, 1958. The quantum states are *potentia*, hovering ghost like between an idea and a reality. I here adopt Heisenberg's view (8). *Reality consists in ontologically real Possibles, Res potentia, and ontologically real Actuals Res extensa, linked by measurement.* This interpretation explains at least 5 mysteries of quantum mechanics, including nonlocality, which way information, and null measurement, (9) so may rightly be considered seriously. *This is not a substance dualism so does not inherit the mind body problem arising due to an7 substance dualism, (10). Thus, the hypothesis that brain mind is partly quantum makes a new prediction: It suggests a natural role for mind: Mind actualizes quantum potentia. (*4) Mind collapses the wave function, as von Neumann, Wigner and Shimony hoped (11,12,13).

Remarkably, this testable hypothesis stands quite well confirmed. Radin and others have shown at 5.2 sigma across 28 experiments that a human can *try* to alter the outcome of the two slit experiment and succeed. 5.2 sigma is one in 50,000,000, substantially strong but not yet strong enough. If very strongly confirmed, *responsible free will is not ruled out* (7). *This result, if strongly confirmed, alters the foundations of quantum mechanics* (7,11,12,13).

V. **We try to and do collapse the wave function to a single state. We experience that state as a qualia.**

The evidence for quantum aspects of mind and our capacity to play a role in "collapsing" or actualizing the wave function, invites a new hypothesis for how we *see affordances* that we cannot see as classical systems including classical Universal Turing Machines. Our Brain-Mind entangles with the world in a vast superposition**.** We *try to and do collapse the wave function to a single state*. *We experience that state as a qualia*. Qualia! Why not?

At least three further lines of evidence support the hypothesis just above that qualia are associated with collapse of the wave function.

First**,** as D. Chalmers points out (14), qualia are never superpositions. Chalmers suggests from this that consciousness plays some role in the collapse of the wave function. We agree.

Second, *finding novel affordances is not deductive*. *Collapse of the wave function is also not deductive. Our experienced qualia are not deductions.* Neither need ideas that pop into mind when the Muse calls be deductions. Sudden insight gained upon grasping the point of a metaphor is also not a deduction. Insight in doing mathematics is not deductive (15). Creativity is not deductive, it is insight (16).

Third, our analysis of the incapacity of universal turning machines and any classical system to see affordances has a further implication. The evolution of the biosphere with *zombie organisms* can only find new affordances by accidentally stumbling upon them and seizing them by heritable variation and natural selection. It works but *is slow.*

In stunning contrast, sentient organisms can literally perceive, "*search and see"* (1) affordances, are responsible and free-willed, and with preference and emotion choose to act to use them. Watch a cat and mouse near a low chest of drawers. The chest affords the mouse a hiding place. The chest threatens the cat with mouse escape. We do this all the time. So did *T. rex*.

The resulting selective advantage of mind rapidly seeing affordances via experienced qualia due to mind actualizing quantum potentia and free will choosing and acting is enormous. Mind evolved with diversifying life and played a large role the evolution of life that was far more rapid than were organisms philosophic zombies. Niche construction is at least one major area in evolutionary biology in which purposive behavior plays a major role (17,18).

Further issues: The classical brain is dynamically critical (edge of chaos (19). Genetic regulatory networks are critical. (20,21,22) Criticality is magical classically with small stable attractors, maximum entropy transfer, monotonic increase in basin entropy with the number of variables, N and graceful evolution under change of connections and logic (23,24,25). Life is co-evolving self-constructing Kantian Wholes dynamically on the Edge of Chaos (26,27). Co-evolving organisms may co-evolve to mutual criticality to maximize diversity of coordinated activities (28).

VI. **Relation to Established Neurodynamics.**

Years of superb work in neuroscience models an astonishing diversity of brain dynamics – perceptual behaviors with a variety of non-linear mathematical models (29). These models are entirely classical physics. If the claim that no classical system can constitute an analog model for novel affordances is correct, as we claim, then a new pathway to investigate is the possibility of extending classical dynamical models to Hilbert space and seek homologous quantum behaviors.

Such homologous behavior may be possible: For example: can Brain mind be partly quantum and dynamically critical? Maybe with more specific hypotheses: *Quantum scars* (30): The wave function remains in the vicinity of the classical attractor. Does the wave function of a quantum/classical critical brain remain in the vicinity of classical critical attractors that are usually taken to store alternative content addressable "memories"? In this quantum case, repeated actualizations could create highly similar qualia. In short, can such quantum systems inherit the magic of classical critical systems? Perhaps. More generally, can we seek a mapping from well-studied classical neuro-dynamics to quantum models with homologous behaviors? Perhaps.

VII. **Possible Soft Matter Systems to Examine**

At present enormous effort is focused on quantum computers that must maintain quantum coherence until decoherence or measurement achieves a solution, often the minimum of a complex classical potential, representing the solution, then computation stops. (31). Cells do not stop. There is abundant evidence for quantum biology (32,32,34). Work in the past half decade has explored a Poised Realm hovering reversibly between quantum and classical behavior (35). Small molecules, peptides and proteins at room temperature can be quantum ordered, critical or chaotic. Quantum criticality lies at the metal insulator transition. Such systems have delocalized wave functions, conduct electrons very well, and have power law slow decoherence that may underlie quantum effects in biology (36). The Schrodinger equation does not propagate unitarily in the presence of decoherence (35).

Intracellular and intercellular protein - protein complexes may constitute such a new class of soft matter and can be studied with molecular dynamics and Boltzmann Lattice methods for quantum and classical behaviors (37). More such soft matter systems might constitute Trans-Turing-Systems" with their own new internal dynamical behaviors and receiving and outputting quantum, classical and poised realm variables (35). Living cells may be Trans-Turing- Systems (ibid).

VIII. **Conclusion**

The hypothesis that qualia are the experience of the actualized wave function, even if sensible, raises major issues: Are all actualizations of quantum superpositions associated with qualia in some form of panpsychism? Does the Strong Free Will Theorem bear on this issue? (37). When a human is in a coma or dreamless sleep, are there qualia? What is unconscious mind from whence the muse? How could we possibly test the hypothesis?

Moral: Artificial Intelligence is wonderful, but algorithmic. We are not algorithmic. Mind is almost certainly quantum, and it is a plausible hypothesis that we collapse the wave function, and thereby perceive affordances as qualia and seize them by preferring, choosing and acting to do so. We, with our minds, play an active role in evolution. The complexity of mind can have evolved with and furthered the complexity of life. At last, since Descartes' lost his Res Cogitans, Mind can act in the world.
Free at last.

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Diamonds and Condensed Types:

The New Mathematics of Pro-Emergence and Temporal Nonlocality

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Keywords: diamonds, emergent time, temporal nonlocality, condensed sets, grand unified theory

Abstract

Our reflection to S&T Foresight Workshop is two-fold and takes the form of proposing both a new mathematics and a new theory of emergent time, pro-emergence, and temporal nonlocality addressing the questions of set theory and affordance, and upgrading time as either a wave function or an imaginary number. Specifically, we introduce condensed types and v-stack time, through the language of diamonds, perfectoid spaces, and the condensed category of diamonds $Cond(D^{\{diamond\}})$. Our model is a double emergence, but profinitely many copies of emergence. We frame the inquiry *from information to action* as new mathematical interfaces relating relations and rejecting any modeling of time as a total order with a connexity property, in favor of modeling time using infinity-categories, descent conditions, and infinity-stackification, where descent conditions are gluing and reconstruction conditions and stacks take values in categories and not sets. There is much power in using the geometric language of sheaves to account for the nonlinearity of time, modeling time with singular support, and any temporal entanglement. We have used the language of diamonds to propose a new diamond holographic principle in terms of a Grothendieck six operations formalism and the profinite condition of diamonds. We question why every temporal object be deemed comparable and invoke a new mathematics to support singular notions of time. The structure of sheaves over a point, which take the form of condensed sets, is a possible contender. Secondly, topological localization is a way of sending morphisms to equivalences by passing to the reflective subcategory, where objects are paired with their reflections. Together, condensed sets and topological localization can provide enough structure to consider emergent time and entanglement in time, rather than entanglement in space. Continuing further, condensed types offer new ways of equating objects using condensed-like weak equivalences of homotopy types and therein represent a new way of understanding how multiple interfaces between information and action agree on object persistence. Perfectoid spaces are a specific type of adic space which live in the nonarchimedean realm and are a perfect contender for a new theory of time. If quantum mechanics works spatially nonarchimedean, we question why it does not also work temporally nonarchimedean. Instead of thinking of time using operator language, we propose to reframe it as a nonarchimedean structure, specifically a stack in the v-topology, where a stack is a 2-sheaf taking values in categories rather than sets and the v-topology is a topology finer than the pro-‘etale topology. Thus, we build emergence as a structure and not a property, mathematically upgraded to allow the phenomenology and possible ontology of temporal simultaneity and nonlocality through pro-emergence and temporal multiplicity. With this, the movement *from information to action* is infinity-categorical and diamond-geometrical through diamond-descent.

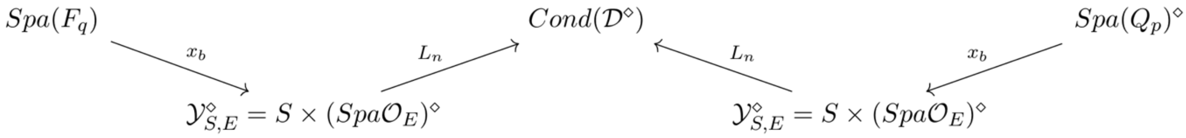

Figure 1. V-Stack Time $Cond(D^{\{diamond\}})$ [Dob21]

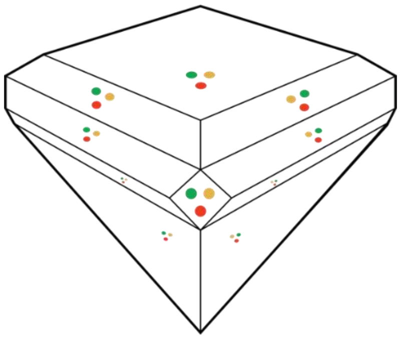

Figure 2. Diamond $Spd(Q_p)$ [Dob21]

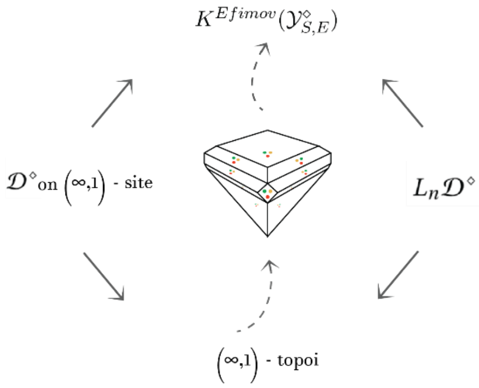

Figure 3. Efimov K-theory of Diamonds [Dob21]

Framework

Our reflection to S&T Foresight Workshop is two-fold and takes the form of proposing both a new mathematics and a new theory of emergent time and temporal entanglement addressing the questions of set theory and affordance, and upgrading time as neither a wave function nor an imaginary number, but as emergent as a diamond object in the category of condensed sets. Commensurate with a new model of emergent time, we propose that the formalism of information to action is a descent condition on $(D^{\{diamond\}})$. What is immediate is the question of what would be a mathematics of temporal simultaneity? That is, what could be a new mathematics that allows for the physics of temporal simultaneity? We claim that the mathematics of infinity categories, diamonds (pro-'etale sheaves on the category of perfectoid spaces) [Sch17], condensed sets (sheaves over a point) [CS20], and condensed diamonds [Dob21] allow a structure supportive of temporal emergence and simultaneity. We introduce our new model of emergent time, v-stack time, descent on $Cond\left(D^{\{diamond\}}\right)$, and a concomitant theory of condensed types, which are, proposedly, immediate from our recently introduced diamond holographic principle [Dob21].

A series of glowing interrogatories leads our present discussion: Even when we adamantly claim that there are no ontic boundaries, the question that is immediate is *ontic boundaries of what?* How do we parse affordance with a boundary that is profinite? If affordance works topologically, how do we put a topology on an infinity-category? Why is time modeled as continuous from information to action? Why is time assumed a total order with a connexity property? When we say two events take place at the same time, what time is that specifically? What would entail a discretization of time and what if time were singular or nonmeasurable? Why can we not simultaneously sustain two different temporal experiences? How can we measure time without therefore constructing it and making our measurement, therein, antiphrastical? How can we measure emergence without constructing it? How can we describe object persistence over a discretized time? How can we use infinity categories to provide an nth-order temporal logic? How does object persistence work in anterograde amnesia? We attempt to at least hold onto these questions by providing a new mathematics of diamonds and condensed sets, that can structure their claims, towards a new reciprocity law between mathematics and physics, and towards reframing emergence as a structure and not a property.

We recently conjectured the idea of being able to experience simultaneous experiences, to the effect of existing in the present while also being fully elsewhere as a Cambridge Apostle, for instance [DP21], [DP20]. What would it require to partition experience so that we could indeed have simultaneous experiences and what ontically, epistemically, and neurologically, prevents our accomplishing this feat? We proposed the mathematics of infinity categories and diamonds as providing the structural support to at least give apt visualization to these questions. We propose the new mathematics of diamonds and condensed sets as the mathematics of simultaneity; that is, as the mathematics capable of providing the structural support to work with simultaneity. Diamonds use the pro-‘etale topology for a local multiplicity, while the ‘etale cohomology of diamonds works in v-stacks with the v-topology. Both are Grothendieck topologies [Sch17].

Emergent Time

We recently conjectured a new theory of pro-emergence, which is a theory of emergent time which features a double emergence immediate from our diamond holographic principle, where ADS/CFT is modified by our proposed six operations/diamonds pro-duality. Local time emerges from the six operations which are translated into a condensed setting. Time is singular here given it is a condensed set, which is a sheaf of sets over the pro-‘etale site of a point [CS20]. Global time is in the diamonds, where the profinite condition is translated into a form of nonlocality in the many incarnations of possible quasi-pro-‘etale covers per each geometric point/mathematical impurity. There are implications for coupling in the following form: strong coupling refers to many incarnations of $(C) \rightarrow D\ in\ the\ nonlocality\ of\ time$; weak coupling refers to condensed and singular perfectoid time.

Incarnation of global time emerges from diamond nonlocality. Local time emerges from condensed sets. A 2-infomorphism, consisting of two pairs of adjoint functor’s from Scholze’s ‘etale cohomology of diamonds, connects local to global time to get temporal simultaneity and temporal nonlocality. In this construction, we are asking what is the difference between simultaneity and temporal nonlocality? That is, what are the preconditions to have either simultaneity as nonlocality or a difference between simultaneity and temporal nonlocality.

We conjectured the following dictionary:

<u>Dictionary</u>

Collapse/decoherence	Pro-‘etale Site/Localization
Coupling Perturbation	Tilting + p-divisible formal group laws; kernels are p^n-torsions; torsion in Langlands
Strong Coupling: v-stack emergent/ profinite emergence	Many incarnations of $Spa(C) \rightarrow D; nonlocality\ of\ time;$ irreversibility/reconstructability
Weak Coupling	Condensed and singular perfectoid time;
ADS Bulk	Six operations; Cond(D)
CFT	diamonds
Nonlocality	Diamond profiniteness
Unitarity	Diamond Descent; Diamond Localization

To complete the dictionary, we need to construct the six operations in condensed setting, and link diamond profiniteness with nonlocality, diamond descent, and diamond localization.

V-Stack Time

We introduce our new model of emergent time, v-stack-time, and a concomitant theory of condensed types, which are, proposedly, immediate from our recently introduced diamond holographic principle. Connecting geometrized local Langlands-stacks with emergent time is a new incarnation of a new reciprocity law.

Our model is a double emergence, but profinitely many copies of emergence, making it a pro-emergence. Our model gives levels of nonlocality as a stackification. The movement from local to global localization is by our conjectured diamond descent and diamond localization. We recall that localization in the reflective subcategory is a descent condition. The question is how to construct diamond nonlocality for temporal multiplicity? The hope is by diamond descent satisfied by v-stacks along all covers [Sch17]. If the mathematical essence of strong coupling is an intrinsic irreversibility, we show, forthcoming that a diamond D is reconstructable up to irreversibility by diamond descent, where coupling is in the levels of profinite nonlocality.

Displayed in Figure 1 is our conjecture of v-stack time, our major goal towards a new reciprocity law between mathematics and physics, linking diamonds, condensed sets, and emergent time [Dob21]. We let C be the category of diamonds. Let Cond(C) be the category of condensed objects in C; objects are condensed diamonds. Let R be the reflective full subcategory of Cond(C); objects in R are reflections. We let $D^{\{diamond\}}$ be the infinity-category of diamonds and extend to $(D^{\{diamond\}})$. We follow precedent and claim that the fiber product of this diagram is a moduli space and a diamond. Overall, the diagram is linking the diamond and adic spectra of the p-adics with the category of condensed diamonds in hopes of a new Grand Unified Theory between mathematics and physics.

We exemplify the simplest case. An event (a topological localization of any particular reference frame) is considered a point in a diamond topological space T. On that point is the pro-‘etale site *pro-‘et, the category of profinite sets S. Singular (local) time emerges as the set of continuous maps from all profinite sets S to T. So, singular (local) time is constructed as a sheaf of sets on *pro-‘et; that is, as a condensed set. Global time emerges in passing to the larger category of sheaves to consider a condensed version of our K-theory above. So, there is a double emergence, which, via descent explained below, becomes a single emergence linked by a 2-morphism [Dob21].

Diamonds

We provide a rapid review of diamonds and condensed sets [Dob21]. A diamond, in the sense of Scholze [Sch17], is a pro-‘etale sheaf on the category of perfectoid spaces of characteristic p. Specifically, we say a "pro-‘etale sheaf X is a diamond if X can be written as the quotient of a perfectoid space by a pro-‘etale equivalence relation." The etymology is due to the resemblance of these objects to mineralogical diamonds. There are geometric points in the diamonds resembling mineralogical impurities, rendering the points mathematical impurities, in the sense that we can never see the impurity, only its many reflections on the sides of the diamonds. Geometric points, which are morphisms of schemes, obey this same property: invisible they are made 'visible' upon pulling back by a quasi-pro-‘etale cover, resulting in profinitely many copies of the point [Sch17]. Recall, a profinite set is a totally disconnect compact topological space. So, to have visibility via profinitely many copies of what will always remain invisible, is to have visibility as some sort of representational cantor-set like cluster. See Figure 2 which shows the diamond spectrum of the field of p-adics [Dob21].

We propose that the mathematics which can truly capture *information to actio*n takes the form of a pro-object, a pro-emergence, which is a double emergence, and a profinite condition of diamonds and object persistence via infinity categories. What is hoped immediate is a new theory of time discretized without the connexity property to allow for local pockets of partial emergence of action in lieu of any notion of continuity [Dob21].

We also work with v-stacks, which are stacks in the v-topology, where a stack is a 2-sheaf that takes values in categories rather than sets. The v-topology is a Grothendieck topology where a cover takes the form of any maps such that for any quasicompact open subset U, there are finitely many quasicompact open subsets that jointly cover U [Sch17].

Condensed Sets

A condensed set, in the sense of Clausen and Scholze [CS20], captures the notion of a sheaf over a point.

Definition [(Dob21)7.2.1.2, (CS) 1.2]: The pro-‘etale site *pro'et of a point is the category of profinite sets S, with finite jointly surjective families of maps as covers. A condensed set is a sheaf of sets on *pro-‘et. Similarly, a condensed ring/group…is a sheaf of rings/groups… on *pro'et.

Example [(Dob21) 7.2.1.3 (CS 1.5)]: Let T be any topological space. We associate to T a condensed set $\underline{T}$, by sending any profinite set S to the set of continuous maps from S to T.

Condensed Types

Condensed types are objects weakly equivalent under condensed-equivalence.

Information to Action as Descent

As stated above, the localization condition is already a descent condition. Therefore, our conjecture is that the event of *information to action* is built into the very structure of our v-stack pro-emergence and is immediate from the diamond equivalence relation; diamond descent takes place in the multiple incarnations of the covers of the geometric points and allows the double reconstruction of *information to action* and of *action to information* from the higher coherence datum.

Diamond Holographic Principle

We use the structure of a specific Grothendieck six operations formalism, a way of reinterpreting Poincare' duality as Verdier duality, from which to build a new holographic principle, the diamond holographic principle, from which our theory of emergent time, v-stack time, is conjecturally immediate. We use Scholze's six functor formalism in the 'etale cohomology of diamonds [Sch17].

Specifically, we conjecture a diamond holographic principle that replaces Anti de Sitter space and conformal field theory with Scholze's six operations in the 'etale cohomology of diamonds and diamonds, respectively. Formally, we consider the site of all perfectoid spaces over X with the v-topology, where X is a small v-stack. The six operations are a six-functor formalism consisting of two adjoint pairs $(f^* and\ Rf_*; and\ Rf_! and\ Rf^!)$ an internal tensor product, and an internal Hom functor [Dob21].

The idea is to construct a 2-infomorphism using the two pairs of adjoint functors. To get the duality, we will reformat the separability condition as a combination of the qcqs condition of the v-sheaf and the non uniqueness of the generic point as the failure of the sober property of the spectral space. Recalling, all diamonds are v-sheaves [Sch17], the conformal property is reformatted as the profinitely many copies of the geometric points of the diamond. We can continue to construct n-infomorphism using n-pairs of adjoint functors in our infinity category of diamonds and thus extend the six operations to infinity-derived categories [Dob21].

The six operations formalism is apropos to the holographic principal. Informally, the six operations formalism is, in a sense, a higher cohomological analogue of the ADS/CFT duality. Moreover, v-stacks are highly holographic in their encoding of profinitely many copies of data that is already multiple on two fronts: the pro-etale cover and the mathematical impurity of the diamond itself. If we extend our formalism to our proposed infinity-category of diamonds, we will decide which topology to put on the infinity-category and extend the functors to the infinity-setting [Dob21].

Our next framework is that of topological localizations, pictured in Figure 3. Localization is a formal way of adding inverses to objects and of adding more equivalences in categories. Topological localization adds equivalences by passing to a special full subcategory called the reflective subcategory, where objects in the subcategory are reflections of objects in the main category. This rich structure could support the phenomenology of object persistence [DF] in the guise of basic recall of a meta memory and extending to meta memories remembering themselves [Dob21].

Lastly, the language of K-theory allows us to compare objects using isomorphism classes of vector bundles on the objects. Pictured in Figure 3 is our conjecture of an Efimov K-theory of diamonds. Efimov K-theory is K-theory for large stable infinity-categories. Efimov's idea is to weaken to dualizable the compactly generated condition carefully ensuring K-theory remains well defined. Dualizability is a nice condition because C dualizable implies that C fits into a localization sequence $C \to S \to X$ with S and X compactly generated. Recall, a localization sequence is a cofiber sequence. We introduced the Efimov K-theory of diamonds in conjectured localization sequence:

$K(D^{\{diamond\}} \to K^{\{Efimov\}}(Y^{\{diamond\}}{}_{\{S,E\}}) \to K^{\{Efimov\}}(Y_{(R,R^+)}, E)$ where:

$D^{\{diamond\}}$ is a stable, dualizable presentable infinity-category;

$D_{\{diamond\}}$ is the complex of v-stacks of locally spatial diamonds;

$(Y_{(R,R^+)}, E)\ = Spa(R, R^+)\ x_{\{Spa\ F_q\}Spa}F_{q[[t]]}$ is the relative Fargues-Fontaine curve; and $Y_{S,E}^{\{diamond\}} = S\ x\ (SpaO_E)^{\{diamond\}}$. (cf. [Dob21]).

Temporal Simultaneity and N-time

We developed a notion of N-time particular to a level of awareness, given by fixing a Turing Degree and modeling 'interactions and experiences' as morphisms [DP20]. Continuing, we allowed for N-time to accompany N-awareness, through the play of n-morphisms, which are morphisms between morphisms. Structuring levels of time using infinity categories allows for the phenomenology of temporal simultaneity. For instance, a 2-awareness is modeled after a 2-category which contains objects, 1-morphisms between the objects, and 2-morphisms between the 1-morphisms. Consider the following: If I am a two-awareness, I can have a 1-morphism experience of reading a book on Friday May 1st at 8:00pm in 2021. I can have another 1-morphism experience such as playing with my kitty Artemis the same night at 9:30pm. A possible 2-morphism would be a morphism between these morphisms, thus allowing for the simultaneous experience of reading and petting Artemis, thus begetting temporal simultaneity. It is conjectured that the space of information to action is an n-stack space analogous to the above, allowing for temporal simultaneity, that is then localized down to 1-awareness and 1-morphisms.

Temporal Nonlocality

We must envision a two-point perspective of time commensurate with that of space, wherein an observer measures two 'distinct' times that, from the point of view of an entangled photon pair, are the 'same' time, assuming a entangled photon pair has a point of view and however that works. With the advent of temporal nonlocality comes the question if simultaneity is merely a localization of a broader nonlocality. With the imposition of reference frames, follows a question about ontic boundaries in a temporal nonlocality. Leaving aside our contention that there are no ontic boundaries, what is immediate is the question *ontic boundaries of what?* A question which fails identity. A question which fails affordance [Dob21].

Overall, working in categories and no longer sets, allows for a much richer development in subtleties, which are not allowed using sets alone. As a case in point, we consider the idempotent complete (infinity,1)-category. A category is idempotent complete if every idempotent morphism splits in way respecting the idempotent property of "squaring to itself." In an (infinity,1)-category, we extend the idempotent condition to that of having an equivalence s such that composing s with itself once again yields s, thus saying that equivalences are equivalent and continuing up to the infinity morphisms [NC]. Perhaps it is the idempotent property that is accountable for object persistence, framed with respect to object self-composition.

With a theory of emergent time supported by condensed sets and diamonds, we can more strongly claim that there is no synchronous reference from information to action, only topological localizations between sheaves on points.

Results

We have posited six conjectures [Dob21], the three most relevant to this discussion are the diamond holographic principle, the Efimov K-theory of Diamonds, and the diamond descent. See [Dob21] for technical details.

There are various experiments measuring emergent time from entangled photons and we wish to measure emergent time on the macro scale. Specifically, there is rich precedence in the field of biology and, in particular, in planarian regeneration of larger-than-photon macro entanglement. Levin/Fields have asked the following: "Is it energetically feasible that all biological information processing is classical." They then conjecture that "a model in which decoherence is localized to intercompartmental boundaries suggests a strong and potentially testable prediction: that internal, bulk states of daughter cells may remain entangled for macroscopic times following cell division." This conclusion is so incredibly inspiring and will help fortify our pro-emergence, 2-infomorphism formalism [FL].

Reflections

We repose the grand interrogatory underlying our mathematics: how can we measure emergent time without constructing it? When we assume time is emergent, is it necessary that we ask *from what is it emergent?* What does it mean to ask of the eschatology of time?

To assume time has an eschatology assumes it is debatable whether time will always exist, in whatever forms it does exist, with what properties and concomitant structure. In asking of the formalism from information to action, it is crucial to ask what is the shape and duration of time accompanying this formalism. We contend that the movement from information to action is singular and assumes continuity in the condensed setting, geometrically via sheaves over points and profinitely. We contend that the space of information is globally a v-stack which locally works categorically. Dually, we contend that time is a multiplicity in two ways: at the local level of singular information transfer and at the global level connecting the local levels. This double multiplicity beckons a double eschatology.

We revisit our opening interrogatories with a few conjectural answers from using our presented formalism.

Even when we adamantly claim that there are no ontic boundaries, the question that is immediate is ontic boundaries of what? If ontic boundaries are replaced by topological localizations of condensed diamonds, then the 'of what' would refer to the v-stack.

How do we parse affordance with a boundary that is profinite? To truly model affordance of totally disconnected boundary requires a new model of discretized time, which our formalism provides in the condensed setting. The formalism of information to action is a descent condition on Cond(C).

If affordance works topologically, how do we put a topology on an infinity-category? We are working on this currently for our proposed infinity-category of diamonds.

Why is time modeled as continuous from information to action? Why is time assumed a total order with a connexity property? Perhaps because a mathematics was used that did not account for simultaneity. In our formalism of sheaves over points and profinite conditions with descent, we do not impose any connexity on time.

When we say two events take place at the same time, what time is that specifically? In our formalism, we would say simultaneity is, at its most basic, a 2-morphism in an infinity-category. It is so very exciting to consider what then is simultaneous in a 3-morphism, and so on.

What would entail a discretization of time and what if time were singular or nonmeasurable? Using the mathematics of adic perfectoid spaces, we are indeed modeling time as singular and fractal-like. A discretization of time, more properly, a nonarchimedean time, should accompany, in quantum mechanics, the same treatment of nonarchimedean space.

Why can we not simultaneously sustain two different temporal experiences? In our formalism, we construct an n-awareness that can do so. We must fully understand the duration of time to understand the seemingly asymmetry of time, though we question how we can measure temporal asymmetry without constructing it. If it is our ontic boundaries contributing to the irreversibility of macro processes, we must fully explore the perfectoid quality of those boundaries and what that means phenomenologically.

How can we measure time without therefore constructing it and making our measurement, therein, antiphrastical? How can we measure emergence without constructing it? Our formalism cannot yet answer these question, but hopes to provide the mathematical models to do so.

How can we describe object persistence over a discretized time? See Figure 1.

How can we use infinity categories to provide an nth-order temporal logic? See Figure 3.

How does object persistence work in anterograde amnesia? This question has to do with the relation between thoughts and memory recollection. We are interested in the relation between the stop mechanism and the storage and recollection of profinitely many copies of information in the form of mathematical impure geometric points.

We have posited a model of the brain allowing various mathematical partitions in the form of the profinitely many copies of the diamond structure. If neurons are geometric points which are morphisms of schemes, anterograde amnesia would resemble a sustained truncation of morphisms.

Considering temporal nonlocality, if information to action in the form of 'thoughts', we can model thoughts as profinite reflections of pro-'etale topological covers oriented in nonlocality.

If the operator formalism of time is still preferred, we would like to see a suitable theory of object persistence, equal in sophistication, accompanying any time operator acting on an object. Our formalism at least allows for a temporal multiplicity in the profinite condition of the diamond and the language of, at least, idempotent infinity-categories to model object persistence. Let the new mathematics guide our intuition of pro-emergence and temporal simultaneity in *information to action*, and not fail affordance in all that is equally commensurate.

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A review of some ideas in Mathematical Biology

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Mathematical biology is an extremely large area in Mathematics. The covered topics range from molecules to cell behavior to physiology, global ecological systems and population dynamics. The methods come from many parts of mathematics: ordinary and partial differential equations, probability, numerical analysis, control theory, graph theory, combinatorics, geometry, computer science, and statistics.

In the past centuries mathematical developments were strictly connected with physics. The inventions of the calculus by Newton and Leibniz in the17th century were stimulated by physical problems such as planetary orbits, ballistics, and optical calculations.

But there are many deep differences between physics and life sciences. In classical physics we consider inanimate objects like a ball, a pendulum or a planet. We can rely on conservation principles (energy, momentum) and entropy. The complexity is moderated.

In life sciences the situation is completely different. The sheer complexity of living organisms cannot be reduced to simple physical laws and the description of biological phenomena can be made only by using very simplified models at different scales.

Quoting a celebrated paper by Joel E Cohen, for the mathematical community, biology is really the next physics, only better. For the biomedical community, mathematics is a sort of the next microscope, only better.

In this lecture I will sketch some mathematical ideas used to deal with two different topics.

1. Shapes of life. Starting from the seminal book “On growth and form” by D’Arcy Thompson, mathematicians have tried to understand the laws governing the organization of biological aggregates. From simple bacteria to our bodies, it is difficult to master all the phenomena underlying the formation of a full organism. The modern theories start with the thorough ideas proposed by Alan Turing in the Fifties, and nowadays we are trying to deal with more sophisticated models involving stem cells and the generation and regeneration of tissues.

2. Struggle for life. Another topic which seems promising is the dynamics of population both on the scale of the individuals and of the species. Charles Darwin wrote that people with an understanding “of the great leading principles of mathematics… seem to have an extra sense”. One hundred years ago, Vito Volterra described the cycles of life and death inside some groups of fishes in the Adriatic Sea. Few years later Ronald Fisher proposed a simple equation to describe the space diffusion of an advantageous gene. However, only in the Seventies, John Maynard Smith started to use John Nash’s Game Theory to understand the competition between the species, so starting the modern theory of the evolutionary dynamics.

The common ground for this two topics relies on the possibility of finding relatively simple mechanisms to generate a full world of complexity.

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The Music of matter

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'Allostery' has been termed as the second fundamental dogma of molecular biology. It is the process by which information is transmitted at a distance across biomacromolecules and their clusters. Typically the information concerns the '1-bit' status of binding, or non-binding, of a small molecule at a binding site, to switch on and off another, distant, binding event. Homodimers and quadramers may increase the information string to 2-bit or 4-bit. A set of canonical examples is provided by the transcription factor proteins involved in gene control.

A general challenge for the theory (and of course practice!) of allostery, is to transmit the information within a noisy, thermal environment. The binding event typically needs to record the attainment of a threshold in concentration of the small-molecule 'effector,' for example, yet fluctuations in locan concentration, as well as thermal fluctuations in binding, set limits on the fidelity of information transmission. This in turn sets constraints on the generalised distance between the two conformational states ('realaxed – R' and 'tense – T') implicated in the standard (Wyman, Monod, Changeux) model for allostry [1].

There is, however, a lesser-known mechanism for allostery which implies no mean conformational change (on binding) at all. Such 'allostery without conformational change' was first presented by Cooper and Dryden [2], but has been developed and applied widely since. The remarkable feature of this subtle, evolved, process of information transfer in molecular biology is that it 'recruits' thermal noise to act as a sort of 'carrier wave' for the information, rather than attempt to overcome it. Instead of registering the presence or absence of the effector molecule by a conformational change, the binding *modulates the amplitude* of the thermally excited normal modes of elastic strain *around* the mean conformational change. This process has many advantages over conformational change, including 'higher order' allosteric control of *third* sites where binding or mutatation can act as a modulator on the allostric connection between effector and allosteric sites (in much the same way that a base current into a transistor modulates the emitter-collector current).

We present a quantitative theory for how allostery can occur in this way. One important feature is the prominence of low frequency dynamical modes in communicating the allosteric signal. This is because the elastically inhomogeneous structure typical of proteins tends, through the phenomenon of Anderson localisation, to localise higher frequency modes spatially. Long-range allostery by this mechanism requires that the dynamical modes that support it span both sites (in detail they must both lie at antinodes of local strain, for such contributory modes).

The thermal dynamical mechanism of allostery in proteins motivates a set of wider questions about information-transfer in thermally-activated elastic matter, including as a function of the dimensionality of the material. One interesting result is that homogenous matter does *not* support 'fluctuation allostery' [4].

Remarkably, many globular proteins display just this class of elastic structure, in particular those that support allosteric binding of substrates (long-range co-operative effects between the binding sites of small molecules). One example is the CAP homodimer of *E.* coli. Through multi-scale modelling of global normal modes using an Elastic Network Model (ENM), negative co-operativity is demonstrated between its two cAMP ligands without change to the mean structure. Crucially, the value of the co-operativity is itself controlled by the interactions around a set of *third* allosteric 'control sites.' (see figure 1). The theory makes key experimental predictions, validated by analysis of variant proteins by a combination of structural biology and isothermal calorimetry. [5]

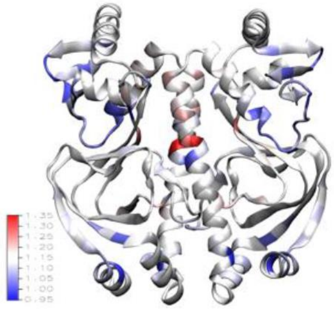

Figure 1 CAP protein featuring fluctuation-allosteric control sites calculated in an ENM formalism

A quantitative description of allostery as a free energy landscape reveals a protein 'design space' that identified the key inter- and intramolecular regulatory parameters that frame CRP/FNR family allostery. Furthermore, by analyzing naturally occurring CAP variants from diverse species, we demonstrate an evolutionary selection pressure to conserve residues crucial for allosteric control. The methodology establishes the means to engineer allosteric mechanisms that are driven by low frequency dynamics [6] and has applications to drug design related to the SARS-COV-2 virus [7].

Finally, I would like to reflect on this case study briefly, as an example of how metaphors and cross-fertilisation of ideas contributes to creativity in science. The narrative of order out of chaos, the musical metaphor of protein vibrations, and the electronic analogy of the transistor, all speak of the phenomenon of sub-conscious creativity that mathematicians (e.g. Poincaré), and scientists (e.g. Heisenberg,) have reflected on, and that I have found widespread in honest accounts of the scientific and artistic creative process [8].

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Energy, Information and Time Scales in Human Brain Dynamics:

Can there be quantum computation?

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In this paper we use simple reasoning based on time, length and energy scales to analyze the possible information processing rates of the human brain based on the energetic cost of encoding a bit of information. We use some well-known empirical information about the brain and its constituent neurons and sub-neuronal structures to arrive at characteristic information processing rates at all relevant scales. In order to maintain consistent metabolic rates and clocking frequencies for updating information content, we conclude that tubulin is not likely to operate at a quantum level if its functions include information storage and processing. On the other hand, ion channels, if synchronized may be able to operate in a quantum mechanical regime.

The human body requires approximately 100 W of metabolic power being consumed on average for its functional demands. This leads to the production of its weight in ATP every day in order to function, which translates into the synthesis of 1021 ATP molecules per second. Since there are on the order of 3.5 × 1013 cells in the human body and each cell has on the order of 103 mitochondria, so there are approximately 3.5 x10 16 mitochondria in the human body and approximately 3 × 104 ATP production events per mitochondrion per second. This involves a complex set of biochemical reactions called oxidative phosphorylation whose net effect is a conversion of 1 molecule of glucose into 38 molecules ATP. Since each mitochondrion produces 3 x10 4 ATP/s and each ATP synthase operates at a rate of 600 ATP molecules/s, we estimate that each mitochondrion has on average 50 ATP synthase enzymes. The brain is the organ with the highest rate of energy consumption, accounting for roughly 25% of the total energy demand, or 25 W. The vast majority of biochemical energy supply is provided by ATP molecules, each of which gives off on the order of 10 kT of free energy, or $4x10^{-20}$ J. Almost all individual processes such as motor protein motion, enzymatic catalysis, filament polymerization steps, etc., require one or more molecules of ATP per elementary step of each of these processes.

Undoubtedly, the main role of the human brain is to store and process information provided by sensory inputs. A vast percentage of the metabolic energy, including the human brain is used to maintain constant temperature, approximately 70-80%. Most of the remaining free energy is used in the protein synthesis machinery, i.e. by the ribosomes. It can be therefore safely assumed that less than 5% of the metabolic energy of the brain is utilized by information storage (memory) and processing (cognition) demands. As this paper is concerned with order of magnitude estimates, we will use a conservative estimate of 4 W being consumed for these purposes.
It is important to stress that any form of information, physical or biological, always comes at an energetic cost. Landauer first stated that the minimum energetic cost of one bit of information is
ε= kT ln (2) = 4x10-21 J, which basically comes from the thermodynamic formula that F=U-TS and the entropy S being equivalent to negative information, -I. Shannon's formula for information is I=-kT ln Ω where Ω is the number of equal probability states in the ensemble representing the choices available for information storage at a given step. The value ε is the minimum energetic cost of creating a bit of information. In the context of biological systems such as the brain's neurons, it is not expected that the minimum of energy cost is actually attained but, rather, the value for ATP (or GTP) which is an order of magnitude greater. In order to relate the metabolic energy expenditure to the information processing rate and estimate the maximum value of the latter, the time scale of the predominant "bit switching" processes, Δτ, must be estimated. Therefore,

$$\Delta I / \Delta\tau = P / \varepsilon \ 10\ 20 \text{ bits/s}$$

This the absolute upper limit estimate on the processing power of the brain. This can be very favorably compared to the processing rate of the most powerful modern day supercomputer clusters such as the BlueGene, for which the processing rate is on the order of 10^{16} bits/s but the corresponding power consumption is enormous, on the order of 10 MW.

Entropy is an additive physical quantity meaning that the entropy of a set of subsystems is equal to the sum of entropies of each constituent unit. Since information is negative entropy, the same can be said about information. Consequently, the total information stored in the brain is equal to the sum of information contribution stored in each of its constituents. As stated above, the characteristic time scale of information processing units in the brain are crucial in determining the maximum information processing rates given the power consumption of the brain. The seminal experiments conducted by Libet determined the pre-processing time of the human brain to be approximately 500 ms. Therefore, it can be inferred that for the whole brain, $\Delta\tau$ is on the order of 1s or less consistent with the frequency of brain waves, f, in the 10-100 Hz range. Once again, for the whole brain, it appears that the maximum value of the information processing rate is $\Delta I/ \Delta\tau = 10^{20}$ bits/s. Within the human brain, the next level of the structural and functional hierarchy involves neurons. There are approximately 10^{11} neurons in the brain, hence assuming all of them being equal, a neuron is expected to have an information processing rate on the order of $\Delta I/ \Delta\tau = 10^9$ bits/s. The time scale of these processes is largely determined by their firing rates, hence $\Delta\tau$ is on the order of 1 ms and the corresponding frequency, f, is expected to be in the 10 kHz range. Assuming for the sake of argument that the computational elements within neurons are microtubules (MTs), and estimating the number of MTs per neuron as 10^3, we find that the average processing rate per MT would be $\Delta I/ \Delta\tau = 10^6$ bits/s. The corresponding time scales are therefore on the order of $\Delta\tau \sim 1$ μs which is a typical time for a conformational change to occur in a protein. The corresponding frequency, f, is expected to be 10 MHz. Finally, the lowest level of information processing discussed in the literature is that of the constituent protein, tubulin. For a typical 10 μm-long MT, there are on the order of 10^4 tubulin dimers. We conclude that if a tubulin dimer is the basic computational element (corresponding to a bit of biological information), then its maximum information processing rate is $\Delta I/ \Delta\tau = 10^2$ bits/s. These estimates maintain the basic principle of energy conversation together with the energetic cost of processing each bit of information. The latter estimate, however, leads to a contradiction with the various claims of tubulin being a biological qubit that processes information on much shorter time scales. The value of $\Delta I/ \Delta\tau$ arrived at above indicates tens of millisecond transitions which would correlate with microtubule coupling with action potential but most definitely not the sub-nanosecond electronic transitions with concomitant GHz frequency rates. If these very rapid transition rates were to be present, a calculation of the corresponding energetic cost of information processing would indicate enormous power consumption in the tens or hundreds of MW, clearly an absurd value in the context of the human brain.

In summary, if information processing taking part in the brain does so in a hierarchical manner with neurons forming the second layer and MTs the next one with final steps being made by tubulin dimmers, we have found that the maximum theoretically possible information processing rates can be: (a) 10^{20} bits/s per brain, (b) 10^9 bits/s per neuron, (c) 10^6 bits/s per microtubule and 10^2 bits/s per tubulin. These numbers may be a reasonable quantification of biochemical processes occurring in the brain in the classical regime, consistent with various possible biochemical scenarios. For example, phosphorylation events of tubulin by calmodulin kinase II (CaMKII) enzyme would
possible occur on a time scale of tens of milliseconds, as could interactions of MTs with action potential fields. It challenges the present-day knowledge about biochemistry and cell biology as well as quantum physics to claim that such slow processes can be performed in a quantum mechanical regime.
Based on the discussion presented in this paper, we propose a multi-fractal hypothesis since the scaling laws connecting different information processing hierarchies are not identical. Specifically, this shown in the table below.

Element	Number N	characteristic frequencies f_1	f_N	scaling exponent $fN \sim (f1)^{\alpha}$ α
Neuron-brain	10^{11}	10^{4}	10^{1}	¼
MT-neuron	10^{3}	10^{7}	10^{4}	4/7
channel-neuron	10^{4}	10^{8}	10^{4}	½
tubulin-MT	10^{4}	10^{9}	10^{7}	7/9

Feddbacks: closing the loop

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The quest for the link between information and action invites us to ponder the biophysical mechanisms that undergird the teleonomic agency and vitality observable in living creatures.

Such an investigation will require:

1) Transcendence of limited paradigms that fail to honor *first-person subjective perspective*; This will include transcending Newtonian mechanism, Cartesian Dualism, rigid Neo-Darwinism, anthropocentrism and neurocentrism, in order to fully honor the intelligent behavior of simple animals and plants. This includes transcending paradigms that carry forward indefensible assumptions about human nature from both science and religion.

2) A Post-Shannon definition of information: A semiotic Batesonian [1] sort of definition that is relative to a subjective observer as interpretant, a sentient "self" in its immediate environment. (The *difference that makes a difference* – ***to me***.) This definition of information will embrace and elucidate the causal role of the self in the creation, transfer and storage of that information; and the original functional purpose it serves. (Why it makes a difference to me; How its informative value works within the grander physical scheme at both large and small scales in space and time; How it emerged from the physical laws, forces and flux of the universe.) This inquiry may extend to the hard problem of consciousness, its physical instantiation, and its efficacious functional capacities.

3) An investigation of precisely what we mean by *the self* as a bounded physical structure, as a complex adaptive non-equilibrium system exchanging matter and energy with its environment and in the context of complex self-organizing systems. This will include explication of the relationship between *self as part* and *Self as whole* – the "Kantian Whole" [2] (whose "parts exist for and by means of the whole"). This would be a foundational definition of identity serviceable from the nested hierarchical fractal/holonic structure of complex adaptive systems to the complex human body-mind.

4) Identifying a minimal form of information required to animate and in-form decision making in living systems; including how this foundational bit can give rise to the variety of logic gates and information processing motifs observable in neural and non-neural computations.

5) An addition to network theory, wherein stochastic models [3] are enhanced with an active nonrandom dynamic at the level of individuals nodes. This would add a level-independent "self-regulatory" component to the story of self-organizing holonic structures (#3 above). One that enhances the vertical depiction of bidirectional information flows (top-down, bottom-up) by considering the ongoing *horizontal* interactions between the node in its local external environment (nearest neighbor nodes). This would elucidate how each node can actively *alter* self-states and connectivity parameters, thereby mediating the global behavior (and phase space) of the collective whole. This would be akin to models of cellular automata, wherein this new kind of information might play a role in the "simple rules" [4] and "nearest neighbor information" that foster global systemwide behavior.

My contribution to this inquiry will demonstrate how each of the above conditions can be satisfied by a broader and deeper understanding of the *emotional system*, and its biological "self-regulatory" function [5].

1) This new science suggests that emotional system is much more ancient and has far more functional value than old paradigms suggest. Emotion is actually an entire sensory system, the first to have emerged on the evolutionary stage. An early manifestation of "emotional sentience" is evident in the sensorimotor chemistry of the E coli bacterium. Hedonic qualia, including some binary sensory signal akin to pleasure and pain and it's coupled behavioral approach/avoidant response. Hedonic qualia undergird the ubiquitous "hedonic" pattern of behavior: toward that which is beneficial and away from that which is harmful – a pattern observable in all living creatures up and down the evolutionary ladder [6]. Emotion serves as the mechanism once touted as a vital force [7], both animating and guiding living systems.

2) Hedonic qualia encode a simple Yes/No evaluative logic, the *fundamental semantic information bit*,

that serves as semiotic informative interface between organism and its immediate environment. It pulls triple duty in the cybernetic "loop of mind" also known as the 5E enactive mind [8]. It serves as the new Batesonian form of personally meaningful information, a bodily signal with its coupled response, which further feeds back into the enactive mind leaving evaluative memory traces that lead to feed-forward motivations and teleological behavior. The experiential difference that creates a self-generated difference to body, the mind and its immediate time/space relationship with external world.

3) This self-regulatory function of emotion elucidates an inclusive range of *self-identity* ranging across each level of a complex living organism (cells, tissues, organ systems), to that of non-living matter (molecules, atoms, sub-atomic particles), in terms of the part-to-whole relationship.

4) This fundamental semantic information bit can be examined within a conceptual framework akin to Taoist dance of opposites – The Tao, The Way, the creative engine of being and becoming. We can root its various manifestations on different scales in time and space in the level independent sweet-spot of "edge-of-chaos" criticality, born of coupling of positive and negative feedback functions. Born of physical energy conservation principles, it mediates the ongoing balance between exploiting chaotic/entropic opportunity and preserving negentropic order stability. Yet its ultimate most valuable offering is a subjective reflection of the criteria for natural selection: balancing imperatives of self-development (via emotional resonance) and self-preservation (via emotional dissonance), affording all living systems direct participation in the evolutionary process.

5) This new framework implies teleological "turtles" - self-regulating networks - all the way down. Perhaps even a panpsychist universe, with Whiteheadian "prehensions" [9] containing consciousness as well as efficacious free will and an innate desire to Self-actualize. This can bring science full circle with experiential spirituality. The implications for cultivating optimal human potential, creative cooperation and global humanitarian coherence are promising if not profound.

References

[1] Bateson, G. (1970). Form, substance, and difference. *Essential Readings in Biosemiotics*, *501*.
[2] Kauffman S. A. (2019). *A world beyond physics: the emergence and evolution of life*. Oxford University Press.
[3] Csermely, P., Kunsic, N., Mendik, P., Kerestély, M., Faragó, T., Veres, D. V., & Tompa, P. (2020). Learning of signaling networks: Molecular mechanisms. *Trends in biochemical sciences*, *45*(4), 284-294.

[4] Pavlic, T. P., Adams, A. M., Davies, P. C., & Walker, S. I. (2014). Self-referencing cellular automata: A model of the evolution of information control in biological systems. *arXiv preprint arXiv:1405.4070*.
[5] Peil, K. T., (2014). The self-regulatory sense. *Global Advances in Health & Medicine*. 3(2)80-108. Or PubMed: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4010957/
[6] Medicus, G., (1987). Toward an ethnopsychology: A phylogenic tree of behavior. *Ethology and Sociobiology*. 8, (3sl), 131-150.
[7] Bergson, B. (1919). L'Energie spirituelle: Essais et conf´erences. In: *Oeuvres* (1959), 811–977. Translated by H. Wildon Carr as
Mind-Energy: Lectures and Essays (1975), Westport, CT: Greenwood Press.
[8] Kauffman, K. P. (2020). Fractal Epistemology and the Biology of Emotion. In Terry Marks-Tarlow, Yakov Shapiro, Katthe P Wolfe, & Harris Friedman (Eds.*) A Fractal Epistemology for a Scientific Psychology: Bridging the personal with the transpersonal.* Newcastle, UK: Cambridge University Press. Chapter 5, pp 144-185.
[9] Whitehead, A. N., & Sherburne, D. W. (1957). *Process and reality* (pp. 349-350). New York, NY: Macmillan.

S&T Foresight Workshop:
A quest for an interface between information and action

7, 9 and 20 April 2021 (remotely)

7 April (17:00 – 20:00 BST) Chair: Pier Francesco Moretti

17:00 – 17:20 Rationale of the workshop: from materials to immaterial concepts (**Pier F. Moretti**)
17:20 – 17:50 Languages of nature (**Cédric Gaucherel**)
17:50 – 18:20 The Music of matter (**Tom McLeish**)
18:20 – 18:50 Nature-inspired computing (**Andrew Adamatzky**)
Leg stretching
19:00 – 19:30 Emergence of organisms (**Andrea Roli**)
19:30 – 20:00 Strong AI and Quantum Brain (**Stuart A. Kauffman**)
Questions are collected on chat and on a living open access document

9 April (17:00 – 20:15 BST) Chair: Vasileios Basios

17:00 – 17:30 The generalization of the periodic table (**Vasil Penchev**)
17:30 – 18:00 A review of some ideas for a mathematics of biology (**Roberto Natalini**)
18:00 – 18:30 Synchronism (**Andrey Shilnikov**)
Leg stretching
18:40 – 19:10 Chaos, rhythms and processes in structure and function
(**Vasileios Basios & Yukio-Pegio Gunji**)
19:10 – 19:40 Signals in cells (**Jack A.Tuszyński**)
19:40 – 20:10 COMA-SAN: Innovative experiments on sensing biological communication
(**Marco Girasole & Giovanni Longo**)
20:10 – 20:15 Towards the third day
Questions are collected on chat and on a living open access document

20 April (17:00 – 20:00 BST) Chair: Pier Francesco Moretti

17:00 – 17:20 Report and analysis of main points and questions
17:20 – 17:50 Dynamic information in complex networks (**Enrico Capobianco**)
17:50 – 18:20 Feedbacks: closing the loop (**Kathrine Peil Kauffman**)
Leg stretching
18:30 – 19:50 Debate
19:50 – 20:00 Next steps

Expert Bio and keywords

Family Name	Basios	Given Name	Vasileios	Sex	M	Picture	
Nationality	Greek			Year of birth	1962		
Organization	Interdisciplinary Centre for Nonlinear Phenomena and Complex Systems (Cenoli-ULB) & Département de Physique des Systèmes Complexes et Mécanique Statistique.			Degree[s] in Physics	PhD, MSc, BSc		
Your best professional achievement	Participation in developing a new paradigm of crystallization/aggregation during ESA's complex matter initiative.						
Your best personal achievement	Developing a novel approach for biological information processing implementing inverse Bayesian inference.						
Short bio (max 300 words)	Vasileios Basios is a senior researcher in Complex Systems, interdisciplinary physics, with over 25 years in research and teaching. He is conducting research in the foundations of complexity science and nonlinear systems, in self-organization of complex matter. He serves as an adviser for research projects and as research faculty in international graduate schools on Complexity and Non-linear dynamics. He worked on self-organization and a new paradigm of nucleation/aggregation in nano-materials (proteins and zeolites) with the team of Prof. G. Nicolis at ULB sponsored by the European Space Agency (ESA). That was a biotechnology initiative for the, in orbit laboratory, of the 'ProMISS' and 'GCB' experiments on Thermodynamic and Statistical Mechanical Aspects of Protein Crystallization and Pattern Formation in Reaction-diffusion systems; "Complex Matter" initiative. Where he also organized and led panel discussions of ESA Topical Teams, workshops and conferences on Complexity science. The issue of collective dynamics in living and non-living matter is a focal interest of his current studies and in collaboration with the team of Prof. Yukio-Pegio Gunji at Tokyo's Waseda university, they have developed a novel approach to Bayesian inference, called 'Bayesian and Inverse Bayesian inference' (BiB), that has furnished novel insights especially on the area of biological information processing. He has extensive experience in large scale simulations and modelling of nonlinear and stochastic systems, neural networks, Monte-Carlo methods and, Bayesian inference, for nonlinear complex systems. In addition he is engaged in addressing varied and diverse audiences from learned specialists to laymen and students on the theme of complexity, philosophy of science and the history of scientific ideas, related to complex systems' science. During his formative years he was tutored by Ilya Prigogine (Nobel Laureate) and Grégoire Nicolis at ULB; where he got his PhD, after studying with John S. Nicolis 'cybernetics', at the University of Patras.						

Expert Bio and keywords

<table>
<tr><td>Family Name</td><td>Capobianco</td><td>Given Name</td><td colspan="2">Enrico</td><td>Sex</td><td>M</td><td rowspan="5"></td></tr>
<tr><td>Nationality</td><td colspan="2">Italian</td><td>Year of birth</td><td colspan="4">1964</td></tr>
<tr><td>Organization</td><td colspan="2">University of Miami, FL-USA
CNR, ISOF Bologna, IT</td><td>Degree[s] in Physics</td><td colspan="4">PhD</td></tr>
<tr><td>Your best professional achievement</td><td colspan="7">Being a scientist</td></tr>
<tr><td>Your best personal achievement</td><td colspan="7">Doing what I like</td></tr>
<tr><td>Short bio (max 300 words)</td><td colspan="8">Enrico Capobianco is an expert of complex systems with a wide scientific research experience at an international scale. He has explored the field of Biomedicine in multiple areas. He works since 2012 as Lead Scientist at the Center for Computational Science, University of Miami, and collaborates with various Departments of the Miller School of Medicine.

Enrico is contributing to the growth of the Systems Medicine field, especially leading Network Science towards methodological advances and cancer applications. He is now focused on the Complexity found in Precision Medicine, Computational Medical Imaging, Big Data Analytics and Network Science.

Enrico studied as a graduate scholar quantitative disciplines at LSE (London, 1991-92), Northwestern University (1992) and UC Berkeley Statistics (1992-93), while obtaining a doctorate in Statistical Sciences from the University of Padua (1994). He then was a postdoc at Stanford University (Computer Science, PDP-AI Lab, 1994-98), then at the Niels Bohr Institute and Danish Technical University (NATO-CNR Fellow in Neurocomputing, 1999). In 2001 he was elected ERCIM fellow at the CWI - Center for Mathematics and Computer Science, in Amsterdam (2001-02, Stochastics), then he continued with an appointment at the Mathematical Sciences Research Institute, in UC Berkeley (2003), Boston University (2004-05, Biomedical Engineering), and Serono in Evry (2005, Head of Methods).

With the CRS4 (Polaris Science & Tech Park, 2006-11) he was Head of the Quantitative Systems Biology Group, and after he founded a team with the National Research Council, Institute of Clinical Physiology (Pisa, 2012-2015), called LISM - Laboratory of Integrative Systems Medicine. He remained associated with CNR in 2016-2017, as Coordinator in Big Data in Health. Enrico obtained professorships from the Chinese Academy of Science (2011, Shanghai) and the Fiocruz Foundation (2008-2010, Rio de Janeiro, Program, Capes - FIOCRUZ). He had multiple participations in US academic programs at SAMSI, IMA, MSRI, IPAM and Simons Institutes, and he was offered visiting appointments at the International Centre for Theoretical Physics (2003, Condensed Matter, Trieste), and at the Institut des Hautes Études Scientifiques (IHES) (2010, Paris).</td></tr>
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Expert Bio and keywords

<table>
<tr><td>Family Name</td><td>Dobson</td><td>Given Name</td><td>Shanna</td><td>Sex</td><td>F</td><td rowspan="5"></td></tr>
<tr><td>Nationality</td><td>American</td><td colspan="2">Year of birth</td><td colspan="2">1992</td></tr>
<tr><td>Organization</td><td colspan="2">California State University Los Angeles</td><td>Degree[s] in (Phd please in the short bio text below)</td><td colspan="2">PhD Mathematics, UCR (in progress)
Master of Science, Mathematics; Bachelor of Science Mathematics and Physics (CSULA)</td></tr>
<tr><td>Your best professional achievement</td><td colspan="5">Receiving the NSF Mathematical Sciences Graduate Research Fellowship Award and UCR’s Distinguished Chancellor Fellowship for my graduate studies in mathematics, being selected to attend the IAS Women and Mathematics 2021 Summer Program, and writing my manuscript Efimov K-theory of Diamonds, and writing the manuscript Perfectoid Diamonds and N-Awareness: A Meta-Model of Subjective Experience with my colleague Dr. Robert Prentner.</td></tr>
<tr><td>Your best personal achievement</td><td colspan="5">Writing my mathematical fantastical fiction series Artemis Blu and the Solarium Multiversity, creating my own joint academic/studio atelier thematic Exploring Mathematics and Creativity class at ArtCenter College of Design, and rescuing and nurturing, since their infancy, so many beautiful animals, most recently, my glowing two girl cats, Artemis and Natasha.</td></tr>
<tr><td>Short bio (max 300 words)</td><td colspan="6">I am a UCR Chancellor Distinguished Fellow, Caltech SURF Fellow, USC CUE & CETL Faculty Equity Fellow, IAS Women and Mathematics member, and author studying Geometric Langlands, K-theory, and perfectoid spaces. I am a Mellon Foundation grantee, the SEC TF1 String Theory and Quantum Gravity Liaison for SnowMass 2021, and an invitee to WestEd's Reading Apprenticeship STEM Learning Community.

Professional Appointments: I am a mathematics lecturer at California State University Los Angeles, Mount Saint Mary's University, and ArtCenter College of Design.

National and Institute Committees: I am currently Chair of the AWM-MAA Liaison Committee, Program Chair of the Southern California-Nevada Section of the MAA, member of the AWM-MathFest and AWM-Meetings Committee, and the Alternate NSS Lecturer Representative to the Academic Senate at Cal State LA. At ArtCenter College of Design, I am the At-Large Representative and Secretary of the Faculty Council Committee, Chair of the Faculty Outreach Subcommittee, member of the Chair's Council Reopening, Chair's Council Delivery of Classes, and Future Pedagogy Subcommittees, and the Faculty Research Committee.

Research Interests: I am interested in perfectoid spaces, Langlands functoriality, geometrization of local Langlands, and post-quantum cryptography.</td></tr>
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Expert Bio and keywords

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<tr><td>Family Name</td><td>Gaucherel</td><td>Given Name</td><td>Cédric</td><td>Sex</td><td>Male</td><td rowspan="5"></td></tr>
<tr><td>Nationality</td><td>French</td><td colspan="2">Year of birth</td><td colspan="2">1970</td></tr>
<tr><td>Organization</td><td>INRAE (French National Institute in Agricultural and Environmental Sciences)</td><td colspan="2">Degree[s] in (Phd please in the short bio text below)</td><td colspan="2">Senior scientist (Dr. of Sc.)</td></tr>
<tr><td>Your best professional achievement</td><td colspan="5">Certainly, it was that of languages in nature. This working hypothesis argue that we will find languages everywhere in living systems, and my team and I are on the way to demonstrate it.</td></tr>
<tr><td>Your best personal achievement</td><td colspan="5">Without any doubt, my two sons are my best “achievement” in Life … although it is not so personal (as my wife and I were two in this endeavour). ☺</td></tr>
<tr><td>Short bio (max 300 words)</td><td colspan="6">Cédric Gaucherel is senior researcher at INRAE in France, and was also the head of the Department of Ecology of the French Institute of Pondicherry (IFP, India). He has extensive experience in theoretical ecology and related environmental fields, including ecosystem functioning, ecological modelling and biological theories. With about hundred scientific publications, he has demonstrated the capability to study many systems, often with cutting-edge methods such as mathematical and computer science models.</td></tr>
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Expert Bio and keywords

<table>
<tr><td>Family Name</td><td>Kauffman</td><td>Given Name</td><td>Katherine Peil</td><td>Sex</td><td>F</td><td rowspan="5"></td></tr>
<tr><td>Nationality</td><td colspan="2">American</td><td>Year of birth</td><td colspan="2">1957</td></tr>
<tr><td>Organization</td><td colspan="2">EFS International</td><td>BS
MTS</td><td colspan="2">Psychology;
Theology; Science & Religion</td></tr>
<tr><td>Your best professional achievement</td><td colspan="5">Identifying the self-regulatory function of the emotional system.</td></tr>
<tr><td>Your best personal achievement</td><td colspan="5">Creating and guiding two human beings.</td></tr>
<tr><td>Short bio
(max 300 words)</td><td colspan="6">Katherine Peil Kauffman is founding Director of EFS International, a research and education nonprofit whose mission is to foster global emotional wisdom. Her lengthy inquiry spans subjects from clinical psychology to physics and has led to a better understanding of the biological function of emotion. An ancient “self-regulatory” sense and evaluative perceptual mechanism, emotion allows living systems to participate directly in self-organizing and evolutionary processes.
Holding degrees from the University of Washington and Harvard Divinity School, Kauffman speaks internationally on the functional, evolutionary, physio-chemical, and informational nature of emotion and its central role in human development, psychological function, moral reasoning, and universal spiritual experience. An awareness of how universal emotional processes in-form living systems toward optimal health can advance the goals of sustainability and nonviolence in our global village. For an introduction to this work visit http://emotionalsentience.com/.</td></tr>
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Expert Bio and keywords

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<tr><td>Family Name</td><td>LONGO</td><td>Given Name</td><td>GIOVANNI</td><td>Sex</td><td>M</td><td rowspan="5"></td></tr>
<tr><td>Nationality</td><td>ITALIAN</td><td colspan="2">Year of birth</td><td colspan="2">1975</td></tr>
<tr><td>Organization</td><td>CONSIGLIO NAZIONALE DELLE RICERCHE – ISTITUTO DI STRUTTURA DELLA MATERIA</td><td colspan="2">Degree[s] in (Phd please in the short bio text below)</td><td colspan="2">PHYSICS</td></tr>
<tr><td>Your best professional achievement</td><td colspan="5">The nanomotion sensor</td></tr>
<tr><td>Your best personal achievement</td><td colspan="5">20 years in Curva Sud.</td></tr>
<tr><td>Short bio (max 300 words)</td><td colspan="6">Dr. Longo has graduated in physics in 2000 at the Rome university La Sapienza, and has obtained his PhD in 2006 on the “Study of Oligonucleotide-Loaded Silicon Surfaces with AFM and Quantitative Fluorescence”.
Dr. Longo has focused on the characterization of nanostructures and of nanosized systems (mainly of biological and medical interest); particularly on scanning probe microscopies and high-resolution characterization techniques. By developing different kinds of nanomechanical sensors, he has applied them to the study of a wide range of scientific problems. These include the study of nanoscale contaminants in marine environments, the development and characterization of nanostructured coatings for implant osseointegration and the development and use of the nanomotion sensor in microbiology, biology and oncology applications.</td></tr>
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Expert Bio and keywords

<table>
<tr><td>Family Name</td><td>McLeish</td><td>Given Name</td><td>Tom</td><td>Sex</td><td>M</td><td rowspan="5">
Your Picture</td></tr>
<tr><td>Nationality</td><td></td><td>Year of birth</td><td colspan="3"></td></tr>
<tr><td>Organization</td><td colspan="2">University of York</td><td>Degree[s] in (Phd please in the short bio text below)</td><td colspan="2">MA (Cantab), PhD</td></tr>
<tr><td>Your best professional achievement</td><td colspan="5">Creating a multiscale molecular rheology theory for non-linear flow of complex topology polymer melts, including an industrial design tool.</td></tr>
<tr><td>Your best personal achievement</td><td colspan="5">Raising four amazing children, now adults, within a happy marriage.</td></tr>
<tr><td>Short bio (max 300 words)</td><td colspan="6">Tom McLeish, FRS, is Professor of Natural Philosophy in the Department of Physics at the University of York, England, and is also affiliated to the University's Centre for Medieval Studies and Humanities Research Centre. He has conceived and led several radically interdisciplinary research projects, and is a recognized UK expert on formulating and evaluating interdisciplinary research.

His scientific research in 'soft matter and biological physics,' draws on collaboration with chemists, engineers, and biologists to study relationships between molecular structure and emergent material properties, recognized by major awards in the USA and Europe. He currently leads the UK 'Physics of Life' network, and holds a 5-year personal research fellowship focusing on the physics of protein signaling and the self-assembly of silk fibres. He wrote the short book Soft Matter – A Very Short Introduction (OUP 2020).

Other academic interests include the framing of science, theology, society and history, and the theory of creativity in art and science, leading to the recent books Faith and Wisdom in Science (OUP 2014) and The Poetry and Music of Science (OUP 2019). He co-leads the Ordered Universe project, a large interdisciplinary re-examination of 13th century science. He has also contributed to the philosophy of emergence, and to a research project in cross-curricular education for post-16 pupils.

From 2008 to 2014 he served as Pro-Vice-Chancellor for Research at Durham University and was from 2015-2020 Chair of the Royal Society's Education Committee. He is currently a Council Member of the Royal Society and a trustee of the John Templeton Foundation.</td></tr>
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Expert Bio and keywords

Family Name	Natalini	Given Name	Roberto	Sex	M	 My Picture
Nationality	Italy		Year of birth	1960		
Organization	Consiglio Nazionale delle Ricerche		Degree[s] in (Phd please in the short bio text below)	Laurea in Matematica		
Your best professional achievement	As a researcher I started a new line of research on mathematical models for monitoring the damage on the stone monuments.					
Your best personal achievement	My family not considered, I created an original series of comics books, “Comics&Science”, published by Cnr, devoted to promote science (in collaboration with Andrea Plazzi). And also I wrote the plot of a Mickey Mouse story about my institute.					
Short bio (max 300 words)	Roberto Natalini received his PhD in Mathematics from University of Bordeaux (France) in 1986. He is director of the Istituto per le Applicazioni del Calcolo "Mauro Picone"of the National Research Council of Italy since 2014. He published more than 140 articles on peer-review journals and his research themes include: fluid dynamics, road traffic, semiconductors, chemical damage of monuments, biomathematics, communication of mathematics. He is in the Scientific Commitee of the Italian Mathematical Union and is Chair of the Raising Public Awareness Committee of the European Mathematical Society.					

Expert Bio and keywords

<table>
<tr><td>Family Name</td><td>Penchev</td><td>Given Name</td><td colspan="2">Vasil</td><td>Sex</td><td>male</td><td rowspan="5"></td></tr>
<tr><td>Nationality</td><td colspan="2">Bulgarian</td><td>Year of birth</td><td colspan="3">1958</td></tr>
<tr><td>Organization</td><td colspan="2">Bulgarian Academy of Sciences: Institute of Philosophy and Sociology: Dept. of Philosophy of Science</td><td>Degree[s] in (Phd please in the short bio text below)</td><td colspan="3">Doctor of Philosophical Science</td></tr>
<tr><td>Your best professional achievement</td><td colspan="6">The article “A Class of Examples Demonstrating That 'P ≠ NP' in the 'P vs NP' Problem”</td></tr>
<tr><td>Your best personal achievement</td><td colspan="6">to be a scientist</td></tr>
<tr><td>Short bio (max 300 words)</td><td colspan="7">I was born in Sofia, Bulgaria on February 7, 1958; graduated from the Technical University of Sofia in 1983 as a magister in electronics. My PhD thesis about the interpretation of the link between special relativity and quantum mechanics at the Chair of Philosophy of the University of Sofia “St. Kliment Ohridski” was defended in 1995. I worked as a part-time assistant at the same chair from 1997 to 2002, have been an associate professor in the Institute of Philosophy and Sociology of the Bulgarian Academy of Science since 2003 until now, and defended the degree of Doctor of Philosophical Science in philosophy in history in 2009. The thesis is: “The Philosophical Foundation of Civilization Approach in History”. The publications in international and Bulgarian philosophical and scientific journals, totally about 200, include 14 books. The presentations delivered at International Conferences or Congresses all over the world are about 100. The main fields of work and interest are: the theory of quantum information, the link of general relativity and quantum mechanics by means of quantum information; the reinterpretation of the Standard model in terms of quantum information; quantum-information chemistry; merging the foundations of mathematics and quantum mechanics by means of the theory of quantum information; quantum computer as a generalization of Turing machine; civilization approach in philosophy of history; the philosophical interpretation of the famous Bulgarian writer Yordan Radichov’s works.
Most of my publications can be found @ https://philpeople.org/profiles/vasil-penchev .
The article I am writing is: “The Symmetries of Quantum and Classical Information”.</td></tr>
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Expert Bio and keywords

<table>
<tr><td>Family Name</td><td>Roli</td><td>Given Name</td><td colspan="2">Andrea</td><td>Sex</td><td>M</td><td rowspan="5"></td></tr>
<tr><td>Nationality</td><td colspan="2">Italian</td><td>Year of birth</td><td colspan="3">1969</td></tr>
<tr><td>Organization</td><td colspan="2">Alma Mater Studiorum
Università di Bologna

Dept. of Computer Science and Engineering (DISI)

Campus of Cesena</td><td>Degree[s] in (Phd please in the short bio text below)</td><td colspan="3">Electronic Engineering</td></tr>
<tr><td>Your best professional achievement</td><td colspan="6">I had the privilege of helping some students I’ve supervised to discover and cultivate their scientific passions.</td></tr>
<tr><td>Your best personal achievement</td><td colspan="6">I play theorbo and baroque guitar.</td></tr>
<tr><td>Short bio (max 300 words)</td><td colspan="7">Andrea Roli got his PhD in Computer Science and Electronic Engineering from the University of Bologna. He has been assistant professor at the University "G.d'Annunzio" Chieti-Pescara and he is currently with the Dept. of Computer Science and Engineering, University of Bologna, Campus of Cesena. His research interests are in Artificial Intelligence and Complex Systems, with focus on biological models, biorobotics, collective intelligence and foundations of AI. He is also interested in artificial creativity and cognitive processes and emergent phenomena in music. Andrea Roli teaches courses in computer science basics, artificial intelligence and complex systems. He is member of the Italian Association for Artificial Intelligence (AIxIA). He collaborates with IRIDIA (Institut de Recherches Interdisciplinaires et de Développements en Intelligence Artificielle), Université libre de Bruxelles and with the Namur Center for Complex Systems (NAXYS). He is also ECLT Fellow (European Centre for Living Technology, Venice).</td></tr>
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Expert Bio and keywords

<table>
<tr><td>Family Name</td><td>Affatati</td><td>Given Name</td><td>Alice</td><td>Sex</td><td>F</td><td rowspan="5"></td></tr>
<tr><td>Nationality</td><td colspan="2">Italian</td><td>Year of birth</td><td colspan="2">1984</td></tr>
<tr><td>Organization</td><td colspan="2">Memorial University (Canada)</td><td>Degrees</td><td colspan="2">Engineering</td></tr>
<tr><td>Your best professional achievement</td><td colspan="5">In the context of my work at GEOMAR (Kiel, Germany) Alice's findings provided novel insights into the behaviour of silver nanoparticles in seawater, with much faster than anticipated removal of nanoparticles when entering the ocean. The fast removal is due to kinetically rapid coagulation processes, which have not been observed by others due to the improved and novel detection techniques employed. Experiments with high dilutions solutions of nanoparticles in seawater were developed for the first time ever. Hopefully, in the underwater acoustics field the best achievement is jet to come.</td></tr>
<tr><td>Your best personal achievement</td><td colspan="5">She was one of the members of the team that performed the longest ever great white shark (Carcharodon carcharias) continuous acoustic manual tracking (107hrs on a 4.2m female) with the largest ever recorded difference between a white shark stomach temperature and the surrounding waters (+13.5 degrees).</td></tr>
<tr><td>Short bio (max 300 words)</td><td colspan="6">Alice has a background in Engineering but she has tailored my studies to include Oceanography and Marine Biology as well. She worked in the acoustic telemetry and bioacoustics field in South Africa and Namibia focusing on studying the behavior of cetaceans and great white sharks (Carcharodon carcharias) also in relation to the physical properties of the ocean.
Furthermore, at GEOMAR (Kiel, Germany) she was involved in an interdisciplinary experimental oceanography project. At the National Institute of Oceanography and Applied Geophysics – OGS (Trieste, Italy) she researched underwater noise and its effects on marine fauna and at the Laboratory of Applied Bioacoustics (Vilanova I la Geltrú, Spain) cetacean bioacoustics.
Among other things, she was part of a group of experts on the subject of the effects of underwater noise in the Arctic Ecosystem in the Framework on the United Nations Decade of Ocean Science for Sustainable Development in the Arctic Ocean. Alice is currently a PhD student researching underwater noise from shipping and its effects on marine mammals.</td></tr>
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Expert Bio and keywords

<table>
<tr><td>Family Name</td><td>Moretti</td><td>Given Name</td><td>Pier Francesco</td><td>Sex</td><td>M</td><td rowspan="5"></td></tr>
<tr><td>Nationality</td><td colspan="2">Italian</td><td>Year of birth</td><td colspan="2">1967</td></tr>
<tr><td>Organization</td><td colspan="2">CNR</td><td>Degree[s] in</td><td colspan="2">Physics</td></tr>
<tr><td>Your best professional achievement</td><td colspan="5">The interpretation of the reddening of some asteroids' spectra has allowed to develop a procedure for the analysis of hardening of steels, which has been patented.</td></tr>
<tr><td>Your best personal achievement</td><td colspan="5">A noir fiction book I wrote to transfer my dreams and fears.</td></tr>
<tr><td>Short bio</td><td colspan="6">Pier Francesco Moretti is a physicist with two PhDs, more than 80 international publications in astrophysics, material sciences, and a patent. His skills in research were mainly focused in spectroscopy, image analysis and innovative technologies. He worked in USA and Austria. He has been involved in many international research projects and has been responsible of the Office for the International Activities of the CNR Department of Earth and Environment. He has participated many European projects and Governmental Boards (JPI Oceans, Marine Board, Sherpa groups of G7-Science). He has been vice-chair of the Research Working Party of the EU Competitiveness Council during the Italian Presidency of the European Union.
He was a permanent professor in Physics at nautical and technical institutes.
He now works at the CNR Liaison Office in Brussels, mainly involved in support to policy, coordination of national programmes and foresight activities for technological development.
See also pierfrancescomoretti.eu</td></tr>
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