UNIVERSAL SCIENCE OF MIND:
CAN COMPLEXITY-BASED ARTIFICIAL INTELLIGENCE SAVE THE WORLD IN CRISIS?

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Abstract

While practical efforts in the field of artificial intelligence grow exponentially, the truly scientific and mathematically exact understanding of the underlying phenomena of intelligence and consciousness is still missing in the conventional science framework. The inevitably dominating empirical, trial-and-error approach has vanishing efficiency for those extremely complicated phenomena, ending up in fundamentally limited imitations of intelligent behaviour. We provide the first-principle analysis of unreduced many-body interaction process in the brain revealing its qualitatively new features, which give rise to rigorously defined chaotic, noncomputable, intelligent and conscious behaviour. Based on the obtained universal concepts of unreduced dynamic complexity, intelligence and consciousness, we derive the universal laws of intelligence applicable to any kind of intelligent system interacting with the environment. We finally show why and how these fundamentally substantiated and therefore practically efficient laws of intelligent system dynamics are indispensable for correct AI design and training, which is urgently needed in this time of critical global change towards the truly sustainable development.

1. Unreduced interaction complexity and the exact science of mind (natural, artificial, and conscious intelligence)

Practical realisation of complicated computer control tools known as artificial intelligence (AI) has now become a major technological development drive underlying emerging global progress in the situation of general critical stagnation of world development. At the same time, any rigorous and consistent concept of intelligence and consciousness is still absent [1-26], thus leaving all the huge AI activity with the purely empirical, conceptually blind kind of search by usual trial-and-error methods. The latter, however, show quickly growing inefficiency just in cases of such ultimately complicated system dynamics. Here we demonstrate that this unacceptable contradiction can be resolved with the help of the universal dynamic complexity concept [27-46], including the rigorous general theory of unreduced intelligence and consciousness and its applications to efficient understanding and design of any kind of intelligent system [33,34]. We also specify the exact reason why these fundamental notions (as well as the universal complexity concept) cannot be consistently defined within the standard theory framework.

We start by a quite general idea that any intelligent system is realised as a complicated enough (and thus arbitrary) *interaction process* of operational units, "generalised neurons", where the property of intelligence as such is the *dynamically emerging* result of this *unreduced* interaction process. While this arbitrary many-body interaction problem has no solution (or even its reasonable idea) in usual science framework, we show that such solution does exist and possesses qualitatively new, extended properties just explaining its impossibility in conventional theory and naturally giving rise to the universal concept of dynamic complexity [27-35,40-46]. If we start formulating this arbitrary interaction problem by a general and already universal enough Hamiltonian kind of equation, we later confirm that it is indeed the truly universal formalism for description of any unreduced system dynamics. We call this starting Hamiltonian equation *existence equation* as it really only

fixes the initial configuration of arbitrary interaction process (of generalised neurons, in our case), without any additional assumptions (including usual, formally introduced time, which we later obtain instead as emergent and physically real form of unified dynamic complexity):

$$\left\{\sum_{k=0}^{N}\left[h_k(q_k)+\sum_{l>k}^{N}V_{kl}(q_k,q_l)\right]\right\}\Psi(Q)=E\Psi(Q), \qquad (1)$$

where $h_k(q_k)$ is the generalised Hamiltonian of the k-th system component (here generalised neuron) in its "free", "integrable" state (in the absence of interaction), q_k stands for the degrees of freedom of the k-th component, $Q=\{q_0,q_1,...,q_N\}$ by definition, $V_{kl}(q_k,q_l)$ is the interaction potential between the k-th and l-th components, $\Psi(Q)$ is the system state function, and the summations are performed over all system components numbered from $k,l=0$ to $k,l=N$ (the total number of interacting entities).

It is convenient to start from a more specified but equivalent form of existence equation, where one of the degrees of freedom, say $q_0\equiv\xi$, is explicitly separated from other ones, $Q=\{q_1,...,q_N\}$, so that ξ can be interpreted as common, e.g. spatial, system variable(s), characterising its "global" configuration or interaction, while $Q=\{q_1,...,q_N\}$ may describe "internal" degrees of freedom of corresponding elements:

$$\left\{h_0(\xi)+\sum_{k=1}^{N}\left[h_k(q_k)+V_{0k}(\xi,q_k)+\sum_{l>k}^{N}V_{kl}(q_k,q_l)\right]\right\}\Psi(\xi,Q)=E\Psi(\xi,Q), \qquad (2)$$

where k,l vary now between 1 and N.

Now we can use the known solutions for the free components,

$$h_k(q_k)\varphi_{kn_k}(q_k)=\varepsilon_{n_k}\varphi_{kn_k}(q_k), \qquad (3)$$

where $\{\varphi_{kn_k}(q_k)\}$ and $\{\varepsilon_{n_k}\}$ are the eigenfunctions and eigenvalues of the k-th component Hamiltonian $h_k(q_k)$, and the eigenfunctions $\{\varphi_{kn_k}(q_k)\}$ form the complete set of orthonormal functions. Expanding the total system state-function $\Psi(q_0,q_1,...,q_N)$ over complete sets of eigenfunctions $\{\varphi_{kn_k}(q_k)\}$ for the "functional" degrees of freedom $(q_1,...,q_N)\equiv Q$, we are left with functions depending only on the selected "structural" degrees of freedom $q_0\equiv\xi$:

$$\Psi(q_0,q_1,...,q_N)\equiv\Psi(\xi,Q)=\sum_n\psi_n(\xi)\Phi_n(Q), \qquad (4)$$

where the summation spans all eigenstate combinations $n\equiv(n_1,n_2,...,n_N)$

and we designated $\Phi_n(Q) \equiv \varphi_{1n}(q_1)\varphi_{2n}(q_2)...\varphi_{Nn}(q_N)$ for brevity. Inserting the expansion of eq. (4) into eq. (2), multiplying by $\Phi_n^*(Q)$ and integrating over all variables Q (using the eigenfunction orthonormality), we get the following system of equations for $\psi_n(\xi)$:

$$\left[h_0(\xi)+V_{nn}(\xi)\right]\psi_n(\xi)+\sum_{n'\neq n}V_{nn'}(\xi)\psi_{n'}(\xi)=\eta_n\psi_n(\xi), \tag{5}$$

where

$$\eta_n \equiv E-\varepsilon_n\ ,\ \varepsilon_n \equiv \sum_k \varepsilon_{n_k}\ , \tag{6}$$

$$V_{nn'}(\xi)=\sum_k\left[V_{0k}^{nn'}(\xi)+\sum_{l>k}V_{kl}^{nn'}\right], \tag{7a}$$

$$V_{0k}^{nn'}(\xi)=\int_{\Omega_Q} dQ\Phi_n^*(Q)V_{0k}(\xi,q_k)\Phi_{n'}(Q)\ , \tag{7b}$$

$$V_{kl}^{nn'}=\int_{\Omega_Q} dQ\Phi_n^*(Q)V_{kl}(q_k,q_l)\Phi_{n'}(Q)\ . \tag{7c}$$

It will be convenient to separate the equation for $\psi_0(\xi)$ in the system of equations (5), describing the usually measured generalised "ground state" of the system elements, i.e. the state with minimum energy and complexity (corresponding, by convention, to $n=0$):

$$\left[h_0(\xi)+V_{00}(\xi)\right]\psi_0(\xi)+\sum_n V_{0n}(\xi)\psi_n(\xi)=\eta\psi_0(\xi)\ , \tag{8a}$$

$$\left[h_0(\xi)+V_{nn}(\xi)\right]\psi_n(\xi)+\sum_{n'\neq n}V_{nn'}(\xi)\psi_{n'}(\xi)=\eta_n\psi_n(\xi)-V_{n0}(\xi)\psi_0(\xi), \tag{8b}$$

where now $n,n'\neq 0$ (also everywhere below) and $\eta\equiv\eta_0=E-\varepsilon_0$.

It is interesting to note that the same system of equations is obtained by a similar procedure for a much simpler system, where one has two distributed entities ("fields") attracted to each other [27,30,31,40-45]:

$$\left[h_g(\xi)+V(\xi,q)+h_e(q)\right]\Psi(\xi,q)=E\Psi(\xi,q)\ . \tag{9}$$

This existence equation describes our world emergence and dynamics at its most fundamental, "quantum" levels, in interaction between two initially homogeneous "protofields" of different ("gravitational" and "electromagnetic") physical nature, described by the Hamiltonians $h_g(q)$ and $h_e(q)$ respectively.

However, if we take into account that the protofields have their internal structure, then the system description may be not really different from the above "explicitly many-body" problem, which explains the coincidence of the transformed formulation of both problems in terms of the element degrees of freedom, eqs. (5) and (8). The unreduced brain dynamics can also be considered as a result of interaction between the distributed electromagnetic and chemical components, though provided with the developed super-structure within the neuron network [30,31,33]. This analogy between the lowest and highest levels of world dynamics has not only formal, but profound physical meaning, as we shall see below.

Expressing $\psi_n(\xi)$ from eqs. (8b) with the help of the standard Green's function technique [47,48] and inserting the result into eq. (8a), we reformulate the problem in terms of *effective* existence equation formally involving only "common" ("structural") degrees of freedom (ξ) [27-35,40-44]:

$$\left[h_0(\xi)+V_{\text{eff}}(\xi;\eta)\right]\psi_0(\xi)=\eta\psi_0(\xi)\,, \tag{10}$$

where the *effective (interaction) potential (EP)*, $V_{\text{eff}}(\xi;\eta)$, is given by

$$V_{\text{eff}}(\xi;\eta)=V_{00}(\xi)+\hat{V}(\xi;\eta),\ \hat{V}(\xi;\eta)\psi_0(\xi)=\int\limits_{\Omega_\xi} d\xi' V(\xi,\xi';\eta)\psi_0(\xi'), \tag{11a}$$

$$V(\xi,\xi';\eta)\equiv\sum_{n,i}\frac{V_{0n}(\xi)\psi_{ni}^0(\xi)V_{n0}(\xi')\psi_{ni}^{0*}(\xi')}{\eta-\eta_{ni}^0-\varepsilon_{n0}}\ ,\ \varepsilon_{n0}\equiv\varepsilon_n-\varepsilon_0\ , \tag{11b}$$

and $\{\psi_{ni}^0(\xi)\}$, $\{\eta_{ni}^0\}$ are the complete sets of eigenfunctions and eigenvalues of an auxiliary, truncated system of equations (recall that $n,n'\neq 0$):

$$\left[h_0(\xi)+V_{nn}(\xi)\right]\psi_n(\xi)+\sum_{n'\neq n}V_{nn'}(\xi)\psi_{n'}(\xi)=\eta_n\psi_n(\xi)\ . \tag{12}$$

The general solution of the initial existence equation, eq. (2), is then obtained as [27-35,40-44]:

$$\Psi(\xi,Q)=\sum_i c_i\left[\Phi_0(Q)+\sum_n\Phi_n(Q)\hat{g}_{ni}(\xi)\right]\psi_{0i}(\xi)\ , \tag{13}$$

$$\psi_{ni}(\xi)=\hat{g}_{ni}(\xi)\psi_{0i}(\xi)\equiv\int\limits_{\Omega_\xi}d\xi' g_{ni}(\xi,\xi')\psi_{0i}(\xi')\ , \tag{14a}$$

$$g_{ni}(\xi,\xi') \equiv V_{n0}(\xi') \sum_{i'} \frac{\psi^0_{ni'}(\xi)\psi^{0*}_{ni'}(\xi')}{\eta_i - \eta^0_{ni'} - \varepsilon_{n0}} \,, \qquad (14b)$$

where $\{\psi_{0i}(\xi)\}$ are the eigenfunctions and $\{\eta_i\}$ eigenvalues found eventually from the effective dynamic equation, eq. (10), while the coefficients c_i should be determined from the state-function matching conditions along the boundary where the interaction magnitude vanishes. The observed system density, $\rho(\xi,Q)$, is given by the squared modulus of the state-function amplitude:[1] $\rho(\xi,Q) = |\Psi(\xi,Q)|^2$.

If we avoid usual perturbative reduction [48] of the complete EP expression (10)-(11), we note the *self-consistent nonlinear* EP dependence on the eigen-solutions to be found, appearing *dynamically*, even for the formally linear initial equations (1), (2), (5), (8), or (9). It can be shown [27-35,40-44, 46,47] that this *dynamic, essential nonlinearity* of a problem, remaining hidden in its starting formulation, gives rise to the **qualitatively new phenomenon of *dynamic multivaluedness (or undecidability)***, appearing as the *redundant number* of physically complete solutions which, being *equally real* and *mutually incompatible*, are forced, by the main system interaction itself, to permanently replace each other in the *causally random* order thus defined.

Indeed, if we designate by N_ξ and N_Q the numbers of terms in the sums over *i* and *n* in eq. (11b) (often $N_Q = N_\xi = N$, where N is the number of interacting modes or, in general, mode combinations), then it follows that the total number of eigen-solutions of eqs. (10)-(11), determined by the maximum eigenvalue power in the characteristic equation, is

$$N_{\max} = N_\xi (N_Q N_\xi + 1) = N_\Re N_{Q\xi} + N_\xi \,, \qquad (15)$$

where $N_{Q\xi} = N_Q N_\xi$ is the "normal" complete set of eigen-solutions for the initial system of equations, eqs. (5), (8), while $N_\Re = N_\xi \gg 1$ is the redundant number of such physically complete system configurations called *realisations*

[1] This rule corresponds to the so-called "wave-like" (undulatory) levels of complex dynamics [30], where the main entities have a distributed and compressible physical structure and are described by wave equations using, in general, complex-number presentation. Those undulatory levels alternate with "particle-like", or "classical", levels of complexity, where the main entities have a permanently localised, "hard" structure and the measured quantities like "generalised density" are derived from the state-function amplitude itself, $\rho(\xi,Q) = \Psi(\xi,Q)$ (it obeys now classical equations for real-valued, directly measurable distribution function). In the case of (truly) intelligent and conscious behaviour one deals with undulatory, "quantum" kind of behaviour at the main underlying levels of dynamics (see below for more details) and therefore one should use rather the "wave-like" relation between the state-function and measured "density", but these technical details do not influence the main conclusions about complex system dynamics.

(each with its normal complete set of $N_{Q\xi}$ eigen-solutions), and an additional, "incomplete" set of N_ξ eigen-solutions is added to that redundant number of $N_{\Re}N_{Q\xi}$ eigen-solutions. As we shall specify below, this incomplete eigen-solution set forms a special, transient system realisation with the vanishing EP magnitude. Other estimates of the number of solutions, using geometric, model, and simple physical considerations [27,29,30,40,46,47], give the same result and confirm that the revealed redundant realisations are equally real (not spurious) and have generally similar origin and structure.

This conclusion is confirmed by observation of the chaotic change of states in various many-body systems and interaction processes, without a really consistent explanation for it within the standard, dynamically single-valued, or *unitary*, theory.[2] Therefore, based on the rigorously obtained multivaluedness of unreduced many-body problem solution, we can state that its **general, now *really complete* solution**, can be expressed, in terms of observable generalised density $\rho(\xi,Q)$, as the *causally probabilistic sum* of individual realisation densities, $\rho_r(\xi,Q)=\left|\Psi_r(\xi,Q)\right|^2$ (with $\Psi_r(\xi,Q)$ from (13)-(14)), numbered by index *r* here and below:

$$\rho(\xi,Q)=\sum_{r=1}^{N_{\Re}}{}^{\oplus}\,\rho_r(\xi,Q)\,, \tag{16}$$

where $N_{\Re}$ $(=N_\xi=N)$ is the total number of system realisations, and the sign $\oplus$ serves to designate the special, *causally random* meaning of summation. The nontrivial origin of the latter, which has no correct analogy in the unitary theory, involves the *unceasing*, explicit change of system realisations, occurring in *truly random* (rigorously unpredictable and noncomputable) order and driven exclusively by the main, initially totally *deterministic* interaction between system components, the *same* one that shapes the details of each emerging realisation configuration (functions $\{\rho_r(\xi,Q)\}$).

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[2] The dynamically single-valued, or *unitary*, models used, in particular, in scholar versions of the "science of complexity" try to *imitate* system realisation plurality by various artificial constructions, such as "attractors", in *abstract*, mathematical "spaces", but those illusive structures are always "produced" by the *single* available system state and trajectory, i.e. without any real change of system configuration in the real space. As a result, various imitative structures of the unitary "complexity science" represent at best only extremely limited, one- or zero-dimensional (point-like) projections of real, dynamic multivaluedness [29-31,39]. This difference between the unreduced dynamic multivaluedness and its unitary imitations is especially important in such explicit complexity manifestations as intelligence and consciousness, whose very essence is given by the detailed, fractally structured system configurations (see below) and their permanent change, rather than a smooth "trajectory" of a system with a fixed or "adiabatically" evolving configuration in the unitary theory.

We obtain thus the universal definition of *event* of realisation emergence (and change) and discover that *all* events occur in a *truly random, causally probabilistic* way. Correspondingly, we can provide the **definition and value of *purely dynamic, a priori probability***, α_r, of the event of each r-th elementary realisation emergence:

$$\alpha_r = \frac{1}{N_{\Re}} \quad (r = 1,\ldots,N_{\Re}) , \qquad \sum_{r=1}^{N_{\Re}} \alpha_r = 1 . \tag{17a}$$

As in many practical cases such elementary system realisations are grouped into actually observed compound realisations, the dynamic probability expression takes, in general, the following form:

$$\alpha_r(N_r) = \frac{N_r}{N_{\Re}} \left(N_r = 1,\ldots,N_{\Re}; \sum_r N_r = N_{\Re} \right) , \ \sum_r \alpha_r = 1 , \tag{17b}$$

where N_r is the number of "elementary" realisations in the r-th compound (actually observed) realisation.

The qualitatively new, causally complete probability definition thus derived, eqs. (17), does not depend on the number of observed events or even any event observation at all: contrary to any conventional probability version, it remains valid even for a single expected event or any their "statistically small" number. However, if the number of observed events does become statistically large, we can correctly define the *expectation (average) value* of the observed quantity:

$$\rho_{\exp}(\xi,Q) = \sum_{r=1}^{N_{\Re}} \alpha_r \rho_r(\xi,Q) . \tag{18}$$

The internal structure of realisation change process can be better seen if we rewrite in full detail the expressions for the unreduced EP and state-function, eqs. (12) and (14), for a given, r-th realisation:

$$\begin{aligned} V_{\text{eff}}\left(\xi;\eta_i^r\right)\psi_{0i}^r(\xi) &= V_{00}(\xi)\psi_{0i}^r(\xi) + \\ &+ \sum_{n,i'} \frac{V_{0n}(\xi)\psi_{ni'}^0(\xi) \int_{\Omega_\xi} d\xi' \psi_{ni'}^{0*}(\xi') V_{n0}(\xi') \psi_{0i}^r(\xi')}{\eta_i^r - \eta_{ni'}^0 - \varepsilon_{n0}} , \end{aligned} \tag{19}$$

$$\rho_r(\xi,Q) = \left|\Psi_r(\xi,Q)\right|^2 ,$$

$$\Psi_r(\xi,Q)=\sum_i c_i^r\left[\Phi_0(Q)+\sum_n \Phi_n(Q)\hat{g}_{ni}^r(\xi)\right]\psi_{0i}^r(\xi)\ , \tag{20a}$$

$$\psi_{ni}^r(\xi)=\hat{g}_{ni}^r(\xi)\psi_{0i}^r(\xi)=\int_{\Omega_\xi} d\xi' g_{ni}^r(\xi,\xi')\psi_{0i}^r(\xi')\ , \tag{20b}$$

$$g_{ni}(\xi,\xi')=\sum_{i'}\frac{\psi_{ni'}^0(\xi)V_{n0}(\xi')\psi_{ni'}^{0*}(\xi')}{\eta_i^r-\eta_{ni'}^0-\varepsilon_{n0}}\ . \tag{20c}$$

As can be seen from eqs. (19)-(20), the same resonant denominator structure that gives the unreduced EP multivaluedness, eq. (19), explains the structure of each realisation, eq. (20), which tends to concentrate around a particular location, given by the corresponding eigenvalue η_i^r (it can be conveniently marked as η_r^r), also due to the "cutting" action of integrals in the numerator. The system in each particular realisation as if "digs" a dynamic potential pit for itself, where it temporarily falls, until the well and related system localisation disappear in favour of a transient delocalisation in a specific "intermediate" state called also the "main" realisation and common for all "regular", localised realisations, before falling into the next "regular", compact realisation with another, randomly chosen centre of localisation, and so on. This unceasing realisation change and related qualitative change of system configuration and properties, forming the universal basis for any real, *dynamically multivalued (chaotic) structure formation*, results from the intrinsic and *permanently* present *dynamic instability* of a real system interaction process, revealed explicitly by the unreduced EP formalism in the form of nonlinear feedback loops (self-consistent EP dependence on the eigen-solutions to be found) and absent in any perturbative, "exact" solutions obtained just by cutting those essential links (they also remain "hidden" in any straightforward problem formulation, such as eqs. (1), (2), (5), (8), and (9)).

As to the mentioned specific, delocalised system realisation, it corresponds to the "incomplete" set of eigenvalues revealed above in the analysis of the total number of eigenvalues, eq. (15), and can be explicitly obtained from the effective existence equation, eq. (10), as a particular solution for which, contrary to all other solutions, the EP magnitude is indeed close to its weak-interaction, separable value, $V_{\text{eff}}^0(\xi;\eta_i^0)\simeq V_{00}(\xi)$. Therefore, this "main" realisation is the origin and direct analogue, within the unreduced,

dynamically multivalued description, of the single realisation remaining in the usual, dynamically single-valued theory, where it realises the averaged, "statistical" projection of the multivalued, permanently changing dynamics to the limited, zero-dimensional space of a unitary "model". The specific role of the intermediate realisation in the multivalued system dynamics outlined above corresponds to its properties of the ***generalised wavefunction*, or *distribution function***, with its causally explained chaotic structure [30-34,40-45]. It takes the form of ordinary quantum-mechanical wavefunction at the lowest, quantum levels of world complexity (now causally understood without any inexplicable "mysteries"), but is defined also for any other complexity level, where it can be closer to the quantum wavefunction properties for "wave-like" complexity levels (e.g. unconscious brain dynamics, see below) or closer to the (extended) classical "distribution function" for "particle-like" complexity levels (with permanently localised interacting entities).

The mentioned dynamical link between the delocalised wavefunction state and regular, localised system realisations takes the form of *generalised Born probability rule*, expressing a regular realisation probability α_r, causally defined in eqs. (17), through the wavefunction value for the corresponding system location (configuration) $x_r = \eta_r^r$ [27,30-34,40-43]. The probability rule has a transparent physical meaning in the multivalued dynamics picture, since it asserts that the probability of wavefunction "reduction" (dynamical squeeze) to a regular realisation state is proportional to the wavefunction magnitude around that particular realisation (and vice versa). In view of the permanent probabilistic transformation between the wavefunction and regular realisations, one could not imagine anything else. One can derive the probability rule in a mathematically rigorous way by invoking the state-function matching conditions that should be used for evaluation of the coefficients c_i^r in the general solution expression of eqs. (13)-(14) or (20) (as noted after eqs. (14)). The state of wavefunction represents just that "dynamical border" of "quasi-free" system configuration, where the effective interaction is transiently "disabled" and the system "automatically" matches "itself to itself", but in a different state, i.e. it follows a "dynamic reconstruction" procedure (always driven by the same, major interaction). Therefore matching the state-function of eq. (20) in its "wavefunctional" phase to the corresponding "reduced" phase of a regular realisation (averaged over the internal degrees of freedom, unimportant here), we can see that the *r*-th realisation

probability, $\alpha_r = \alpha(x_r) = \alpha(x)$, is given by both the squared modulus of c_i^r (properly averaged over *i*) and squared modulus of the wavefunction $\Psi(x)$:

$$\alpha_r = \alpha(x_r) = \alpha(x) = |\Psi(x)|^2 , \tag{21}$$

with the detailed definition of emerging space coordinates $x_r = \eta_r^r$ given below. Note that in this form the probability rule is directly applicable to the "wave-like" levels of complexity (such as those of quantum behaviour and "subconscious" brain dynamics), whereas for levels with the dominating particle-like ("generalised classical") behaviour one should use the generalised wavefunction, or distribution function, itself instead of its squared modulus.

The rigorously expressed ***notion and quantity of dynamic complexity*** as such can be *universally* defined now in terms of the above unreduced interaction analysis as any growing function of the total (or observable) number of system realisations, or related rate of their change, equal to zero for (actually unreal) case of only one realisation [27-35,40-44,46]:

$$C = C(N_{\Re}), \quad \frac{dC}{dN_{\Re}} > 0, \quad C(1) = 0 , \tag{22}$$

where C is a quantitative complexity measure and $C(N_{\Re})$ is an arbitrary smooth function with the designated properties. An *integral complexity measure* is given e.g. by the popular logarithmic expression, $C = C_0 \ln(N_{\Re})$, which properly reflects the hierarchical structure of complexity, but acquires its true meaning and usefulness only in combination with the universally nonperturbative analysis of the underlying interaction process that specifies relevant system realisations. Various *differential complexity measures* appear as rates of unceasing realisation change (temporal or spatial), taking the form of familiar quantities, such as mass, energy, or momentum, but now provided with a quite new, causally complete and universal meaning (see below). It is evident from the above picture that the unreduced, dynamically multivalued complexity basis thus defined includes also the ***unified notion of omnipresent chaoticity***, although the actually observed, *apparent* degree of *randomness/irregularity* may vary depending on the regime of complex dynamics (with the unreduced, internal chaoticity *always* staying there and being proportional to the unreduced complexity-entropy, see also below).

Note that, according to the definition of eq. (22), the unreduced, genuine dynamic complexity of any dynamically single-valued "model" from usual theory (including all standard versions of "complexity science") is strictly

zero, with the single realisation of this unitary projection being usually close to the "averaged" structure of the main realisation (or generalised wavefunction) of the unreduced picture. However, that zero-dimensional projection of the unitary theory may have a structure, and various really observed or arbitrarily postulated, often purely abstract elements of that point-like structure are often substituted for real system realisations, existing in real space, after which a non-zero (but absolutely incorrect) value of complexity is readily obtained by formal application of the same expressions (e.g. the above logarithmic complexity measure). In addition, the notion of complexity is inevitably confused, within the unitary framework, with various "similar" notions, such as "information", "entropy" and "chaoticity" (see refs. [30-34] and below for more details).

The basic structure of realisation change process involves also the phenomenon of *dynamic entanglement* of interacting system components, which is inextricably related to the main feature of dynamic multivaluedness of the unreduced system dynamics and expressed formally by the dynamically involved products of functions of ξ and Q in the state-function expressions, eqs. (13), (20). Dynamic entanglement specifies the abstract property of "nonseparability" of the unitary theory: any real system is "nonseparable" because the degrees of freedom of interacting components are physically, dynamically "entangled" with each other ("woven") into a permanently changing complex-dynamical texture. Therefore the whole interaction process and its results can be described as *dynamically multivalued entanglement* of interacting entities, where the emerging entanglement of system components constitutes each "regular" realisation, while during realisation change the components first transiently disentangle, forming the quasi-free state of generalised wavefunction, and then entangle again in a new regular realisation. In that way one obtains the real, physically tangible and permanently internally changing "tissue of reality", constituting the "flesh" of any real system or structure, while in the unitary theory the latter is replaced by its abstract, illusive and "immaterial" envelope of "separated variables", constituting the essence of all imitative, "exact" solutions and "integrable" models. As we shall see below, the dynamic entanglement feature of the unreduced interaction dynamics is crucially important for causal understanding of the emergent properties of genuine intelligence and consciousness.

The dynamic entanglement and physical nonseparability of real system structure have also the important dimension of *dynamically multivalued (probabilistic) fractal* [27-35], playing essential role in intelligent system dynamics. Indeed, the unreduced problem solution, eqs. (10)-(20), contains explicitly only one level of system splitting into incompatible and permanently changing realisations, while it refers also to unknown solutions of the "auxiliary" system of equations, eqs. (12). In principle, after having revealed the major nonperturbative effect of dynamic multivaluedness, we have some freedom to use an approximate solution for this, auxiliary system and obtain its eigen-solutions $\{\psi_{ni}^0(\xi),\eta_{ni}^0\}$ entering the main formulas (eqs. (11), (13)-(14), (19), (20)) from a reduced, "integrable" version of eqs. (12), such as

$$\left[h_0(\xi)+V_{nn}(\xi)+\tilde{V}_n(\xi)\right]\psi_n(\xi)=\eta_n\psi_n(\xi), \tag{23a}$$

where the ordinary, single-valued potential $\tilde{V}_n(\xi)$ may vary within some more or less evident borders:

$$0\le\left|\tilde{V}_n(\xi)\right|<\left|\sum_{n'}V_{nn'}(\xi)\right|. \tag{23b}$$

In this case we limit our attention to the first, main level of multivalued dynamics and ignore its further development hidden in the unreduced solution of the auxiliary system of equations. If, however, we want to continue the study of the real, non-simplified system dynamics, we can avoid the above approximation and apply the same EP method to solution of eqs. (12).

Separating explicitly the equation for $\psi_n(\xi)$ in eqs. (12), we rewrite the auxiliary system in the form analogous to eqs. (8) for the main system:

$$\left[h_0(\xi)+V_{nn}(\xi)\right]\psi_n(\xi)+\sum_{n'\neq n}V_{nn'}(\xi)\psi_{n'}(\xi)=\eta_n\psi_n(\xi)\ , \tag{24a}$$

$$\left[h_0(\xi)+V_{n'n'}(\xi)\right]\psi_{n'}(\xi)+\sum_{n''\neq n,n'}V_{n'n''}(\xi)\psi_{n''}(\xi)=\eta_{n'}\psi_{n'}(\xi)-V_{n'n}(\xi)\psi_n(\xi),$$

$$n'\neq n\,. \tag{24b}$$

Expressing now $\psi_{n'}(\xi)$ through $\psi_n(\xi)$ from eqs. (24b) with the help of the Green's function for its truncated, homogeneous part and inserting the result into eq. (24a), we arrive at the effective formulation for the auxiliary system of equations taking now an "integrable" configuration similar to eq. (10):

$$\left[h_0(\xi)+V_{\text{eff}}^n(\xi;\eta)\right]\psi_n(\xi)=\eta_n\psi_n(\xi), \tag{25}$$

where

$$V^{n}_{\text{eff}}\left(\xi;\eta\right)=V_{nn}\left(\xi\right)+\hat{V}_{n}\left(\xi;\eta\right),\ \hat{V}_{n}\left(\xi;\eta\right)\psi_{n}\left(\xi\right)=\int\limits_{\Omega_{\xi}}d\xi' V_{n}\left(\xi,\xi';\eta\right)\psi_{n}\left(\xi'\right),$$

(26a)

$$V_{n}\left(\xi,\xi';\eta\right)=\sum_{i,n'\neq n}\frac{V_{nn'}\left(\xi\right)\psi^{0n}_{n'i}\left(\xi\right)V_{n'n}\left(\xi'\right)\psi^{0n*}_{n'i}\left(\xi'\right)}{\eta_{n}-\eta^{0n}_{n'i}+\varepsilon_{n0}-\varepsilon_{n'0}}\ , \tag{26b}$$

and $\{\psi^{0n}_{n'i}(\xi),\eta^{0n}_{n'i}\}$ are the eigen-solutions of a yet more truncated auxiliary system of the next level:

$$\left[h_{0}\left(\xi\right)+V_{n'n'}\left(\xi\right)\right]\psi_{n'}\left(\xi\right)+\sum_{n''\neq n}V_{n'n''}\left(\xi\right)\psi_{n''}\left(\xi\right)=\eta_{n'}\psi_{n'}\left(\xi\right)\ ,\ n'\neq n\,. \tag{27}$$

We can obviously continue this process, obtaining each time ever more truncated system of auxiliary equations, until we remain with only one equation for a single mode, which is solved explicitly and terminates the real process of dynamical fractal formation.

It is important that at each level of the fractal hierarchy we have the same phenomenon of dynamically multivalued entanglement generated by the same dynamically nonlinear feedback mechanism as the one revealed above for the main level of splitting and described now by the unreduced EP formalism of eqs. (23)-(24). This means that, contrary to usual, dynamically single-valued fractals (including their artificially "stochastic" versions), each level of the unreduced fractal hierarchy contains *permanent change* of realisations in *dynamically random* order [27-35]. As a result, such real fractal becomes a permanently, *coherently* moving and *adaptively* developing, "living" arborescent structure representing the ***really complete solution of the many-body problem in its full complexity***. It can be expressed as a "multilevel" causally probabilistic sum (cf. eq. (16)):

$$\rho\left(\xi,Q\right)=\sum_{j=1}^{N_{\text{f}}}\sum_{r=1}^{N_{\Re j}}{}^{\oplus}\rho_{jr}\left(\xi,Q\right)\ , \tag{28}$$

where $\rho_{jr}(\xi,Q)$ is the measured quantity for the *r*-th realisation at the *j*-th level of dynamic fractality, $N_{\Re j}$ is the number of realisations at the *j*-th level, and N_{f} is the final or desired level number. This expression is accompanied by the corresponding dynamic definitions of probability and expectation values for each level of fractal hierarchy, analogous to eqs. (17), (18).

The dynamic entanglement at each level of fractality endows the unreduced fractal structure with "flesh and blood" specific for the given system

and determining the perceived detailed *"quality"*, or *texture*, of system structure, now in its full version. The latter is related to the problem *nonseparability*, acquiring a transparent *physical* meaning (it is impossible to separate *fractally* entangled components forming *unstable, permanently irreversibly changing* realisations) and underlying the *real* system *existence* itself.[3]

It is clear that due to the hierarchy of levels of dynamical splitting the total number of system realisations is exponentially large (where already the argument of the exponential function will be a large number for any real multi-component system), which determines the huge dynamic efficiency of the unreduced dynamic fractality, playing the key role in various applications, including intelligence dynamics (see below). On the other hand, and this is another side of "living" structure efficiency, the probabilistic dynamical fractal always preserves its *integrity (wholeness)* and forms and changes as an *intrinsically unified* configuration of the entire interaction process.

Since the real-world structures at any scale result from interaction process development, it becomes clear that the entire universe, or any its part, can be considered as the single, dynamically unified, probabilistic fractal structure, where the emerging more solid branches of a certain level correspond to interacting objects, whereas the finely structured fractal "foliage" around them constitutes the well-specified, *material* content of their interaction (potential). Therefore, unlike the simplified symmetry of usual fractals (scale invariance) and its limited number of prototype real objects, the unreduced dynamical fractal represents the *exact* structure and dynamics of *any* kind of object and can show approximate scale invariance only within a limited range of scales. However, the huge diversity of possible dynamic regimes within the world fractal hierarchy can be *universally classified* as variation between two limiting cases, designated as *uniform, or global, chaos* and *dynamically multivalued self-organisation*, *or self-organised criticality (SOC)*.

To demonstrate the origin of both regimes, we note that in the limit of small eigenvalue separation (frequency) for the structure-dependent, or "external", degrees of freedom (ξ) with respect to those for the element-dependent (internal) degrees of freedom (Q), $\Delta\eta_i \ll \Delta\eta_n \sim \Delta\varepsilon$, or $\omega_\xi \ll \omega_Q$ (where $\Delta\eta_i$ and $\Delta\eta_n$ are the eigenvalue separations with respect to i and n in eq.

[3] It shows, in particular, that all basically separable, "exact" solutions and dynamically single-valued models and concepts of unitary science can *never* describe the real system as it is, in its *essential*, major *quality*, providing instead just a zero-dimensional, point-like version of external, "immaterial", abstract system shape.

(11b), while ω_ξ and ω_Q are respective frequencies), the summation over *i* in the general EP expression, eq. (11b), can be performed independently in the numerator, giving a local and single-valued EP limit [27,31,33]:

$$V\left(\xi,\xi';\eta\right)=\delta\left(\xi\text{-}\xi'\right)\sum_n \frac{\left|V_{0n}\left(\xi\right)\right|^2}{\eta-\eta_{ni}^0-\varepsilon_{n0}}\ ,$$
$$V_{\text{eff}}\left(\xi;\eta\right)=V_{00}\left(\xi\right)+\sum_n \frac{\left|V_{0n}\left(\xi\right)\right|^2}{\eta-\eta_{ni}^0-\varepsilon_{n0}}\ . \qquad (29)$$

Similar results are obtained for the state-function, eqs. (14)-(15) [27,31]. This is the limiting regime of self-organisation, giving a distinct and externally regular system structure. However, it remains only an approximation to reality, and the unreduced EP deviations from the limit of eqs. (29), however small they are, have a *qualitatively strong* character: the real EP and state-function are composed from *many* similar and quickly changing but different realisations, which means that *any* real self-organisation, and the resulting "distinct" structure, has *dynamically multivalued*, internally *chaotic*, *fractal* character and *permanently* (and randomly) fluctuates, in a range of scales, around the observed average shape, thus *comprising* and *extending* the phenomenon of *self-organised criticality (SOC)*, which otherwise suffers, in its standard version, from conflicts with chaoticity and separation from other self-organisation cases [30,31]. The internal chaotic realisation change within an externally regular structure constitutes, despite its "hidden" character, the true basis of that structure emergence and existence, without which it loses any realistic meaning (including its *proper time flow*, which is a persisting difficulty of unitary theory). This limiting case also unifies the extended versions of all other unitary imitations of dynamically multivalued SOC, such as "control of chaos", "synchronisation", "phase locking", etc., remaining separated and incomplete in their usual versions.

The opposite limiting case of *uniform, or global, chaos*, is realised when the above characteristic system frequencies (or eigenvalue separations) are close to each other, $\Delta\eta_i \simeq \Delta\eta_n \sim \Delta\varepsilon$, or $\omega_\xi \simeq \omega_Q$, i.e. the corresponding degrees of freedom fall in resonance. In that case the individual realisation eigen-solutions are so entangled among them that there is no possibility to separate them, even approximately, and the permanent, chaotic realisation change takes its explicit, externally visible form, where *sufficiently different*

realisations change at a not too fast and not too slow rate close to the main system frequencies. One obtains thus the *universally* applicable *criterion of global, strong chaoticity* that coincides with the *condition of resonance* between the main system motions [27-34,42,43,46,47]:

$$\kappa \equiv \frac{\Delta \eta_i}{\Delta \eta_n} = \frac{\omega_\xi}{\omega_Q} \simeq 1 , \qquad (30a)$$

where the parameter of chaoticity κ is introduced by this definition. In that way we also clarify the true meaning of the "familiar" phenomenon of resonance, remaining hidden in its conventional, perturbative description.

As shown above, the opposite condition,

$$\kappa \ll 1 \qquad (30b)$$

(as well as $\kappa \gg 1$), provides the universal criterion of occurrence of (multivalued) SOC kind of dynamics and external regularity. Note that at $\kappa \gg 1$ one obtains just another kind of chaotic mode enslavement within an externally regular shape (or multivalued SOC), which is "complementary" with respect to that obtained at $\kappa \ll 1$, and usually only one of them is of real interest within each particular problem.

Universality of the criteria of eqs. (30) is especially important for the unreduced complexity science, since it provides the simple and **unified *principle of classification* of *all* possible kinds of real-world dynamics**, unimaginable in usual theory. It implies that system behaviour can vary between those too extreme cases of "global regularity" and "global chaos", depending on the value of chaoticity parameter κ. These statements are confirmed by the independent analysis of the particular case of quantum chaos [46], where the corresponding parameter of transition to global chaos, K, is directly related to κ, $K = \kappa^2$. The conceptual and technical transparency of the proposed criteria of chaos and regularity is to be compared with its unitary imitations, containing incorrect statements and technical trickery. We see that the genuine complexity of unreduced, multivalued dynamics underlies the unified simplicity of the key criteria and related harmony of the general picture, whereas the illusive simplicity of dynamically single-valued, perturbative "models" leads to technical and conceptual uncertainty, leaving no hope for universally applicable, realistic understanding. In particular, the above limiting regimes of complex dynamics, as well as their universal meaning and relation, are indispensable for understanding of the emerging phenomena of intelligence and consciousness and respective applications (see below).

The purely dynamic world emergence in the unreduced interaction process of existence equations (1), (2), or (9) brings us to the ***dynamic origin of space and time hierarchy***, obtained within the unreduced problem solution. Indeed, the "spontaneous" (dynamic) structure emergence, in the form of system "concentration" around each of its permanently changing realisations, *consistently derived* by the unreduced EP formalism, should be considered as *real, physical* space structure emergence at the corresponding "level of complexity". The generalised "space point" of each complexity level is provided by the emerging realisation structure at the moment of its maximum dynamical squeeze (before system transition to the next realisation), given by eqs. (19)-(20), with the centre of this "point structure" being designated by the corresponding eigenvalue, η_r^r (as discussed after eqs. (19), (20)). The characteristic size, r_0, of this real space element is given by the eigenvalue separation, $\Delta\eta_n$, with respect to the (suitably ordered) "internal" degrees of freedom (Q), within one realisation: $r_0 \simeq \Delta\eta_n$ [27-35,42-44]. A yet more important space dimension, the elementary distance (length element, or characteristic wavelength), $\Delta x = \lambda$, emerges in the form of eigenvalue separation with respect to "external" degrees of freedom (ξ), i.e. between neighbouring realisations: $\Delta x \simeq \Delta\eta_i \simeq \Delta\eta_r^r$. This is the spatial measure, or "size", of a single system jump between its successive realisations.

The dynamically emerging *time element* measures the *intensity*, actually given by *frequency*, ν, of realisation change, which is inversely proportional to the direct time "distance" (or *period*), $\Delta t = \tau = 1/\nu$, between two successive *events* of realisation emergence, thus universally specified by the unreduced EP formalism. It can be estimated as $\Delta t = \Delta x/c$ (where c is the speed of signal propagation in the initial, "structureless" system material). In other words, the time element provides the dynamically emerging duration of system jump between its two successive realisations.

Note that the space structure thus derived is intrinsically *discrete* (eventually due to the *wholeness* of unreduced interaction dynamics [30,31]), while time is fundamentally *irreversible* (because of the *causal unpredictability* of each next realisation choice) and *unceasingly flowing* (due to the same *dynamic multivaluedness*, driven by the main interaction process itself and thus unstoppable, if the system preserves its existence as such).

Because of the above dynamically fractal structure of any system and the hierarchy of complexity in the whole, the emergent space and time have

the same hierarchic, fractal structure, with the well specified dynamical links between successive levels (branches) of the dynamical fractal. The lowest, most fundamental level of space and time is provided by the interaction between two primordial, initially homogeneous and physically real protofields (see eq. (9)), which gives rise to (dynamically emerging) elementary particles and their interactions [27,30,31,40-45]. Here r_0 is equal to the intrinsic particle size, such as the "classical radius of the electron", $\Delta x = \lambda = \lambda_C$ is the (generalised) Compton wavelength, and $\Delta t = \tau = h/m_0c^2$ is the internal *quantum beat* period of the particle (where *h* is Planck's constant, m_0 is the particle rest mass, and *c* is the speed of light).

Whereas the space and time elements at each level are *dynamically* related among them, they are also qualitatively different from each other by their origin and role: space determines the *tangible*, "material" system structure, texture, or *specific "quality"* (including the above *dynamically entangled* structure of each regular realisation forming the space element), while time has an *immaterial* nature (as opposed to its incorrect formal "mixture" with space in the unitary science framework) and characterises the *intensity* of unceasing and irreversible *change* of the material space structure.

It follows that space and time thus universally defined by the unreduced interaction dynamics constitute two major, universal *forms of complexity* that can take a variety of different shapes in particular systems at various complexity levels. Space and time are directly made by the successively emerging and changing realisations of any real system, and therefore one can say that these two basic complexity forms and their dynamic relation determine everything in the world structure. By contrast, various *measures of complexity* introduced above (starting from eqs. (22)) are suitable functions of realisation number or rate of change and thus of space and time, which provides the fundamental, *dynamically specified* origin of the very *notion of function*, usually considered in its abstract, mathematical meaning. Since the simplest possible combination of space and time, independently proportional to both space and time elements, is given by *action*, we arrive at the *extended interpretation of action* as a universal, integral *measure of unreduced dynamic complexity*, incorporating its *essentially nonlinear* origin and entangled internal structure:

$$\Delta\mathcal{A} = -E\Delta t + p\Delta x \ , \tag{31}$$

where p and $-E$ are initially just coefficients relating the dynamically

determined increments of space Δx and time Δt to the increment of action $\Delta\mathcal{A}$. The analogy with the well-known relations from classical mechanics (where our *universal* description should remain valid) immediately shows, however, that *p* and *E* can be identified with the system *momentum* and *(total) energy*, now in their extended versions of *differential complexity measures*:

$$E = -\frac{\Delta\mathcal{A}}{\Delta t}\Big|_{x=\text{const}} \simeq \frac{\mathcal{A}_0}{\tau}\ , \tag{32}$$

$$p = \frac{\Delta\mathcal{A}}{\Delta x}\Big|_{t=\text{const}} \simeq \frac{\mathcal{A}_0}{\lambda}\ , \tag{33}$$

where $\mathcal{A}_0$ is the magnitude of the characteristic increment (and value) of action for a given system and complexity level.

The discrete increment of action-complexity (equal to Planck's constant with the negative sign, $-h$, at the lowest, quantum complexity level [27,30,31,40-45]) describes an elementary, indivisible step of system complexity "development" as its structure emerges in the driving interaction process. Appearing structural elements start interacting among them through the fractal web of interaction links, giving rise to higher-order and eventually higher-level structures. Every real change in this hierarchy of creation corresponds to a *negative* increment, or *decrease*, of action-complexity, or *dynamic information* ($\Delta\mathcal{A} < 0$), whereas another universal complexity measure, *generalised dynamic entropy S*, simultaneously *increases* by the amount lost by action, so that their sum, the *total system complexity C*, remains constant during (closed) system evolution [27-35,42-44]:

$$C = \mathcal{A} + S = \text{const}, \tag{34a}$$

$$\Delta S = -\Delta\mathcal{A} > 0\ . \tag{34b}$$

This *universal law of conservation, or symmetry, of complexity*, determining evolution and existence of *any* system, from elementary particle to the universe and conscious brain, has a transparent physical meaning, where action-complexity describes available stock of "potential", latent form of initial interaction complexity (generalised, integral version of "potential energy") that is transformed, by system evolution during interaction development, to the explicit, final form of fully developed system structure and dynamics represented by complexity-entropy (generalised, integral version of "kinetic" and "heat" energy). Entropy, as a measure of chaoticity, can only grow, due

to the fundamental dynamic uncertainty at every single step revealed above, but this is possible only at the expense of equally decreasing action-complexity that provides the universal "motivation" for the dynamic structure (entropy) creation. Because of such role of action-complexity, it is also called dynamic information and provides thus the correct, complex-dynamic extension of the notion of information (incorrectly replacing entropy in usual theory). In that way, the universal science of complexity considerably extends and puts in order various reduced, often erroneous ideas of unitary science about complexity, entropy, information and relations between them [30-34].

Now, in order to find the universal *dynamic* expression of the symmetry of complexity, we can divide the differential form of complexity conservation law, eq. (34b), by $\Delta t|_{x=\text{const}}$ to obtain the *generalised Hamilton-Jacobi equation* [27-35,42-44]:

$$\frac{\Delta\mathcal{A}}{\Delta t}|_{x=\text{const}} + H\left(x, \frac{\Delta\mathcal{A}}{\Delta x}|_{t=\text{const}}, t\right) = 0 \ , \tag{35a}$$

where the *Hamiltonian*, $H = H(x,p,t)$, expresses a differential measure of the explicit, entropic complexity form, $H = (\Delta S/\Delta t)|_{x=\text{const}}$, and one deals with the *dynamically discrete* versions of partial derivatives giving energy and momentum, eqs. (32), (33). Expanding the Hamiltonian dependence on momentum in a power series,

$$H(x,p,t) = \sum_{n=0}^{\infty} h_n(x,t)\, p^n \ ,$$

where the expansion coefficients, $h_n(x,t)$, can be, in principle, arbitrary functions, we obtain the universal Hamilton-Jacobi equation in the form

$$\frac{\Delta\mathcal{A}}{\Delta t}|_{x=\text{const}} + \sum_{n=0}^{\infty} h_n(x,t)\left(\frac{\Delta\mathcal{A}}{\Delta x}|_{t=\text{const}}\right)^n = 0 \ , \tag{35b}$$

where its coincidence with many particular dynamic equations for various $h_n(x,t)$ and series truncations becomes evident, especially if we rewrite it in terms of usual, continuous-limit symbols for partial derivatives:

$$\frac{\partial\mathcal{A}}{\partial t} + \sum_{n} h_n(x,t)\left(\frac{\partial\mathcal{A}}{\partial x}\right)^n = 0 \ . \tag{35c}$$

Note that functions $h_n(x,t)$ here can depend on $\mathcal{A}$, either through "potential energy" in the Hamiltonian or due to the EP dependence on the solutions to be found in the effective formalism (see eqs. (11)-(14), (19)-(20)).

The unreduced, dynamically multivalued system evolution contains also phases of transition between realisations through the extended state of "generalised wavefunction" (or intermediate realisation), where the above expression in terms of action, reflecting the regular, "condensed" realisation quality, becomes inexact. The wavefunction state can be properly taken into account if we note that transitions between regular and intermediate realisations can also be considered as system structure development by transitions between neighbouring complexity sublevels, where the total complexity C, expressed by the product of complexity-entropy (regular realisations) and *wavefunction* Ψ itself, should remain constant, $C = S\Psi = \text{const}$, meaning also that $\mathcal{A}\Psi = -S\Psi = \text{const}$. Therefore $\Delta(\mathcal{A}\Psi) = 0$ during one cycle of realisation change, which expresses the obvious condition of structural permanence of the *unique* intermediate realisation and leads to the following *universal* and *dynamically derived (causal) quantisation rule* [27,30-34,41-45]:

$$\Delta\mathcal{A} = -\mathcal{A}_0 \frac{\Delta\Psi}{\Psi} \ , \tag{36}$$

where $\mathcal{A}_0$ is a characteristic action value that may also contain a numerical constant reflecting specific features of a given complexity level. We see that the relation between action and wavefunction, which takes the form of standard (Dirac) quantisation rules at the lowest (quantum) levels of complexity, can now be causally explained (contrary to "mysterious" postulates in the standard quantum theory) as expression of physically real realisation change dynamics and thus extended to any complexity level.

Substituting the obtained action expression through the wavefunction, eq. (36), into the generalised Hamilton-Jacobi equation, we get the respective forms of *generalised Schrödinger equation* [27,30-34,41-45]:

$$\mathcal{A}_0 \frac{\Delta\Psi}{\Delta t}\Big|_{x=\text{const}} = \hat{H}\left(x, \frac{\Delta}{\Delta x}\Big|_{t=\text{const}}, t \right)\Psi(x,t) \ , \tag{37a}$$

$$\mathcal{A}_0 \frac{\Delta\Psi}{\Delta t}\Big|_{x=\text{const}} = \sum_{n=0}^{\infty} h_n(x,t)\left(\frac{\Delta}{\Delta x}\Big|_{t=\text{const}} \right)^n \Psi(x,t) \ , \tag{37b}$$

$$\mathcal{A}_0 \frac{\partial\Psi}{\partial t} = \sum_{n=0}^{\infty} h_n(x,t) \frac{\partial^n\Psi}{\partial x^n} \ , \tag{37c}$$

where the operator form of Hamiltonian, $\hat{H}$, is obtained from its functional form of eq. (35a) with the help of the causal quantisation rule of eq. (36). If

the Hamiltonian does not depend explicitly on time, we obtain the time-independent form of the universal Schrödinger equation:

$$\hat{H}\left(x, \frac{\Delta}{\Delta x}|_{t=\text{const}} \right)\Psi(x) = E\Psi(x) \,, \tag{37d}$$

where E is the (constant) energy value. Note that the generalised Schrödinger formalism thus causally derived by the unreduced interaction analysis is especially useful in description of genuine intelligence and consciousness dynamics (see below).

The universal Hamilton-Jacobi and Schrödinger equations dynamically related by the causal quantisation condition, eq. (36), and generalised Born probability rule, eq. (21), constitute together the causally complete, *universal Hamilton-Schrödinger formalism*, eqs. (21), (35)-(37), generalising *all* (correct) dynamic equations for particular systems [27,30-34,43]. The *unrestricted universality* of this description is *indispensable* for understanding of brain (intelligence) dynamics, since the latter obviously "reproduces" and thus encompasses *any* behaviour it can practically apprehend. Note that the explicitly "nonlinear" (in the usual sense) forms of the generalised Hamilton-Jacobi and Schrödinger equations, where functions $h_n(x,t)$ contain various (small) powers of action or wave function to be found, are often postulated in particular applications, but they are rather approximations to respective effective versions of initially formally linear equations, where such *essential, dynamic* nonlinearity appears, as we have seen, as a result of natural interaction loop development (see eqs. (11)-(14), (19)-(20) and the related discussion). Indeed, it is important that the above generalised dynamic equations involve implicitly their *unreduced, dynamically multivalued analysis and solution* within the generalised EP method, constituting the key extension with respect to usual, dynamically single-valued interpretation and solutions. Now we shall analyse manifestations and applications of this universally defined complex behaviour and its description at the level of brain dynamics, including the *emerging* phenomena of intelligence and consciousness.

We begin **application of the above universal complexity concept to the *unreduced intelligence and consciousness* description** by emphasizing once again that the unrestricted *universality* of complexity derivation and concept, applicable to *both* real world dynamics *and* its adequate reflection in *any* "intelligent" system of interacting elements ("generalised neurons"), plays a special, indispensable role in the ensuing theory of intelligence and consciousness, since that exact enough (and apparently unlimited) reflection of real world structure and dynamics is just the main distinctive feature of intelligent system function and behaviour. The latter can be classified with the help of *complexity correspondence principle* [27-34] following in its turn from the above universal symmetry of complexity. This rule provides a rigorously specified expression of a rather evident fact that the full, unrestricted reproduction of a real (complex) behaviour pattern needs at least as much (or in practice even slightly more) complexity of the reproducing system dynamics. Despite its apparent simplicity, this rule has nontrivial practical applications and immediately shows, for example, that *all* directly "quantum" theories of brain function, appearing so readily in recent years and trying to explain it by the dynamics of the lowest, quantum complexity levels (e.g. [10-12,49-60]), are *fundamentally deficient* and therefore *wrong*, irrespective of details, as well as *any unitary*, dynamically single-valued model of consciousness in terms of any system or level of world dynamics (such as many recent "physical" analogies of brain operation [60-67]). Indeed, in those cases the low/zero level of unreduced complexity of the supposed origin of consciousness is far below that of not only conscious, but often *any* real, *multivalued* system dynamics.

Returning to the unreduced interaction process that is at the origin of emerging, universally defined complexity, eqs. (1)-(22), we can now specify that interaction and its results for the case of natural or artificial brain (neural network) dynamics. We define here the generalised brain (intelligence) system as a system with a large enough number of *effectively* rather simple interacting elements (each of them should have at least a few stable enough internal states), which are *massively* connected among them (details are to be specified below), thus realising their strong enough interaction that embraces *the entire system*. Our general existence equation for a system with unreduced interaction, eqs. (1) and (2), includes this case, but it can be further specified for the brain system in the following way, taking into account

explicit dependence on time (mainly due to interaction with the environment):

$$\frac{\partial \Psi}{\partial t} = \left\{ h_0(\xi) + \sum_{k=1}^{N} \left[h_k(q_k) + V_{0k}(\xi, q_k) \right] + \sum_{k=1,\, l>k}^{N} V_{kl}(q_k, q_l) \right\} \Psi(\xi, Q), \quad (38)$$

where the time variable t is suitably added to the independent variables (Q), so that the EP analysis remains practically unchanged (with the proper definition of generalised energies, e.g. in eqs. (3), (6)), including the basic system of equations (5), (8).

Note that eq. (38) generalises various model equations describing neural network dynamics (e.g. [66-68]), but due to its unrestricted universality it implies actually much more than neuron interaction through their direct connection to each other. It involves the most fundamental and indispensable level of *global electro-chemical interaction* within and between natural brain neurons that should also have its analogue in any genuine AI system and should be distinguished from the mere electromagnetic (e/m) interaction transmitted through connections between localised neurons. This latter interaction does always exist in the brain, but it is essentially assisted there by interaction transmission through the biochemical cell connections and system-wide interaction between its two interfaces, the e/m and chemical ones. Recalling the analogy between the driving interaction processes in the brain and at the very first, quantum level of complex-dynamic structure emergence (see eq. (9)), we conclude that the unreduced brain dynamics is determined by the global, brain-wide, but here highly inhomogeneous interaction between the e/m and chemical (physically real) "manifolds" constituted by all neurons and their connections, which is further assisted by individual inter-neuron couplings through both e/m and chemical cell connections [30,31,33]. Emergence of elementary particles and their interactions at much lower, quantum complexity levels are similarly described by interaction between the omnipresent e/m and gravitational protofields [27,30,31, 40-45] (with the evident analogy between more "inert" behaviour of chemical and gravitational components of respective systems), but in that case the initial system configuration is effectively homogeneous, as opposed to the very rugged landscape of initial brain configuration.

It is this general analogy between the driving interaction configurations, as well as universality of the ensuing complex-dynamic structure

formation, that explain a remarkable similarity between the resulting brain and quantum structure behaviour, even though the causally complete origin of dynamic complexity and the related complexity correspondence principle (see above) also show that the microscopic, quantum world dynamics and the brain function dynamics definitely belong to very *different* complexity levels (as opposed to numerous *directly quantum* brain models in the unitary theory [10-12,49-60]). The fact that the much higher level of brain complexity shows striking similarity to quantum system behaviour reflects the universal *holographic, or fractal*, property of the hierarchy of world complexity [30], where any well-defined system part tends to reproduce approximately the dynamical structure of the whole, but with proportionally *smaller* precision (i.e. smaller number of features, or realisations, just determining system complexity, eq. (22)). Since the standard unitary theory and approach *cannot* see that dynamically multivalued fractal hierarchy of permanently changing system structure, it is forced to evoke the single "accepted" but mysterious (unexplained) and *formally postulated* case of that kind of behaviour, i.e. that of a quantum system, in order to account for another, somewhat similar "miracle" of unreduced dynamic complexity, that of intelligent and conscious brain operation (the same extended "quantum" mystification is used by the same unitary science to account for various "miracles of life" and similar manifestations of genuine dynamic complexity in social life, see e.g. [12,60,61,64,69]). However, all the miracles of unreduced complexity, at any quantum and classical (including conscious) levels of world dynamics, including their *essential difference*, obtain their causally complete, i.e. totally realistic, consistent and intrinsically unified, explanation in terms of real, dynamically multivalued and fractal, interaction dynamics [27-35,40-46].

As we have seen above, eqs. (1), (2), (9), (38) are general enough to account for the complicated electro-chemical combination of brain interactions (including interaction with the environment), and in particular, being expressed in terms of system element dynamics, they lead to the same, standard system of equations, eqs. (5) and (8). It would be convenient to consider that the separated degrees of freedom ξ account for the more rigid, "chemical" degrees of freedom, including the initial system structure (i.e. "mechanical"/spatial and related biochemical brain structure on relevant scales), while one/several of the $Q \equiv \{q_i\}$ variables correspond to the "global" (interneuron) e/m patterns, and other variables reflect the internal neuron

excitations. The resulting state-function $\Psi(\xi,Q)$, eqs. (14), (20), (28) (where the explicit time dependence is included in Q variables), represents the entangled electro-chemical dynamical pattern of brain activity, accounting for all its functions. The most complete *general solution for the brain state-function* is provided by the universal, *causally probabilistic* and multi-level sum of eq. (28) over the emerging fractal hierarchy of system realisations, each of them obtained by the unreduced EP formalism, eqs. (10)-(17), (24)-(27) (together with respective values of dynamic realisation probabilities). As follows from the detailed realisation structure, eqs. (19)-(20) (see also [27,30, 33,34,40-43]), the dynamically chaotic realisation change process at each level of dynamic fractality and within the entire probabilistic fractal of brain activity pattern occurs in the form of the *generalised quantum beat* (essentially nonlinear self-oscillation), consisting of unceasing cycles of system *dynamic reduction (squeeze)* to regular, localised realisations it currently takes and the following opposite *dynamic extension* to the delocalised state of the *generalised wavefunction* (intermediate, or main, realisation), where the localised state (regular realisations) involves maximum *dynamic entanglement* of the interacting degrees of freedom (here the e/m and chemical constituents), and the delocalised state of wavefunction is obtained by the opposite *disentanglement* process, transiently liberating the interaction components that perform then the probabilistic choice of the next localised realisation.

If we take into account the *dynamically fractal (multi-level and hierarchically unified) structure* of the quantum beat pulsation and the *generalised, causally derived Born rule* for realisation probabilities, eq. (21), then we obtain a rather complete and unified picture of complex brain dynamics in the form of those unceasing, essentially nonlinear, global and fractally structured cycles of brain activity (as measured by the e/m and chemical component density/flux). Due to its "omnipresent" and permanently changing structure at all scales, the generalised quantum beat solution explains the observed *binding* and *awareness* aspects of intelligence and consciousness, while the fractally structured, detailed distribution of realisation probabilities on every scale according to the dynamic Born rule provides the causal basis for the *meaningful brain operation* and the unreduced, "human" *sense* of the resulting information processing and *understanding*.

In other words, the fractal system of centres of dynamic reduction within every global cycle of quantum beat pulsation is "automatically"

(dynamically) concentrated around currently activated (functionally important) patterns of external (conscious and unconscious) "impressions", their processing, emerging "thoughts" and resulting "ideas". As those patterns change in accord with the "input data" or internal brain dynamics, the fractal structure of each quantum beat cycle automatically adjusts its probability and density distribution to system configuration, ensuring the *intelligent response* and conscious *understanding* (they are thus special, high-complexity cases of the universal *dynamic adaptability* of unreduced complex dynamics, absent in any its unitary imitation [27-34]). In addition, the essentially nonlinear quantum beat of electro-chemical brain activity, with all its internal fractal ramifications, gives rise to the *emerging internal time flow* (as introduced above), thus forming the physically real, universal basis for the perceived "sense of time" (internal clock) of intelligent system, related to but different from the explicit time of eq. (38) originating in external changes.

Although the global quantum beat pulsation and its localised manifestations can be measured in the form of well-known oscillations of the brain e/m activity (see e.g. [1-9]), it is important to emphasize their essential and deep difference from any linear or even formally (but never *dynamically*) "nonlinear" oscillation models of unitary theory. Indeed, the latter will not possess just those essential properties of truly autonomous emergence, flexible fractal "binding" of the entire brain activity and dynamic adaptability, which are especially important for the dynamics of consciousness (see also below). Another essential distinction from existing theories concerns the already mentioned generalised, "indirectly" quantum character of brain dynamics, which has only external, qualitative resemblance to the directly quantum dynamics at the lowest complexity levels and does *not* involve any microscopic quantum coherence on nanometre scales and below (though the *real* similarity between these two well separated levels of dynamics has a rigorous complex-dynamic basis outlined above). Note also that high similarity between quantum (microscopic) and mental levels of complexity is due to the similar, predominantly "wave-like" character of the key entities at both levels (whereas this case is more different from "particle-like" or "classical" behaviour levels, such as that of "Newtonian" systems of permanently localised, rigid bodies). These results provide a *consistent* solution to persisting disputes around various "quantum brain" (and even quantum gravitation) hypotheses [10-12,49-60].

Recalling the universal Schrödinger formalism for the generalised wavefunction, eqs. (37), we find that the wavefunction (intermediate realisation) of complex electro-chemical interaction dynamics in the brain, also designated as the ***brainfunction***, $\Psi(\chi,t)$, satisfies the wave equation of the same kind, accompanied by the causally substantiated Born probability rule, eq. (21), that reflects (together with the causal quantization condition of eq. (36)) the unceasing dynamic collapses of the brainfunction to various regular (localised) brain realisations (constituting mental images, impressions, emotions, thoughts, ideas, etc.):

$$\mathcal{A}_0 \frac{\Delta \Psi}{\Delta t}\Big|_{\chi=\text{const}} = \hat{H}\left(\chi, \frac{\Delta}{\Delta\chi}\Big|_{t=\text{const}}, t\right)\Psi(\chi,t)\,, \tag{39}$$

$$\alpha_r(t) = \alpha(\chi_r,t) = \alpha(\chi,t) = \left|\Psi(\chi,t)\right|^2\,, \tag{40}$$

where χ is the emerging regular realisation configuration, forming the new level of tangible space structure, or causally specified "mental space", made of neuron activities, thoughts and other patterns. The detailed structure of χ is obtained by dynamic entanglement of the interacting degrees of freedom ξ, Q (essentially e/m and bio-chemical ones) according to the unreduced EP formalism, eqs. (10)-(14), (19), (20), (24)-(27). Similar to quantum-mechanical postulates (now causally explained), the measured *dynamic probability*, $\alpha_r(t)$, of a brain activity pattern (*r*-th realisation) emergence is determined by the squared modulus of the brainfunction for that particular pattern, eq. (40), obeying the generalised, dynamically discrete Schrödinger equation, eq. (39). Note that similar to the microscopic quantum mechanics, the Schrödinger equation for the brainfunction does not describe the quantum beat dynamics itself (i.e. system "quantum jumps" between regular realisations), but only the distribution of the probability amplitude (coinciding with the brainfunction density) for the emerging localised patterns (regular realisations): it is the result of the quantum beat process, rather than its origin or development. Correspondingly, the time dependence in eqs. (39), (40) comes essentially from external interactions (within the Hamiltonian operator), rather than the emerging system time flow (hidden e.g. in the coefficient $\mathcal{A}_0$ in eq. (39)).

The Hamiltonian configuration expresses the pre-existing, "hardware" brain structure and can be approximated, in principle, by various model equations, unified e.g. within the series expansion of eq. (36b):

$$\mathcal{A}_0 \frac{\Delta \Psi}{\Delta t}\Big|_{\chi=\text{const}} = \sum_{n=0}^{\infty} h_n(\chi,t)\left(\frac{\Delta}{\Delta\chi}\Big|_{t=\text{const}}\right)^n \Psi(\chi,t)\ . \qquad (41)$$

The discrete form of differential operators in eqs. (39), (41) reflects the *dynamically discrete (or quantum)* character of unreduced interaction dynamics, resulting from its *wholeness* [27,30,31,42,43] and appearing as visible discreteness of observed brain activity patterns. This kind of essentially nonlinear structure of unreduced brain dynamics, starting from the global quantum beat, may appear *externally* as a quasi-periodic pattern, but it is quite different from any unitary oscillation by its origin and internal dynamics. Nonetheless, at sufficiently fundamental levels of complexity or sometimes in the case of quasi-periodic behaviour (the limit of multivalued SOC, see above) the discrete form of the dynamic equation for the brainfunction can be replaced by its usual, continuous version.

There is, however, another important distinction of the universal Schrödinger formalism from any unitary model that can hardly be neglected, especially for the brain dynamics: it implies the unreduced, *dynamically multivalued* and thus truly *chaotic solution* that provides many essential, easily observed features of the real brain operation (we discuss them below). This kind of behaviour, as well as the entire complex-dynamic understanding and description of the brain operation, highlights the dynamically *emergent*, structure-forming, holistic character of any brain property thus derived, as opposed to various unitary imitations that *cannot* describe explicit structure emergence in principle and are forced therefore to *artificially insert* any its property with the help of *postulated, mechanically fixed* structure or lower-level property. Just as the "miracles" of true intelligence and consciousness cannot be reduced globally to the postulated mysteries of standard quantum mechanics (see above), their essential features cannot be consistently explained by various local models of neuron operation, such as the well-known "integrate-and-fire" model. Such models may only reflect particular details of individual neuron interaction acts, which can constitute important features, but cannot directly account for the emerging result of *many* closely related individual interactions, permanently (and essentially) changing in time.

Due to its inherent universality, the above brainfunction formalism and causal interpretation refer, in principle, to any level or scale of fractal brain dynamics, from the entire brain to any its level or activity pattern. In

particular, the universal interaction complexity development introduced above (see eqs. (34)) will appear in the form of natural, generally irregular alternation of patterns of both limiting cases of complex dynamics (eqs. (30)), the more permanent (distinct) structures of multivalued SOC and irregularly changing (smeared) patterns of uniform chaos.

Having thus established the general dynamic content of neural networks with massively interacting components, we can now proceed with the dynamical meaning of the ***emerging properties of intelligence and consciousness***. Already the obtained general picture of unreduced interaction development and complexity properties, applied now to the neuron interaction processes, show that intelligence and consciousness can only be understood as big and high enough *levels of unreduced dynamic complexity* (where the level of consciousness is generally higher than that of intelligence). In accord with the unified probabilistically fractal structure of complexity [27,30-32], complexity levels of neural network dynamics have hierarchical, fractal structure, where big enough "branches" (levels) describe qualitatively specific behaviour types separated by "steep" and big complexity "jumps" from those of lower and higher complexity levels. Since genuine intelligence, including its unconscious, "animal" forms, is characterised by efficient control of a large enough environment, its major complexity level can be defined as that of the *complete environment complexity* (including the reverse influence upon it from intelligent species, etc.).[4]

The necessary part of this condition follows from the complexity correspondence rule outlined above, while its sufficiency can be related to the "principle of parsimony" (Occam's razor), which can, however, be causally derived itself as another aspect of the same complexity correspondence principle. In other words, the dynamic complexity of intelligent behaviour can come exclusively from interaction of the intelligent system with its "generalised" environment and will therefore, in its *sufficient* version, only slightly (though definitely) exceed the total complexity of the latter. It is worthy of noting that contrary to lower-level dynamic complexity of non-intelligent systems (including living organisms) that can also quite "successfully" exist in the same environment, a truly intelligent system will *concentrate* within

[4] In fact, the highest complexity of any well-established (developed) environment is determined basically by its intelligent components (if any), which interferes self-consistently with intelligence definition as environment complexity and explains why the level of (minimum) intelligence depends relatively weakly on the details of non-intelligent environment dynamics.

its *individual*, single copy the complete, *distributed* complexity of the dynamic environment.

In accord with our universal complexity definition, eq. (22), this level of complexity, where the true intelligence begins, can be expressed quantitatively in terms of the number of permanently changing realisations of all interactions in the "generalised environment". However, it is the qualitatively big and high enough *level* of complexity that is much more important than the particular realisation number it contains (the latter can vary considerably during internal development of any given complexity level), which explains why certain minimum *natural* intelligence can be defined rather well (although it inevitably has a "fractal", partially smeared structure), despite apparently large possible variations of various environment details. In this sense, if we define artificial (or any) intelligence in a similar way with respect to arbitrary (artificial) environment complexity, it can certainly vary in a much larger range, including systems whose "perfect" intelligence in a particular, restricted environment will become totally useless ("nonintelligent") in another environment with higher complexity (such situations can happen also for natural intelligent systems).

Being a direct and "minimum sufficient" reflection of the unreduced environment complexity, the nonconscious intelligence is inevitably characterised by the globally chaotic kind of dynamics, as opposed to the limit of multivalued self-organisation (see eqs. (30)). Therefore such minimum, or animal, intelligence is qualitatively insufficient for appearance of the main features of conscious behaviour.[5] The next higher level of brain dynamic complexity, able to provide the ***minimum true consciousness*** is naturally obtained then in the form of simplest *permanently localised*, SOC type of structures, which can be realised as *elementary bound states* of nonconscious (but typically intelligent) brain patterns. At this point a general analogy with similar complexity development at its lowest, quantum levels can be useful. Dynamic consciousness emergence in the form of bound states is analogous to complex-dynamic emergence of the level of permanently localised, classical states from purely quantum, delocalised and chaotic behaviour at the lowest complexity sublevels [27-31,40-43]. If two elementary particles, such

[5] This result is actually close to the conclusion that a natural environment in the whole cannot possess itself any kind of emergent, dynamic consciousness, irrespective of its detailed interpretation, while the same environment can, in principle, be characterised by a (nonconscious) intelligence determined by the highest complexity of intelligent species living in it (if any).

as proton and electron, form an elementary bound system, such as atom, then the probability of their simultaneous quantum jumps in *one* direction is low and quickly (exponentially) decreases with the number of jumps (in the same direction). This is because the quantum beat jumps of *each* of the bound particles are *chaotic* and *independent* from those of its partner. The bound quantum beat processes can therefore only perform their chaotic "dance" around each other but cannot progress together to a big distance in one direction (in the absence of external force).

Now, the same mechanism of "generalised classicality" emergence in a bound system applies also to the emergence of localised, conscious states in the brain in the form of *bound systems* of various strongly chaotic, delocalised structures of unconscious levels of brain complexity. The first conscious level of brain activity results therefore from further (binding) interaction of unconscious activity products ("generalised impressions" from the environment) leading to formation of various *bound, permanently localised, or conscious, states* (their life time should be at least much greater than the period of internal generalised quantum beat of each bound component). These simplest "elements of consciousness" start then interacting among them to form new localised (SOC) or globally chaotic states of higher sublevels, which constitute the developing fractal structure of growing consciousness complexity.

Such *additional* interaction with respect to unconscious intelligence needs a special "space" for its development and result accumulation, which explains the emergence and functional role of the *cerebral cortex* in the human brain as *inevitable* feature of conscious brain structure, where those bound, conscious states can form and further interact among them, giving rise to conscious "imagination" and similar specific features of *independent, internal* consciousness dynamics. Correspondingly, the unreduced complexity of conscious brain dynamics does not need to be limited any more to that of a particular environment and can grow by itself to comprise and create ever new features of real or imaginary world. Note that similar to purely *intrinsic*, dynamic origin of classicality in quantum behaviour at the lowest complexity levels that needs no external, artificially imposed "decoherence" of the unitary theory, the complex-dynamic origin of consciousness results basically from internal brain interactions, using interaction with the environment only as a source of "input data" (fixed initially at the unconscious complexity levels). We see again that the analogy with quantum complexity levels

provides a useful "holographic" reproduction of similar complexity development features but does not imply the direct quantum (microscopic) origin of consciousness.

Consider in more detail the simplest case of conscious structure emergence in a binding interaction of two nonlocal, globally chaotic unconscious structures. Each of them is represented by a *complex-dynamical (generalised) quantum beat process* (essentially different from any regular structure or dynamics!) at the level of unconscious intelligence, characterised by unceasing change of $N_{\Re} \gg 1$ realisations taken in dynamically random order (let $N_{\Re}$ be the same for both interaction participants, for simplicity of expressions only). The probability of a quantum jump of each of the interacting quantum beat processes towards any its particular, localised realisation is $\alpha \simeq 1/N_{\Re}$, in agreement with the general expression of eq. (17a). When two interacting unconscious structures form a conscious, bound state, the probability of their correlated jump in one direction is $\alpha_{\text{corr}} = 1/N_{\Re} = \alpha \ll 1$ (whereas the probability of arbitrary jumps, or system existence as such, is evidently $\alpha_{\text{arb}} = 1$). In the same way, the probability of *n* consecutive jumps in one direction is $\alpha_n = (\alpha_{\text{corr}})^n = (1/N_{\Re})^n = \alpha^n = \alpha^{\chi/\chi_0} = (N_{\Re})^{-\chi/\chi_0} = \alpha(\chi)$, where $\chi = n\chi_0$ is the total distance of chaotic system wandering and χ_0 is the length of elementary jump of each component, both expressed in terms of respective brain space coordinate χ. We see that $\alpha_n = \alpha(\chi)$ decreases exponentially with χ, so that the non-interacting bound system will remain localised within its size, of the order of χ_0.

It is important, however, that the complex-dynamic "internal life" (*chaotic* realisation change) continues within such localised conscious state, ensuring its proper evolution in interaction with other, conscious and unconscious, brain states within the *unceasing* and *unifying* quantum beat dynamics. We deal here with the essential difference between the unreduced, dynamically multivalued self-organisation and its dynamically single-valued (unitary) models in usual theory. It explains, in particular, why the dynamics of consciousness is characterised by much slower processes than unconscious reactions: according to the universal criterion of absence of global chaos, eq. (30b), the system should be far from its main resonances in order to preserve a distinct enough, e.g. localised, configuration and changes, therefore, at its slow component rate. The role of chaoticity/complexity is also reflected in the above expression for $\alpha(\chi)$ showing that localisation grows

with $N_{\Re}$ and disappears at $N_{\Re}=1$, i.e. in the (unrealistic) case of single-valued, regular (or "averaged") dynamics with zero complexity.

It is not difficult to outline further brain complexity development within its conscious activity. It is important that each qualitatively new level of complex brain dynamics as if *starts from the beginning* in the image of environment complexity it provides. Thus, conscious world reflection by permanently localised structures represents the same outside world dynamics that has already been properly reflected by unconscious levels of brain dynamics but now acquires a "new life" in the form of permanent and subjectively "controlled" images of real entities, which become relatively independent of their real prototypes (especially for higher levels of consciousness). When this new, conscious representation of reality approaches a correct enough image of external dynamic complexity, it naturally tends to produce a *general image of itself*, appearing as a **state of *awareness*** and giving rise to emergent *next level of consciousness*. This superior level of consciousness operates now with indirect images of world complexity from the first level of consciousness, closely entangled among them in a system of "associations". This superior consciousness "looks" upon its own complex-dynamic (and generally localised) images of external dynamical patterns at least as much as at those patterns directly. We obtain thus the detailed complex-dynamic interpretation of the property of *reflection* of conscious brain activity. Since the genuine "technical" capacity of a large neural network is fantastically high [31-34], far beyond usual unitary estimates (see also below), the hierarchy of complex-dynamic reflection levels can grow considerably to ever superior levels of consciousness, where already the lowest level provides the necessary minimum for conscious understanding of the environment.

The emergent, complex-dynamic consciousness is not only explicitly obtained as a result of unreduced interaction processes in the brain, but possesses a hierarchic, *multi-level*, or *fractal* (and thus *holographic*), structure, where each next level provides a qualitatively new, "superior" image (and extension) of reality, including complex-dynamic images of all lower levels of consciousness. Practical emergence of a new complexity level needs the suitable stock of latent interaction complexity, or dynamic information (see eqs. (34)), and is accompanied by the complex-dynamic resistance (generalised *inertia*) of the already existing structures, so that the appearance of a new, big enough level of consciousness is similar to a revolutionary change, or

"generalised phase transition" [30]. The persisting qualitative difference between the unitary and complex-dynamic reality images in knowledge structure provides a relevant example of consciousness levels dynamics.

With this general dynamic concept of intelligence and consciousness and their development, let us verify now how exactly can it reproduce the known ***properties of intelligent and conscious behaviour*** (e.g. [1-9]), including those that can be postulated as necessary, empirically based demands for ***artificial consciousness*** systems [13-15].

Note, first of all, that our complex-dynamic interpretation of intelligence and consciousness provides their *well-specified* origins and definitions, including the clear-cut *distinction* between these two "close" levels of higher brain activity, remaining rather ambiguous within unitary approaches to both their natural and artificial versions.

We can proceed with *autonomous dynamic adaptability* (I) of intelligent and conscious reflections of reality. As we have seen above, this feature emerges as a universal property of any unreduced, complex interaction dynamics (absent in its unitary imitation), while its necessary magnitude for the efficient intelligence and consciousness operation is determined by the complexity correspondence principle relating the degree of adaptability with the sufficient dynamic complexity of the brain that should exceed that of the controlled environment (we provide quantitative estimates below).

The *"logical", "binding", and "supervising" features* (II) of a *conscious* system are obtained within the key interpretation of conscious states as physically *bound* states of chaotic quantum beat processes of electro-chemical interactions in the brain neuron system, emerging as *localised* realisations of the *whole* system of brain interactions at a special complexity level, which exceeds and therefore *includes* all realisations from lower, unconscious reflection of the environment.

This superior structure of the level of bound conscious states underlies also all versions of clearly recognised *separation between the "self"*, represented by those *dynamically unified* bound states in the cortex, *and the "rest" (environment)*, the latter being reflected already at the lower level of unconscious intelligence (III).

The superior, ultimately emerging form of this property is provided by the complex-dynamic *awareness* (IV) described above, where the bound conscious images of reality include that of oneself, i.e. the cumulative image of

the conscious representation of the environment, thus actually forming the *next higher sublevel of complexity*. In terms of human species evolution (and for illustrative purposes only), property (III) could be figuratively designated as *Homo habilis*, while its version (IV) would correspond to the true (and still uncertain/developing) *Homo sapiens*.

Practical abilities of a conscious brain (also present, in a reduced form, at the level of unconscious intelligence), such as *reality control and self-control, imagination and planning-anticipation* (V), follow from the *emergent, interaction-driven* origin of respective brain structures, where conscious, bound structures acquire their own dynamics (in principle, of ever growing complexity), showing only general, weak dependence on the environment.

The properties of intelligent and conscious systems summarised as *emotions, desires, and motivations* (VI) are manifestations of universal *creativity* of complex dynamics expressed by the universal symmetry (including transformation) of complexity (eqs. (34)) and appearing as "élan vital" in the development of any living system: it is a result of interaction potentialities expressed by the dynamic information of action-complexity and forced, by the *unreduced* interaction itself, to evolve into the fully unfolded system structure, or its dynamic entropy-complexity.

Finally, the *sustainable, autonomous growth of intelligence and consciousness* underlying also the property of *education*/*learning* (VII) results from the same complexity development of the unreduced interaction process (eqs. (34)), constituting thus the basis for unlimited (in principle) growth of consciousness, as explained above.

In accord with the complexity correspondence principle, any of the above properties (I)-(VII) of the dynamically multivalued, essentially nonlinear and intrinsically creative interaction processes in the brain neuron system *cannot* be correctly reproduced by conventional, unitary theory, just because of its dynamic single-valuedness and strictly *zero* value of unreduced dynamic complexity, which is the unified, genuine origin of all difficulties and ambiguities in the existing understanding of consciousness, irrespective of details [1-26]. Indeed, the unitary reduction of real interaction in the canonical theory cannot explain even the *simplest*, quantum system behaviour at the *lowest* complexity levels and is forced to postulate the "impossible" and "inexplicable" features of those *real* systems in the form of "quantum mysteries" and "paradoxes" (see [11,27-31,40-45] for more details). This intrinsic

deficiency of unitary theory is inherited by its complexity imitation at higher levels of world dynamics. Therefore, the existing "general" applications of those effectively zero-dimensional imitations from the unitary "complexity science", often in a characteristic post-modern "hermeneutics" style, can create essential confusion in the already quite obscure field of knowledge. Speculative description of consciousness in terms of "attractors" and other abstract "models" of unitary theory (see e.g. [18-26,66-68,70,71]) operates, in fact, with zero-complexity entities and is unable to explain even much simpler patterns than those of conscious brain dynamics. An "attractor" is produced by a *continuous trajectory* of a system with *fixed, postulated configuration* in an *abstract, artificial* "space" and therefore has nothing to do with the real system dynamics based on the permanent, qualitative, and intrinsically chaotic change of its configuration, obtained as inevitable, generic consequence of the unreduced dynamic equation solution (replaced by a trivial notation change in the conventional, effectively zero-dimensional, perturbative "approximation"). Replacement of *dynamic*, *interaction-driven* multivaluedness of *incompatible* system realisations (its *different configurations*) and *probabilistic fractality* by "multiple attractor basins" produced by a *postulated* system configuration and *coexisting* in an abstract space is a very rough verbal trick of the unitary complexity imitation, which *cannot* explain *any* property of the unreduced system dynamics but persists in "rigorous" interpretation of its highest-level property, consciousness.

The huge contrast between the unreduced, multivalued dynamics of a multi-component interaction system and its unitary projection appears in a transparent form within a quantitative brain power estimate [31-34]. The unreduced power of a complex-dynamic process, P, i.e. the maximum number of operations it can perform per time unit or the number of units of information it can store, is proportional to its dynamic complexity C as given by the full number of system realisations $N_{\Re}$: $P = P_0 C\left(N_{\Re}\right) \simeq P_0 N_{\Re}$, where the coefficient of proportionality P_0 is of the order of unitary, sequential operation power, so that the relative power of unreduced, complex-dynamic process is given by its realisation number, $\delta P = P/P_0 = N_{\Re}$. If a natural or artificial brain consists of N_{cell} generalised neurons, each of them connected in average to n_{link} cells, then the full number N of system links is $N = N_{\text{cell}} n_{\text{link}}$. In the unreduced, multivalued system dynamics, the total realisation number is given by *all combinations of links*, i.e. $N_{\Re} \simeq N!$, whence

$$\delta P = N_{\Re} \simeq N! \simeq \sqrt{2\pi N}\left(\frac{N}{e}\right)^{N} \sim N^{N}, \qquad (42)$$

where we have used the Stirling formula valid for large N. Since for the human brain we have $N_{\text{cell}} \sim 10^{10}$ and $n_{\text{link}} \sim 10^{4}$, the estimate $N = 10^{12}$ for the number of conscious brain links should not be exaggerated. The expression of eq. (42) gives for $N = 10^{12}$ the following estimate for the relative full power of complex-dynamic brain operation: $\delta P \gg 10^{10^{13}} \gg 10^{10^{12}} \sim 10^{N}$, which is a *practical infinity*, implying that the unreduced brain power is "infinitely" greater than that of its unitary, mechanistic models.

This "astonishing" result is certainly due to the *complex-dynamic parallelism* of the unreduced interaction dynamics, where the system itself creates, in a real-time mode, the necessary dynamic structures and ways of search for a solution. The mechanistic "parallel information processing" does not have this property and represents only additive reconfiguration of the same sequential dynamics that cannot provide a real gain in power (with the same hardware capacities). Indeed, assuming that the average frequency of brain realisation change is not less than 1 Hz (which is a very moderate estimate), one can compare the above estimates of complex-dynamic brain power with the unitary estimate of the "ultimate" computation power for the whole (known) universe [72] to see that the former still remains "infinitely" greater than the latter [31-34] (although curiously this unitary estimate of the power of a very special, "quantum" computation process relies on a strong emphasis of "advanced", "magic" parallelism and "complexity" [73], demonstrating once again the absence of any power in unitary imitations of reality). The inevitable payment for such tremendous superiority of the unreduced complex-dynamic power takes the form of irreducible dynamic randomness, just underlying the above huge efficiency. However, the related result uncertainty is not really a problem, since it can be reduced to a necessary minimum in the multivalued SOC regime, without any essential loss of the total operation power. It is easy to see that the huge values of δP provide a quantitative expression of the "magic" qualitative properties of complex brain operation, such as those of intelligence and consciousness [31-34]. This conclusion will remain valid for much smaller values of N that can be expected for artificial neural networks, thus underlying the corresponding "magic" power also for artificial intelligence and consciousness, produced by their *unreduced*, complex (multivalued) dynamics.

We can conclude our causally complete *complex-dynamical concept of intelligence and consciousness* of this section by a summary of three practically oriented *complexity principles* [27-34], already mentioned above and unified by the universal complexity symmetry (see eqs. (34)). At the superior complexity levels of intelligence and consciousness of our interest here, they constitute the unified *intelligence principles* (see also next sections for their AI versions and applications).

The *complexity correspondence principle* determines the general result of interaction between two complex (including intelligent and conscious) systems, with the most efficient/interesting interaction between systems of comparable complexity. It implies, in particular, that higher complexity/intelligence controls or "enslaves" lower complexity/intelligence, and never the other way around. That is why *any* unitary, zero-complexity tool or approach of *however high* technical sophistication and power, such as (imaginary) unitary quantum computers or regular AI systems, *cannot* correctly control or simulate the behaviour of real systems always characterized by high values of unreduced dynamic complexity.

The *complex-dynamical, or intelligent, control principle* replaces the unitary principle of usual, restrictive and basically regular, control of any system behaviour as inefficient and fundamentally impossible by the suitable *complexity development* (eqs. (34)) around multivalued, internally chaotic SOC regimes (eqs. (30)). The desired globally sustainable evolution is attained here due to suitable local creativity replacing inefficient unitary-control restrictions.

And finally, the *unreduced (free) interaction principle* is the unified expression of the above exponentially huge power of unreduced complex-dynamical interaction, eq. (42), underlying, in particular, the "magic" properties of life, intelligence, and consciousness. It emphasizes the qualitative importance of irreducibly chaotic (multivalued) dynamics and evolution of the probabilistic dynamical fractal of unreduced many-body interaction.

We shall see now how these complexity principles and other laws of unreduced complex dynamics outlined above can be used in practical design, control, and training of real and efficient AI systems.

2. Universal laws of intelligence for efficient AI design and training

As shown in the previous section, intelligence and consciousness can be rigorously defined as well specified, superior levels of unreduced interaction complexity. Since the latter is obtained as multivalued, intrinsically chaotic and therefore fundamentally noncomputable dynamics [27-35], every effort to produce a computer-based, regular kind of "artificial intelligence" can only lead to a qualitatively limited imitation of truly intelligent behaviour. Nevertheless, such attempts seem to be the only currently feasible technology in the field, and our task here will be to propose optimal development ways and laws for any kind of quasi-intelligent system essentially using, however, the above concept and laws of genuine, complex-dynamic intelligence (as opposed to usual way of blind trial-and-error search becoming *increasingly inefficient* at these higher complexity levels).

Since we have clearly separated, in the above causally complete analysis, lower sublevels of "purely empirical", or "animal", or "quantum" (delocalized), intelligence and essentially higher sublevels of conscious, or "classical" (localized), intelligence dynamics, one may speak about their respective artificial (probably limited, but progressing) versions of *simple, empirical artificial intelligence* (AI) and *machine consciousness* (MC), while keeping in mind that AI in a broader sense includes any kind of artificial intelligent behaviour (and thus MC). As follows from applications and our analysis below, in many cases one implies an artificial version of the full, conscious human behaviour under AI efforts, which puts MC systems in the leading research position.

Turning to concrete universal features of AI and MC, we note, first of all, that the advanced version of conscious control and information systems should be considered as the *inevitable*, qualitatively new and *already urgently needed* stage of modern technology development. Indeed, if we apply our *universal* description of various dynamic regimes in arbitrary systems with interacting elements (section 1) to modern technological systems, we conclude immediately that their operation is based on the limiting case of multivalued

self-organisation. However, as the compositional sophistication of technological and related social systems inevitably grows, it finally and *inevitably* attains a level, where the unreduced interaction complexity and related true chaoticity will appear explicitly, with a high enough magnitude. This conclusion follows from the rigorous *criterion of chaos* of the universal science of complexity, eq. (30a), showing that one can avoid explicit, big chaoticity only by maintaining the system far away from all its essential resonances. But as the technical and socio-economic intricacy of the system grows, its level separations (frequencies) inevitably get closer, so that one *cannot* avoid their overlap and thus essential chaoticity above certain critical intricacy of system composition. We can formalise this conclusion by a simple illustration based on the chaoticity criterion (30a), if we accept that the internal element frequency ω_Q can be estimated as $\omega_Q = 2\pi/T_Q \simeq 2\pi\upsilon_Q/d_Q$ (where the internal motion period $T_Q \simeq d_Q/\upsilon_Q$, with the element size d_Q and average motion speed υ_Q), while the external dynamics frequency $\omega_\xi = 2\pi/T_\xi \simeq 2\pi\upsilon_\xi/d_\xi$ (with the external dynamics period $T_\xi \simeq d_\xi/\upsilon_\xi$, average inter-element distance d_ξ, and average motion speed υ_ξ). Taking into account that $d_\xi = D/N$ (where D is the system size and N the number of system elements) and substituting these estimates in eq. (30a), we find that

$$\kappa = \frac{\omega_\xi}{\omega_Q} \simeq N\frac{d_Q}{D}\frac{\upsilon_\xi}{\upsilon_Q} \ . \tag{43}$$

We see that for moderate number N of system elements (or, in general, their modes), one can easily obtain vanishing chaoticity, $\kappa \ll 1$ (for usual conditions $d_Q \ll D$ and $\upsilon_\xi \sim \upsilon_Q$), while with growing N, the emergence of global chaos regime, $\kappa \simeq 1$, is unavoidable.

Needless to say, the critical level of technical and social complexity, $\kappa \simeq 1$, is being exceeded by modern technology in a growing number of cases. Since the unitary, regular technology and society paradigm practically rejects such chaotic elements, they inevitably appear in the form of undesirable, more or less catastrophic system *failures*, which should be counterbalanced by more and more frequent and inefficient direct, "extra-ordinary" human interventions in otherwise automatic processes. Our analysis shows that there is no other issue from this growing "crisis of complexity", than explicit acknowledgement of the unreduced, *really existing* dynamic complexity (multivaluedness) of technological and social interaction processes, followed by transformation of its "destructive" influence on the *unitary* control

scheme into great advantages of its constructive, unlimited realisation outlined above. This result and approach apply to *any* level of technology, economy, and social life [27-30,33-39], but we shall concentrate here on the highest levels related to conscious control systems.

Such conscious technical systems of control and communication can show the features of *genuine*, complex-dynamic consciousness (section 1), but which at the same time *differs* essentially from the natural, human version of consciousness by the characteristic *shape* of conscious operation complexity. As we have seen above, the true consciousness emerges as certain, high enough level of dynamic complexity, which exceeds considerably those of arbitrary living and intelligent systems having themselves extremely high positions in the hierarchy of world dynamic complexity [30-33]. In the case of natural consciousness, i.e. the one obtained within a "natural" (biological) evolution, this means that carriers of consciousness should first be alive and then intelligent in order to have a (generally rare) chance to develop at least a minimum level of conscious intelligence. Since the lowest level of "intelligent" complexity is determined by the total environment complexity (in a reduced formulation, the same will be true for any living system complexity), it follows that the natural consciousness structure, at its initial, lowest levels, is characterised by a specific, relatively *flat* shape of its internal complexity hierarchy (dynamical fractal) resembling a "pancake". Whereas the "consciousness pancake" should have a minimum thickness corresponding to the lowest level of consciousness complexity, its relatively large width is inherited from the shape of unconscious intelligence and comprises a high diversity of the controlled environment complexity (represented by properly localised, conscious states of brain activity, see section 1).

By contrast, *artificial*, man-made systems of machine consciousness need not and actually should not incorporate the entire "horizontal" diversity of a living environment complexity but do need to have a minimum "vertical" dimension of the localised (SOC) reflection of their *limited* environment. Therefore, systems of artificial consciousness would usually emerge in the shape of relatively narrow vertical "rods" (or other "pyramidal" structures) in the "space" of universal complexity hierarchy. They will have the characteristic behaviour of very narrow but highly qualified, conscious "specialists" in their particular environment, knowing very much about it but very little beyond it and therefore suddenly becoming "stupid" just outside of their

"professional interests" (this phenomenon is known, in its milder form, also for human consciousness realisations). Let us emphasize once more that such limiting, "vertical" shape of conscious system complexity would be *impossible* for any truly natural, living system but can and should be realised for conscious machines, providing a *fundamental*, rigorously substantiated basis for their creation and making the latter more *realistic* (as opposed to ill-defined imitations of the full human consciousness).

Another specific feature of modern real MC systems may be the *absence of genuine chaoticity* in their basically *computable* realisation and behaviour. While the free-interaction, naturally chaotic intelligent systems can also be created within neural network [31] and active solid state [28] approaches, one should consider the starting case of fundamentally regular behaviour of usual computer systems. In this case the exponentially huge operation efficiency of naturally chaotic systems, eq. (42), may be lost and with it the "magic" advantages of genuine consciousness. Nevertheless, one may think about suitable imitations of interaction-driven chaoticity, in order to reproduce the main features of complex behaviour expressed by the above complexity principles, including complex-dynamical control and complexity correspondence (section 1). This condition implies that AI and MC systems with traditional computer dynamics should contain special "chaotic drivers" at the level of basic software, which would not only accept interaction-driven chaotic deviations without usual failure of their computable behaviour but will suitably generate such deviations as the means of quicker search for and advance towards the best possible problem solution. In order to be efficient, this artificial complexity development tool should rely on *interaction-guided* chaoticity, rather than arbitrary randomness generator. The more chaotic and less chaotic, quasi-regular processes and levels of operation should properly alternate, in accord with the *unified chaoticity and regularity criterion* of eqs. (30).

The related essential feature of unreduced consciousness dynamics as described in section 1 is its *full, dynamically fractal structure*, with its *hierarchy of association links*, contributing to the key "binding" properties of conscious intelligence. The efficient *dynamic emergence* of this *permanently changing* hierarchy of connections depends critically on the above interaction-driven chaoticity, hence its importance for advanced MC systems. Continuous maintenance of the entire changing hierarchy of association links

necessitates *permanent system-round cycles* of fractal refreshing realised in the brain by the generalised quantum beat process (section 1). Respective system-wide refreshing cycles should therefore be realised in any artificial consciousness system, comprising especially its high-level structures (as opposed to low-level regular cycles of usual computers). This changing and therefore *partially uncertain* fractal hierarchy of association links involves also the *deep-learning system training procedures* that should escape the temptation of simplified reduction and regularisation of natural association link system. The necessary specific *shapes* of particular MC system structure described above are also formed largely due to respective preferences in the association-link system and training process dynamics.

Any correctly implemented AI and MC system features will necessarily reflect and be guided by the *universal symmetry of complexity* and the ensuing practical *complexity principles* described in the previous section. Thus, the *complexity correspondence principle* implies that the MC system design and operation obey the hierarchy of complexity, where lower-complexity features and processes are unified, surveyed, and modified by suitable higher-complexity structures (in the unreduced, interaction-based understanding of complexity, as opposed to unitary mechanistic domination approaches). As intelligence means complexity (section 1), this rule can be formulated as the unified *intelligence correspondence principle*, according to which lower AI is controlled by and included into higher AI (this rule actually refers to intelligence of any origin). In particular, an MC system controls and includes non-conscious AI levels and modules. The *intelligent control principle* implies suitable *development* of system structure in the hierarchy of complexity-intelligence (as opposed to unitary restrictive control imitation). And finally, the *free-interaction, or free-intelligence, principle* emphasizes the power of unreduced, interaction-driven and chaotic interaction, in accord with the above "liberating" role of chaotic drivers in efficient AI system dynamics.

3. Human-machine interaction complexity and social coevolution prospects

Based on the *universal* concepts of intelligence, consciousness and underlying dynamic complexity (section 1), we can further advance towards *scientifically rigorous* understanding of *social* and *mental* implications of artificial intelligence and consciousness by considering the next interaction level between intelligent machines and natural intelligence carriers. It is easy to see, for example, that permanent intense interaction between "complexity rods" of conscious machines and "pancakes" of minimum levels of natural consciousness provides an efficient way of otherwise difficult development of natural consciousness towards its higher-level, less flat shapes, where multiple "rods" of artificial consciousness would "impose", at least partially, their "vertical" dimensions to a naturally diverse, but vertically limited consciousness of living beings. In other words, interaction with (truly) conscious machines can become an efficient, and possibly the only real, way of *massive* natural consciousness development (otherwise stagnating or even turning into degradation).

A complementary conclusion, following from the complexity/intelligence correspondence principle (or the underlying symmetry of complexity), states that systems of artificial intelligence cannot exceed the level of intelligence (complexity) of their creators, which in our case are assumed to be carriers of natural consciousness. This general but now fundamentally substantiated conclusion puts a strong limit on speculative negative consequences from "rogue" AI systems becoming too independent. Contrary to those popular fears, the *only* consistent dynamics of progressive, complexity-increasing human development (both individual and social) can result from (massive) interaction of lower-consciousness society members with conscious artefacts produced by efforts of members with (essentially) higher consciousness level (if any). As a result, a closed enough, e.g. global, society without big enough difference of its members' consciousness levels or unable to profit from it by efficient interaction processes cannot ensure its

complexity development and therefore will end up in degradation: any other interactions (e.g. using only zero-complexity machines of unitary technology) *cannot* provide complexity growth to higher levels of consciousness. One may note that this rigorously derived conclusion contradicts the currently dominating egalitarian social doctrine of a "democratic" flavour (often trickily exploited).

On the other hand, one may argue that interaction between higher- and lower-consciousness society members can proceed by their direct, "natural" communication, including science, education, etc. However, real-life experience clearly demonstrates too low, "subcritical" efficiency of such "natural" interaction, even in the best cases, which is additionally hampered by *inevitable* intervention of machine-intermediated interaction within a technically developed civilisation, where the unitary, zero-complexity machines *impose* their *ultimately low complexity* to the entire system of strong mental and social interactions. In this situation the qualitatively new, complex-dynamic, intelligent and conscious machinery can be the *only realistic* and actually strong *catalyst* of natural consciousness development within a machine-based civilisation, underlying its development in the whole [30,31,33,34].

Inspired by this great purpose of the genuine machine consciousness paradigm, we can briefly consider now *practical possibilities* for its realisation, following from the above description (sections 1 and 2). Since in principle there is no problem today with fabrication of elaborated neural networks, the specific features of conscious networks involve their detailed structure and imposed operation modes. The general conclusion of our analysis implies that the true, complex-dynamic intelligence and consciousness can appear only in a system with the high enough *freedom* of interaction between elements that *cannot* be based only on pre-programmed, regular interaction rules and expected results as it occurs for all unitary machines. Any sequential programming of regular interaction details should be abandoned in the case of (quasi) complex-dynamical devices in favour of natural, dynamic complexity development (including their interaction link modification), always occurring in the general direction determined by the *universal symmetry of complexity* and the ensuing particular laws (section 1). The same is true for *deep-learning and AI training procedures* that should use the *largest* accessible range and depth of unreduced natural intelligence complexity (including dynamically fractal association web, uncertainty, etc.).

A more specific result of the above consciousness analysis (section 1) implies that truly intelligent/conscious system interactions cannot be reduced to local "rapid" (electric) connections between individual elements but should also include a complementary distributed, dissipative, "slow" component necessary for efficient dynamic unification and stability of artificial brain dynamics in the form of generalised quantum beat. In the natural brain such component is provided most probably by chemical neuron structure and interactions, but such "bio-inspired" construction of artificial conscious systems may be not the easiest one. Another candidate for that "slow" interaction component is provided by properly configured magnetic materials and interactions, reproducing generally (but not exactly) the electric connection interface and interacting with it "almost everywhere". It is not difficult to see that the detailed realisation and principles of construction of such explicitly complex-dynamic networks will be very different from the now realised unitary approach and technology, but as we have shown above, this way of development is objectively inevitable and unique at the next stage starting already today (see also refs. [28,31] for similar results for the unreduced nanotechnology concept).

In conclusion of this section, we emphasize again the far-going mental and social implications of the genuine artificial consciousness paradigm, which are briefly outlined above and would certainly need further development using this intrinsically interdisciplinary approach and our universal dynamic complexity concept and formalism. The general motivation for these studies is as big as civilisation development in the whole, since the above rigorous analysis shows the indispensable, unique role of complex-dynamic (multivalued) interaction processes and technology for progressive civilisation development today (see also [27-31,33-37,39] for the universal concept of development). Since artificially produced, technical structures play a major and ever growing role at any scale of world development that *cannot* be abandoned or turned back, increasing replacement of their currently dominating, complexity-suppressive design and operation mode by the unreduced, *explicitly complex-dynamic technology*, inevitably comprising *key elements of machine consciousness*, emerges as the objectively inevitable, *uniquely* progressive way of development, including creative progress of *individual* natural consciousness as its *inherent component*. The above universal and rigorously substantiated science of mind becomes thus the ***universal***

science of meaning implying the *unreduced, causally complete understanding* of progressively developing reality. Note finally that the use of much more restricted, unitary AI versions, which can only imitate, but not reproduce the unreduced consciousness features (see their list in items (I)-(VII) in section 1), can be considered as a first-step motion in the same direction of growing complexity, which should not replace, however, the search for and practical realisation of explicitly complex-dynamic, truly intelligent and conscious machinery.

4. Complexity threshold and reason-based sustainability by the unreduced AI development

The discussion of the complex-dynamic intelligence and consciousness concept in previous sections revealed deep human and social implications of the AI development problem, far beyond technical issues or concrete applications. Moreover, the causally complete analysis of the modern world condition within the same, universally valid concept of dynamic complexity shows that the entire system of human civilisation has just entered, in these last decades, into a ***global critical state***, after which it can either continue to a quick and fatal decline, within the current tendency, or perform the crucial transition to higher-complexity and higher-consciousness level, where it can start the new, basically unlimited, or truly sustainable, progressive development [27-31,33,35,36,39]. It is important to recognise the intrinsic, well-specified relation between and qualitatively new, nontrivial content of these key issues of the *unreduced dynamic complexity* and its *necessary revolution* in *both* scientific understanding of reality (dynamic multivaluedness paradigm) *and* the effective general level of social and individual consciousness.

In this section we specify the details of interrelated major aspects of this necessary ***complexity transition***, including "the last scientific revolution" towards the unreduced, universal dynamic complexity paradigm, the complexity revolution and transition to a superior level of consciousness on a broader scale of entire society and global civilisation, and the targeted resulting condition of truly sustainable progress, with the underlying essential role of the advanced AI and MC technologies. We shall see in that way that the unreduced dynamic complexity is the unifying basis of both further progressive development in all its aspects and its AI components, which in their turn are indispensable for the forthcoming genuine sustainability, just in their advanced, complexity-based version.

We start from emphasizing the modern state of ***deep crisis in fundamental science***, which becomes ever stronger and more evident within a growing range of fields and aspects of scientific knowledge (see e.g. [27-

31,39,74-81] and further references therein). It is the extreme, limiting parts of the latter that reveal especially striking and quickly accumulating signs of a critical state, including the persisting old and growing new "mysteries" in the microworld of particles and fields, the glaring contradictions in cosmology on various astronomical scales (up to the entire universe), and the ultimate complexity of living matter, conscious brain, and developed society dynamics. It is no coincidence that this critical state of fundamental knowledge reproduces the critical bifurcation of the embracing civilisation development mentioned above, with its difficult choice between the default fatal degradation and unlimited new progress at the superior level of conscious understanding.

Note the important difference of such kind of real crisis in modern science from its much more comfortable image within the well-known concept of the end of science [74] as being due to a "practically perfect" (or "fundamentally saturated") state of knowledge that does not reasonably imply any essential further progress. This latter vision shows a strange correlation with the equally deficient (and much more widely accepted) attitude towards the state of the encompassing social system, which presents its current (unitary) "liberal democracy" realisation as close to a practically possible maximum of social-order efficiency. In reality, both modern official systems of knowledge and social organisation show visible "saturation" signs only within certain, actually very rough and artificially imposed *simplification* of complex reality, revealing huge and quickly growing contradictions, especially now that they have entered into a critically unstable state of global bifurcation (with the ensuing inevitable transition to a qualitatively different state).

As *rigorously* shown in this and other related papers [27-46], this truly critical state of modern science and related contrast choices for further development of entire civilisation have in reality a *well-specified, scientifically nontrivial origin* and *resolution* in terms of the *necessary transition* from the artificially limited, dynamically single-valued, or unitary, science and knowledge paradigm, method, and vision to the dynamically multivalued, causally complete content of the universal science of complexity. As a matter of fact, the totally dominating, dynamically single-valued "model" of unitary science and world vision represents the *maximum possible reduction* of a great realisation number of any system or real interaction process to just one, arbitrarily fixed and "postulated" realisation, corresponding to strictly

zero value of the unreduced dynamic complexity (including all the cases of standard unitary "complexity science") [27-46]. This unitary, effectively zero-dimensional (point-like) projection of reality could provide a correct description only for rare, "almost regular" cases of the limiting SOC regime (section 1) exclusively considered in the "Newtonian" science paradigm, but even in such cases there are the well-known "unsolvable" (or badly solved) problems of genuine chaoticity, time origin and irreversibility.

Such drastic simplification of reality corresponds to the so-called "positivistic" ideology of unitary science (in particular, taking the form of "mathematical physics" in its most "exact" branches), which explicitly rejects the necessity of genuine, "truly complete" understanding of the observed reality (defended especially by René Descartes, the famous precursor of Newtonian positivism) in favour of its "model", simulating description, where inevitable glaring contradictions and ruptures (i.e. nonuniversality) are "compensated" by simplicity of an "exact" (or perturbative) model, "sufficiently correctly" imitating a particular kind of observable behaviour (but usually not other ones described by separate "models") and not resulting from the complete interaction problem solution. It becomes clear now that this only slightly decorated empiricism of the dominating positivistic ideology of the unitary science is but a general expression of the underlying dynamic single-valuedness, whereas the dynamic multivaluedness of the truly complete (and thus truly exact!) problem solution (section 1) leaves no place for any "mysteries", ruptures and other contradictions of the postulated unitary models. We can say therefore that the current "end of science" represents indeed the definite end of just that, actually very special kind of positivistic, or unitary, science, which should now be extended, with the help of the causally complete, universally applicable problem solution, to the intrinsically non-contradictory, at least locally complete knowledge of the universal science of complexity (it is limited only by inaccessible observation possibilities, which does not really change the practical completeness of the obtained picture of reality).

Whereas the rigorous basis of the universal science of complexity is exposed consistently in section 1 and its advantages in application to AI problems are discussed in sections 2 and 3, we can emphasize here the **unified, "ideological", and *mathematically exact* fundamental distinctions** of this new, extended science framework with respect to usual, unitary science postulates and results [27-29,32-34,39,42].

(1) The entire framework and content of usual, dynamically single-valued, positivistic science is deeply based on the tacit *self-identity postulate* and related "rigorous" statements of various *theorems of uniqueness of problem solution*. The self-identity postulate implies the apparently "evident" identity of any mathematical (and respective real) structure $\mathfrak{A}$ to itself, $\mathfrak{A} = \mathfrak{A}$, including its formal time dependence, if any, $\mathfrak{A}(t) = \mathfrak{A}(t)$. However, as we have seen above (section 1), the unreduced interaction process within any real structure has the dynamically multivalued result, in the form of multiple system realisations, *permanently replacing one another* in causally (and truly) random order. Therefore any realistic structure, described in the causally complete framework of the universal complexity science by the unreduced, dynamically multivalued problem solution, is *not* self-identical, $\mathfrak{A} \neq \mathfrak{A}$, which also gives rise to the real, naturally unstoppable and irreversible *time flow*, $\mathfrak{A} \neq \mathfrak{A} \Rightarrow \mathfrak{A}(t)$ (section 1). We deal here with the deeply diverging qualities of reality vision and presentation in unitary science and universal complexity science: the static, fixed structures of the former (including formal, postulated time dependence) are opposed to permanently, intrinsically and chaotically changing structure-processes of the latter (including *externally* regular or static structures and processes). As to the notorious "uniqueness theorems" of unitary science, they just realise a standard logical trap, where the tacitly presumed single-valuedness (e.g. of interaction potential) is then restated as the "rigorously derived" theorem conclusion [39]. As a matter of fact, no realistic, truly rigorous and complete problem solution can possess the uniqueness property, already because one cannot stop the real, entropy-increasing (and thus structure-changing) time flow. Needless to say, already the most obvious empirical properties of intelligence and consciousness provide a clear demonstration of the absence of self-identity and uniqueness, in correlation with the persisting difficulties of genuine understanding of intelligence and consciousness within the unitary science framework [1-12].

(2) Another characteristic, inevitable property of the unitary projection of reality is the *absence of well-specified, tangible material quality* of purely abstract structures used (forming the basis of mathematical-physics approach), which is directly related to its artificially limited, dynamically single-valued scheme, or "model", of reality. As shown in our unreduced interaction analysis (section 1), the material quality is rigorously defined by the *dynamically multivalued entanglement* of interacting system components,

organised into the hierarchy of *dynamically probabilistic fractal*, which is quite different from usual, unitary fractality and provides the truly exact (causally complete) description of real structures. It also underlies such universal properties, especially important for intelligent and conscious behaviour, as autonomous *dynamic adaptability* and *teleology* (creation of and evolution towards local and global goals).

(3) The *absence of the origin of genuine randomness* in the dynamically single-valued approach of conventional science is closely related to its self-identity property and unique-solution projection (item 1). Whereas the intrinsic and omnipresent dynamic randomness and chaoticity is immediately implied by the unreduced, dynamically multivalued problem solution (section 1), the unitary theory is forced to introduce its "officially accepted" notion of chaos and randomness in an artificial and contradictory way, in the form of "exponentially diverging" (but in principle regular) trajectories, *incorrectly* extending the perturbation theory result and supposed to "amplify" small, but already present, externally inserted "random deviations" in initial conditions. The same kind of incorrect trickery is used in other ideas of chaoticity in the unitary "complexity science", such as "strange attractors" or "routes to chaos". Note that only genuine, intrinsic and interaction-driven randomness can explain the observed efficiency of major searching, estimating and planning activities of intelligent and conscious systems.

(4) The *absence of natural, dynamic discreteness* in the dynamically single-valued analysis is actually related to the problem of structure formation, or emergence, fundamentally missing in usual theory and only artificially inserted into its models (including the formally imposed space and time concepts and variables). While the discreteness of real structures emerging in the unreduced interaction analysis is provided by the dynamic discreteness of changing realisations and their complexity levels (section 1), it is replaced either by smooth unitary continuity or by false, mechanistically imposed discreteness in unitary science. Qualitative limitations and deep contradictions of these imitations are characteristic also of other related mathematical constructions of standard theory, including the unitarity itself, calculus, evolution operators, symmetry operators, any unitary operators, Lyapunov exponents, path integrals, and statistical theories. Therefore, the related concepts of emergence, creativity, and qualitative transitions, omnipresent in intelligence and consciousness dynamics ("understanding", "ideas", etc.), can be

consistently formulated only within the unreduced, dynamically multivalued description of the universal science of complexity.

(5) It is important to emphasize finally the unique, *unifying global features* of the unreduced complexity description appearing as unified manifestations of the *single law*, the absolutely *universal symmetry of complexity* (eqs. (34)), which expresses the behaviour of the equally *unified world structure* in the form of *dynamically probabilistic fractal* (section 1). One can compare these rigorously derived and variously confirmed results [27-46] with ever increasing doubts about the possibility of large enough unification in science (or even about the existence of any objective and truly fundamental laws) [74,82-85], even within the limited scope of fundamental physics (after so many failed attempts to obtain it in various schemes of unitary "mathematical physics"). This comparison also reveals the astonishing blindness and deafness of unitary science practice, which is closely related to its strongly limited content [31,39].

We can clearly see now why both techno-social demands of further civilisation progress and modern deep problems of scientific knowledge development necessitate the transition to a superior level of reality understanding equivalent to a higher level of consciousness. According to the complexity and intelligence correspondence principle (sections 1 and 2), this is indispensable already for the genuine, causally complete and practically efficient understanding of consciousness itself, but actually appears to be necessary for further progress in all fields of fundamental science (and thus eventually technology and everything else), starting already from the lowest complexity levels (elementary particles and fields) [27-46].

In the whole, one should speak therefore about a much deeper and wider transition in the entire civilisation development, implied by the universal science of complexity and the observed development tendencies, than the professional knowledge progress itself (which has, of course, its own importance and plays the key role in this transition). In fact, we deal here with the "new way of thinking" and related new, complex-dynamic approaches in all spheres of human activity, as opposed to the still dominating tendency of simplification, even despite the evident advent of superior complexity in practical life (due to the previous huge, but mainly empirically obtained progress). It becomes obvious that the necessary transition from the traditional unitary tendency of maximum possible simplification (where informally "the

simpler the better") to the opposite and the only progress-bringing tendency of growing complexity (where greater complexity is generally better) can occur only as a highly nonlinear, rapid and collective enough (though fundamentally individual) "revelation" called here ***complexity revolution*** (or *complexity transition*) [27-31,33-37,39]. In particular, it is the *provably single possible way* to realise the notorious purpose of *sustainable development* (see also below), which remains but a strongly popularised case of wishful thinking (or even a dangerous illusion) within the traditional, simplification-based unitarity and its mechanistic approach, irrespective of the quantities of technical efforts applied (including the inconsistent global-warming hype or pseudo-green technologies, only imitating ecological advantages).

The case of sustainable development demonstrates an important general constituent and result of the imminent complexity revolution, which implies not only new ways, means and instruments, but also and especially the *new general purpose* of development and human life on every scale. It is evident that today such suitable, universal and practically sustainable purpose of civilisation development (in both its social and individual aspects) is persistently absent, for the first time in "modern" history (~ AD). Former versions of the essentially biological general purpose (under various religious, ideological and techno-scientific guises) have disappeared starting approximately from the beginning of the twentieth century (the famous religious-philosophical "death of God"), while no new ones, of a suitably high level, have appeared until now. The reason for this persisting *purposeless* existence is precisely the necessary *qualitatively big progress of consciousness* in the direction of explicit complexity growth and efficient monitoring.

Now that the necessity of complexity transition becomes evident, together with the key implication of qualitatively growing, complex-dynamic consciousness, we can formulate the expected new general, ultimate purpose at the forthcoming superior level of complexity-driven progress as the permanent, maybe uneven but unstoppable ***progressive growth of that unreduced, now practically unlimited human (including artificial) consciousness*** (in all its now *unified* aspects of mind, spirit, emotions, etc.). It naturally starts with the key, step-like change of complexity transition (from the still dominating unitary thinking) and then continues as a more gradual and stable, never-ending growth of consciousness dominating in all spheres of human activity. The huge, unlimited scale of this new general purpose, far

beyond any traditional limits and separations of usual "science", "spirituality" and "practical life", demonstrates the true scale of consequences of the above dynamic multivaluedness and universal complexity concept (section 1), without any decrease of its intrinsic scientific rigour (taking into account, in particular, its causally complete concept of consciousness, sections 1-3).

As mentioned above, the qualitatively big and nontrivial transition to the *truly sustainable development* way for the entire civilisation constitutes an integral part of the revolution of complexity in science and technology, implying also the social and intellectual transition to the *superior level of consciousness*. This result is very different from all usual, semi-empirical and basically wrong ideas about sustainability, as we show [33-37,39] that this assumed unitary sustainability without essential, qualitatively big transition to the complexity-growth regime in all human activities is strictly impossible and may actually play the negative role of a vain but dominating illusion, preventing the transition to genuine sustainability.

We show first [35] that the universal curve of complexity development from dynamic information to dynamic entropy (see section 1) produces right now a ***major bifurcation point***, after which it can continue, within the current tendency and complexity level, only in the fatal complexity-destruction regime ending in the essential degradation down to qualitatively lower levels of complexity and consciousness, or else it can pass to the intrinsically creative and sustainable way after the transition to the new complexity-creation mode at the superior level of consciousness and complexity development. It is important that this *rigorously derived* conclusion does not depend on the details of unitary regime realisation in the now dominating, default tendency, including strongly imposed pseudo-green technologies and various "resource-saving" practices (they can only slightly slow down the occurring degradation, but also provide a dangerous illusion of problem solution until it will be too late for the genuine, complexity-driven sustainability transition providing the true solution). In other words, it is rigorously shown that we are in a special development point now, facing the *complexity barrier* after the global *complexity threshold*, starting from which the traditional, "eternal" drive of purely empirical "invisible hand", in economy and elsewhere, becomes *fundamentally inefficient* for any further progress, forever and can now produce only increasing systemic degradation over all scales and

dimensions (as opposed to the dominating idea of only temporal crisis, however deep it may be, followed by the natural, empirically driven new rise).

As to the concrete ways of realisation of real sustainability transition and stable progress after that bifurcation point, they will always involve the key change from traditional complexity-destruction practices, approaches and thinking to the qualitatively different *complexity-creation* activities, in science, technology and engineering, social dynamics and governance, settlement structure, and related unifying intellectual development [27-31,34-37,39]. This crucial and direct involvement of the unreduced dynamic complexity, rigorously and universally based on the causally complete, dynamically multivalued interaction problem solution (section 1), constitutes the *well-defined, essential difference* from any dominating unitary ideas of sustainability and further civilisation progress.

We have demonstrated above the crucial advantages of the unreduced concept of dynamic complexity in understanding of intelligence and consciousness dynamics, in direct relation to urgent development problems (sections 2 and 3). It is important that equally great, problem-solving advantages are provided by the same unreduced complexity analysis in *all other fields of scientific knowledge* (otherwise stagnating, or "ending"), from consistent particle physics to reliable genetics, causal biology, integral medicine, creative ecology, and objective development science [27-46]. It is not difficult to see that the same is true for *applied science, technology and engineering development* and its accumulating unaccomplished, pressing tasks related e.g. to the new, pure and practically unlimited energy sources, efficient, sustainable exploitation/development of natural resources combined with infrastructure quality, or emerging medical and psychological difficulties [30,34-37,39]. The observed dangerous stagnation in these key directions, despite quantitatively huge and technically powerful efforts within the unitary approach, confirms the necessity of a qualitatively new vision, which we specify in the form of unreduced dynamic complexity concept.

Similar general transformation from complexity-destruction to complexity-growth mode will inevitably take place in *social structure and science organisation and practice* itself, from the centralised and self-destructive Unitary System (the only type of organisation known until now, in various forms) to the distributed and intrinsically creative Harmonical System [27-30,34,35,39]. The new society of the harmonical level is qualitatively

different from any most "developed" unitary organisation, including the appearance of ***social consciousness*** at the harmonical level located within both individual consciousness and respective ***new governance*** structures [36] and absent in only empirically driven unitary development mode. Assisted by the *advanced AI and MC systems* described above (sections 2 and 3), this new, ***self-aware and reason-based society*** is therefore able, in the normal way of its existence, to *causally understand and guide its own development* as that of a real complex system (with the above general purpose of unlimited consciousness progress), by contrast to any unitary social organisation.

Needless to say, the organisation and role of the new, practically unlimited *knowledge creation system*, now inseparable from the entire social system and replacing the unitary science content and organisation, will also change and grow qualitatively after the sustainability transition, where science will not be isolated any more into an esoteric activity of self-estimated "sages", practically inaccessible for real "public understanding" (and thus any efficient control) but will instead be organically, inseparably interwoven with the fabric of social life and development as its major, driving element (which is the only possibility for a society to be estimated as really "developed" one – but it can actually be realised only at the harmonical level, after the complexity transition). That is why the sustainability and complexity transition can also be called the ***last scientific revolution*** [39] (evoking the famous analysis of Thomas Kuhn [86]), after which the development of science (and actually anything else) occurs in a stable and permanent way, without accumulating antagonistic contradictions followed by a characteristic disruptive "revolution" of unitary science (remaining thus a past phenomenon inherent only to that, artificially limited kind of knowledge). It is evident that such new kind of progress of ever more complex system of self-aware reason-based society can be efficiently guided *only* by the causally complete approach of the *universal science of complexity*, where the organisation and social involvement of that truly new kind of science forms itself a major integral part of the unified complex system of harmonical, intrinsically sustainable society. The urgently needed *sustainability* can thus be *rigorously specified* as that superior level of consciousness and knowledge based on the unreduced and now properly *growing dynamic complexity* of the planetary system consistently described above and essentially involving the *unreduced AI and MC systems*.

References

[1] J. Horgan, *The Undiscovered Mind: How the Human Brain Defies Replication, Medication, and Explanation* (Touchstone, New York, 2000).

[2] S. Blackmore, *Consciousness: An Introduction* (Oxford University Press, New York, 2004).

[3] C. Koch, *The Quest for Consciousness: A Neurobiological Approach* (Roberts & Company Publishers, Englewood, 2004).

[4] F. Crick, *The Astonishing Hypothesis* (Charles Scribner's Sons, New York, 1994).

[5] D. Dennett, *Consciousness Explained* (Little, Brown, Boston, 1991).

[6] G.M. Edelman, *Wider Than the Sky: The Phenomenal Gift of Consciousness* (Yale University Press, New Haven, 2004).

[7] S. Pinker, *How the Mind Works* (Norton, New York, 1997).

[8] D. Chalmers, *The Conscious Mind: In Search of a Fundamental Theory* (Oxford University Press, New York, 1996).

[9] O. Flanagan, *The Science of the Mind* (MIT Press, Cambridge, 1991).

O. Flanagan, *Consciousness Reconsidered* (MIT Press, Cambridge, 1992).

[10] *Towards a Science of Consciousness: The First Tucson Discussions and Debates*, Ed. by S.R. Hameroff, A.W. Kaszniak, and A.C. Scott (MIT Press, Cambridge, 1996). See also https://consciousness.arizona.edu/past-conferences.

[11] R. Penrose, *Shadows of the Mind: A Search for the Missing Science of Consciousness* (Oxford University Press, New York, 1994).

S. Hameroff and R. Penrose, "Consciousness in the universe. A review of the 'Orch OR' theory", *Phys. Life Rev.* **11** (2014) 39. http://dx.doi.org/10.1016/j.plrev.2013.08.002.

[12] D. Zohar, *The Quantum Self* (William Morrow, New York, 1990).

[13] *Machine Consciousness*, Ed. by O. Holland, *Journal of Consciousness Studies* **10**, No. 4-5 (2003).

[14] I. Aleksander, *How to Build a Mind* (Weidenfeld & Nicolson, London, 2000). See also http://www.scholarpedia.org/article/Machine_consciousness.

[15] D. Gamez, "Progress in machine consciousness", *Consciousness and Cognition* **17** (2008) 887.

[16] H. Ritter, J.J. Steil, C. Noelker, F. Roethling and P.C. McGuire, "Neural Architectures for Robot Intelligence", *Rev. Neurosci.* **14** (2003) 121.

[17] C. McBride, "Scientists in silico?", ArXiv:1711.00678 (2017).

[18] M. Oizumi, L. Albantakis and G. Tononi, "From the phenomenology to the mechanisms of consciousness: integrated information theory 3.0", *PLoS computational biology* **10** (2014) e1003588.

[19] C. Koch, M. Massimini, M. Boly and G. Tononi, "Neural correlates of consciousness: progress and problems", *Nature Reviews Neuroscience*, **17** (2016) 307.

[20] J. L. Perez Velazquez, "Brain, behaviour and mathematics: Are we using the right approaches?", *Physica D* **212** (2005) 161.

[21] M. Tegmark, "Consciousness as a state of matter", *Chaos, Solitons & Fractals* **76** (2015) 238. ArXiv:1401.1219.

[22] C. Gros, "Self-Sustained Thought Processes in a Dense Associative Network", In: *KI 2005: Advances in Artificial Intelligence, Proceedings of the 28th Annual German Conference on Artificial Intelligence*, *Lecture Notes in Artificial Intelligence 3698* (Springer-Verlag, Berlin Heidelberg, 2005) p. 366. ArXiv:q-bio/0508032.

[23] B. Cessac and M. Samuelides, "From neuron to neural networks dynamics", *Eur. Phys. J. Special Topics* **142** (2007) 7.

[24] D. R. Chialvo, "Emergent complex neural dynamics", *Nature Phys.* **6** (2010) 744.

[25] R. Sole, M. Moses and S. Forrest, "Liquid brains, solid brains", *Phil. Trans. R. Soc. B* **374** (2019) 20190040.

[26] M. Bertolero and D. S. Bassett, "How matter becomes mınd", *Scientific American*, July (2019) 26.

[27] A. P. Kirilyuk, *Theory of Everything, Ultimate Reality and the End of Humanity: Extended Sustainability by the Universal Science of Complexity* (LAP LAMBERT Academic Publishing, Beau Bassin, 2017). ViXra:1802.0168.

A. P. Kirilyuk, "Dark Matters and Hidden Variables of Unitary Science: How Neglected Complexity Generates Mysteries and Crises, from Quantum Mechanics and Cosmology to Genetics and Global Development Risks", 76 p. (2020), *Hal-02489867*.

[28] A. P. Kirilyuk, "Universal Complexity in Action: Active Condensed Matter, Integral Medicine, Causal Economics and Sustainable Governance", submitted for publication, 25 p. (2019). Hal-02875353.

[29] A. P. Kirilyuk, "Extended Mathematics of Unreduced Dynamic Complexity: The Exact Image of Unified Reality, from the Electron to Consciousness", *2015 FQXi essay contest, http://fqxi.org/community/forum/topic/2398*, 10 p. (2015). Hal-01173946.

A. P. Kirilyuk, "The Unified Complex-Dynamic Origin of Time, Intention, Life, and Everything", *2016-17 FQXi essay contest, http://fqxi.org/community/forum/topic/2774*, 10 p. (2017). Hal-01611317.

A. P. Kirilyuk, "Objective Fundamental Reality Structure by the Unreduced Complexity Development", *2017-18 FQXi essay contest, https://fqxi.org/community/forum/topic/3052*, 7 p. (2018). Hal-01715223.

A. P. Kirilyuk, "Creative Undecidability of Real-World Dynamics and the Emergent Time Hierarchy", *2019-20 FQXi essay contest, https://fqxi.org/community/forum/topic/3473*, 9 p. (2020).

[30] A. P. Kirilyuk, *Universal Concept of Complexity by the Dynamic Redundance Paradigm: Causal Randomness, Complete Wave Mechanics, and the Ultimate Unification of Knowledge* (Naukova Dumka, Kyiv, 1997). ArXiv:physics/9806002.

A. P. Kirilyuk, "Universal Science of Complexity: Consistent Understanding of Ecological, Living and Intelligent System Dynamics", *ArXiv:0706.3219* (2007). Russian version: *Nanosystems, Nanomaterials, Nanotechnologies* **11** (2013) 679.

A. P. Kirilyuk, "Universal Symmetry of Complexity and Its Manifestations at Different Levels of World Dynamics", *Proceedings of Institute of Mathematics of NAS of Ukraine* **50** (2004) 821. ArXiv:physics/0404006.

A. P. Kirilyuk, "Dynamically Multivalued Self-Organisation and Probabilistic Structure Formation Processes", *Solid State Phenomena* **97-98** (2004) 21. ArXiv:physics/0405063.

[31] A. P. Kirilyuk, *Complex Dynamics of Real Quantum, Classical and Hybrid Micro-Machines* (LAP LAMBERT Academic Publishing, Saarbrücken, 2013). ArXiv:physics/0211071.

A. P. Kirilyuk, "Complex Dynamics of Real Nanosystems: Fundamental Paradigm for Nanoscience and Nanotechnology", *Nanosystems, Nanomaterials, Nanotechnologies* **2** (2004) 1085. ArXiv:physics/0412097.

A. P. Kirilyuk, "Complex-Dynamical Nanobiotechnology Paradigm and Intrinsically Creative Evolution", *Nanosystems, Nanomaterials, Nanotechnologies* **14** (2016) 1. Hal-01342331, viXra:1607.0145.

[32] A. P. Kirilyuk, "The Universal Dynamic Complexity as Extended Dynamic Fractality: Causally Complete Understanding of Living Systems Emergence and Operation", In: *Fractals in Biology and Medicine, Vol. III*, Eds. G. A. Losa, D. Merlini, T. F. Nonnenmacher and E. R. Weibel (Birkhäuser, Basel, 2002), p. 271. ArXiv:physics/0305119.

A. P. Kirilyuk, "Complex-Dynamical Extension of the Fractal Paradigm and Its Applications in Life Sciences", In: *Fractals in Biology and Medicine, Vol. IV*, Eds. G. A. Losa, D. Merlini, T. F. Nonnenmacher and E. R. Weibel (Birkhäuser, Basel, 2005), p. 233. ArXiv:physics/0502133.

A. P. Kirilyuk, "New Mathematics of Complexity and Its Biomedical Applications", *Banach Center Publications* **109** (2016) 57. Hal-01147395, viXra:1506.0089.

[33] A. P. Kirilyuk, *Complex-Dynamic Origin of Consciousness and Sustainability Transition* (LAP LAMBERT Academic Publishing, Saarbrücken, 2014). ArXiv:physics/0409140.

[34] A. P. Kirilyuk, "Unreduced Dynamic Complexity: Towards the Unified Science of Intelligent Communication Networks and Software", In: *IFIP, Vol. 229, Network Control and Engineering for QoS, Security, and Mobility, IV*, Ed. D. Gaïti (Springer, Boston, 2007), p. 1. ArXiv:physics/0603132, hal-00020771.

A. P. Kirilyuk and M. Ulieru, "IT Complexity Revolution: Intelligent Tools for the Globalised World Development", In: *IT Revolutions*, Eds. M. Ulieru, P. Palensky and R. Doursat (Springer, Berlin Heidelberg, 2009), p. 1. ArXiv:0910.5495.

A. P. Kirilyuk, "Unreduced Complex Dynamics of Real Computer and Control Systems", *Proceedings of the 20th International Conference on Control Systems and Computer Science (27-29 May 2015, Bucharest, Romania)*, Eds. I. Dumitrache, A. M. Florea, F. Pop and A. Dumitraşcu (IEEE Computer Society CPS, Los Alamitos, 2015), Vol. 2, p. 557. Hal-01162395, viXra:1507.0038.

[35] A. P. Kirilyuk, "Towards Sustainable Future by Transition to the Next Level Civilisation", In: *The Future of Life and the Future of Our Civilisation*, Ed. V. Burdyuzha (Springer, Dordrecht, 2006), p. 411. ArXiv:physics/0509234.

A. P. Kirilyuk, "Dynamic Origin of Evolution and Social Transformation", *Nanosystems, Nanomaterials, Nanotechnologies* **11** (2013) 1. ArXiv:1212.1939, hal-00760100.

[36] A. P. Kirilyuk, "Sustainable Reason-Based Governance after the Globalisation Complexity Threshold", submitted for the *Global Challenges Prize 2017*, 17 p. (2018). Hal-01736865, viXra:1803.0275.

[37] A. P. Kirilyuk, "Unified Complex-Dynamical Theory of Financial, Economic, and Social Risks and Their Efficient Management: Reason-Based Governance for Sustainable Development", In: A. P. Kirilyuk, *Theory of Everything, Ultimate Reality, and the End of Humanity: Extended Sustainability by the Universal Science of Complexity* (LAP Lambert Academic Publishing, Beau Bassin, 2017), section 8.4, pp. 194-199 (2018). Hal-01797479, SSRN-3183233.

[38] A. P. Kirilyuk, "Complex-Dynamic Origin of Quantised Relativity and Its Manifestations at Higher Complexity Levels", In: A. P. Kirilyuk, *Theory of Everything, Ultimate Reality, and the End of Humanity: Extended Sustainability by the Universal Science of Complexity*

(LAP Lambert Academic Publishing, Beau Bassin, 2017), section 8.3, pp. 186-194 (2019). Hal-02107696, PhilPapers, viXra:1904.0449.

[39] A. P. Kirilyuk, "The Last Scientific Revolution", in *Against the Tide. A Critical Review by Scientists of How Physics and Astronomy Get Done*, Eds. M. Lopez-Corredoira and C. Castro Perelman (Universal Publishers, Boca Raton, 2008), p. 179. ArXiv:0705.4562.

A. P. Kirilyuk, "From the End of Unitary Science Projection to the Causally Complete Complexity Science: Extended Mathematics, Solved Problems, New Organisation and Superior Purposes", In: A. P. Kirilyuk, *Theory of Everything, Ultimate Reality, and the End of Humanity: Extended Sustainability by the Universal Science of Complexity* (LAP Lambert Academic Publishing, Beau Bassin, 2017), section 8.5, pp. 199-209. Hal-01864363, vixra:1808.0643.

[40] A. P. Kirilyuk, "Double Solution with Chaos: Dynamic Redundance and Causal Wave-Particle Duality", *ArXiv:quant-ph/9902015* (1999).

A. P. Kirilyuk, "Double Solution with Chaos: Completion of de Broglie's Nonlinear Wave Mechanics and its Intrinsic Unification with the Causally Extended Relativity", *ArXiv:quant-ph/9902016* (1999).

A. P. Kirilyuk, "Causal Wave Mechanics and the Advent of Complexity. IV. Dynamical origin of quantum indeterminacy and wave reduction", *ArXiv:quant-ph/9511037* (1995).

A. P. Kirilyuk, "Causal Wave Mechanics and the Advent of Complexity. V. Quantum field mechanics", *ArXiv:quant-ph/9511038* (1995).

A. P. Kirilyuk, "New concept of dynamic complexity in quantum mechanics and beyond", *ArXiv:quant-ph/9805078* (1998).

[41] A. P. Kirilyuk, "Quantum Field Mechanics: Complex-Dynamical Completion of Fundamental Physics and Its Experimental Implications", *ArXiv:physics/0401164* (2004).

A. P. Kirilyuk, "Electron as a Complex-Dynamical Interaction Process", *ArXiv:physics/0410269* (2004).

A. P. Kirilyuk, "Universal gravitation as a complex-dynamical process, renormalised Planckian units, and the spectrum of elementary particles", *ArXiv:gr-qc/9906077* (1999).

[42] A. P. Kirilyuk, "Consistent Cosmology, Dynamic Relativity and Causal Quantum Mechanics as Unified Manifestations of the Symmetry of Complexity", Report presented at the Sixth International Conference "Symmetry in Nonlinear Mathematical Physics" (Kiev, 20-26 June 2005), *ArXiv:physics/0601140; hal-00017268*. Russian version: *Nanosystems, Nanomaterials, Nanotechnologies* **11** (2013) 437.

A. P. Kirilyuk, "Cosmological Problem Solution by Complex-Dynamical Interaction Analysis", *Nanosystems, Nanomaterials, Nanotechnologies* **12** (2014) 809. ArXiv:physics/0510240, hal-00012639.

[43] A. P. Kirilyuk, "Complex-Dynamical Solution to Many-Body Interaction Problem and Its Applications in Fundamental Physics", *Nanosystems, Nanomaterials, Nanotechnologies* **10** (2012) 217. ArXiv:1204.3460.

[44] A. P. Kirilyuk, "What Do They Actually Probe at LHC?", *Nanosystems, Nanomaterials, Nanotechnologies* **11** (2013) 217. Hal-00740459, viXra:1210.0162.

A. P. Kirilyuk, "Causally Complete Higgsless Theory from Complex Dynamics of Unreduced Interaction", *Nanosystems, Nanomaterials, Nanotechnologies* **13** (2015)161. Hal-01185647, viXra:1508.0174.

[45] A. P. Kirilyuk, "75 Years of the Wavefunction: Complex-Dynamical Extension of the Original Wave Realism and the Universal Schrödinger Equation", *ArXiv:quant-ph/0101129* (2001).

A. P. Kirilyuk, “75 Years of Matter Wave: Louis de Broglie and Renaissance of the Causally Complete Knowledge”, *ArXiv:quant-ph/9911107* (1999).

A. P. Kirilyuk, “100 Years of Quanta: Complex-Dynamical Origin of Planck's Constant and Causally Complete Extension of Quantum Mechanics”, *ArXiv:quant-ph/0012069* (2000).

[46] A. P. Kirilyuk, “Quantum chaos and fundamental multivaluedness of dynamical functions”, *Annales de la Fondation Louis de Broglie* **21** (1996) 455. ArXiv:quant-ph/9511034, 35, 36.

[47] A. P. Kirilyuk, “Theory of charged particle scattering in crystals by the generalised optical potential method”, *Nucl. Instr. Meth.* **B69** (1992) 200.

[48] P. H. Dederichs, “Dynamical Diffraction Theory by Optical Potential Methods”, *Solid State Physics: Advances in Research and Applications*, Eds. H. Ehrenreich, F. Seitz and D. Turnbull (Academic Press, New York) **27** (1972) 136.

[49] M. J. Donald, “Quantum theory and the brain”, *Proc. Roy. Soc. London A* **427** (1990) 43.

[50] S. Hameroff and R. Penrose, “Orchestrated reduction of quantum coherence in brain microtubules: A model for consciousness”, *Neural Network World* **5** (1995) 793.

S. Hameroff, “Quantum computation in brain microtubules? The Penrose-Hameroff ‘Orch OR’ model of consciousness”, *Phil. Trans. Roy. Soc. London A* **356** (1998) 1869.

S. Hagan, S. R. Hameroff and J.A. Tuszynski, “Quantum Computation in Brain Microtubules: Decoherence and Biological Feasibility”, *Phys. Rev. E* **65** (2002) 061901. ArXiv:quant-ph/0005025.

See also http://www.quantumconsciousness.org/.

[51] G. Vitiello, “The dissipative brain”, In: *Brain and Being - At the boundary between science, philosophy, language and arts*, Eds. G. G. Globus, K. H. Pribram and G. Vitiello (John Benjamins, Amsterdam, 2004), p. 317. ArXiv:q-bio.OT/0409037.

E. Pessa and G. Vitiello, “Quantum noise induced entanglement and chaos in the dissipative quantum model of brain”, *Int. J. Mod. Phys. B* **18** (2004) 841. ArXiv:quant-ph/0406161.

E. Alfinito and G. Vitiello, “Formation and life-time of memory domains in the dissipative quantum model of brain”, *Int. J. Mod. Phys. B* **14** (2000) 853; 1613. ArXiv:quant-ph/0002014.

[52] A. Mershin, D. V. Nanopoulos and E. M. C. Skoulakis, “Quantum Brain?”, *Proc. Acad. Athens* **74** (1999) 148. ArXiv:quant-ph/0007088.

[53] M. Perus and H. Bischof, “A neural-network-like quantum information processing system”, *ArXiv:quant-ph/0305072* (2003).

[54] S. Gupta and R. K. P. Zia, “Quantum Neural Networks”, *Journal of Computer and System Sciences* **63** (2001) 355. ArXiv:quant-ph/0201144.

[55] E. C. Behrman, V. Chandrashekar, Z. Wang, C. K. Belur, J. E. Steck and S. R. Skinner, “A Quantum Neural Network Computes Entanglement”, *ArXiv:quant-ph/0202131* (2002).

[56] H. P. Stapp, “Chance, Choice, and Consciousness: The Role of Mind in the Quantum Brain”, *ArXiv:quant-ph/9511029* (1995).

H. P. Stapp, “Decoherence, Quantum Zeno Effect, and the Efficacy of Mental Effort”, *ArXiv:quant-ph/0003065* (2000).

H. P. Stapp, “From quantum nonlocality to mind-brain interaction”, *ArXiv:quant-ph/0009062* (2000).

[57] M. Dugic, M. M. Cirkovic and D. R. Rakovic, "On a Possible Physical Metatheory of Consciousness", *Open Systems & Information Dynamics* **9** (2002) 153. ArXiv:quant-ph/0212128.

[58] A. Kaivarainen, "Hierarchic model of consciousness: from molecular Bose condensation to synaptic reorganisation", *ArXiv:physics/0003045* (2000).

[59] H. Hu and M. Wu, "Spin-mediated consciousness theory: possible roles of neural membrane nuclear spin ensembles and paramagnetic oxygen", *Medical Hypotheses* **63** (2004) 633. ArXiv:quant-ph/0208068.

[60] J. Satinover, *The Quantum Brain: The Search for Freedom and the Next Generation of Man* (John Wiley, New York, 2001).

[61] A. Khrennikov, "Classical and quantum mechanics on information spaces with applications to cognitive, psychological, social and anomalous phenomena", *Found. Phys.* **29** (1999) 1065. ArXiv:quant-ph/0003016.

A. Khrennikov, "Quantum-like formalism for cognitive measurements", *Biosystems* **70** (2003) 211. ArXiv:quant-ph/0111006.

A. Khrennikov, "Probabilistic pathway representation of cognitive infromation", *J. Theor. Biology* **231** (2004) 597. ArXiv:q-bio.NC/0408022.

[62] P. Gralewicz, "Quantum computing in neural networks", *ArXiv:quant-ph/0401127* (2004).

[63] Y. Kurita, "Indispensable Role of Quantum Theory in the Brain Dynamics", *Biosystems* **80** (2005) 263. ArXiv:quant-ph/0408148.

[64] D. Aerts and M. Czachor, "Quantum aspects of semantic analysis and symbolic artificial intelligence", *J. Phys. A* **37** (2004) L123. ArXiv:quant-ph/0309022.

D. Aerts, J. Broekaert and L. Gabora, "A Case for Applying an Abstracted Quantum Formalism to Cognition", *New Ideas in Psychology* **29** (2011) 136. ArXiv:quant-ph/0404068.

[65] E. A. Novikov, "Quaternion dynamics of the brain", *ArXiv:nlin.PS/0311047* (2003).

E. A. Novikov, "Manipulating consciousness", *ArXiv:nlin.PS/0403054* (2004)

[66] V. K. Jirsa and H. Haken, "A derivation of a macroscopic field theory of the brain from the quasi-microscopic neural dynamics", *Physica D* **99** (1997) 503.

V. K. Jirsa and H. Haken, "Field theory of electromagnetic brain activity", *Phys. Rev. Lett.* **77** (1996) 960.

[67] T. D. Frank, A. Daffertshofer, C. E. Peper, P. J. Beek and H. Haken, "Towards a comprehensive theory of brain activity: Coupled oscillator systems under external forces", *Physica D* **144** (2000) 62.

[68] M. Toussaint, "Learning a world model and planning with a self-organising, dynamic neural system", In: *Advances of Neural Information Processing Systems 16*, Eds. S. Thrun, L. K. Saul and B. Schölkopf (MIT Press, Cambridge, 2004), p. 929. ArXiv:nlin.AO/0306015.

[69] *Biophysical Aspects of Coherence* (conference 1995), In: *Neural Network World* **5** (1995) No. 5.

G. L. Sewell, "Quantum model of biological coherence and chaos", *Ibid.*, p. 725.

J. Pokorný, "Fröhlich coherent states: Implications for interaction in biological systems and information transfer", *Ibid.*, p. 831.

[70] A. Juarrero, *Dynamics in Action. Intentional Behaviour as a Complex System* (MIT Press, Cambridge, 2002).

[71] J. A. S. Kelso, *Dynamic Patterns: The Self-Organisation of Brain and Behaviour* (MIT Press, Cambridge, 1995).

[72] S. Lloyd, "Ultimate physical limits to computation", *Nature* **406** (2000) 1047. ArXiv:quant-ph/9908043.

S. Lloyd, "Computational capacity of the Universe", *Phys. Rev. Lett.* **88** (2002) 237901. ArXiv:quant-ph/0110141.

[73] S. Lloyd, "Universe as quantum computer", *Complexity* **3** (1997) 32. ArXiv:quant-ph/9912088.

[74] J. Horgan, *The End of Science. Facing the Limits of Knowledge in the Twilight of the Scientific Age* (Addison-Wesley, Helix, 1996).

J. Horgan, "The Final Frontier", *Discover Magazine*, October (2006), http://discovermagazine.com/2006/oct/cover.

[75] J. Horgan, "From Complexity to Perplexity", *Scientific American*, June (1995) 74.

[76] M. Lopez-Corredoira and C. Castro Perelman, Eds., *Against the Tide. A Critical Review by Scientists of How Physics and Astronomy Get Done* (Universal Publishers, Boca Raton, 2008); http://philsci-archive.pitt.edu/4046/, http://vixra.org/abs/0909.0002, http://www.archivefreedom.org/tide.htm.

[77] M. Lopez-Corredoira, *The Twilight of the Scientific Age* (Brown Walker Press, Boca Raton, 2013). See also: *ArXiv:1305.4144*.

[78] A. Unzicker and S. Jones, *Bankrupting Physics: How Today's Top Scientists are Gambling Away Their Credibility* (Palgrave Macmillan, New York, 2013).

[79] P. Wells, "Perimeter Institute and the crisis in modern physics", *Maclean's*, 5 September (2013), https://www.macleans.ca/politics/ottawa/perimeter-institute-and-the-crisis-in-modern-physics/.

See also http://www.math.columbia.edu/~woit/wordpress/?p=6238.

[80] J. P. A. Ioannidis, "Contradicted and Initially Stronger Effects in Highly Cited Clinical Research", *JAMA* **294** (2005) 218. Accessible at http://jama.ama-assn.org/cgi/content/full/294/2/218.

J. P. A. Ioannidis, "Why Most Published Research Findings Are False", *PLoS Med.* **2**(8) (2005) e124. Accessible at http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1182327.

[81] H. H. Bauer, "Science in the 21st Century: Knowledge Monopolies and Research Cartels", *Journal of Scientific Exploration* **18** (4) (2004). Accessible at https://www.researchgate.net/publication/252797131.

[82] M. Gleiser, *A Tear at the Edge of Creation: A Radical New Vision for Life in an Imperfect Universe* (Free Press, New York, 2010).

M. Gleiser, "The imperfect universe: Goodbye, theory of everything", *New Scientist*, 8 May (2010), No. 2759, p. 28. http://www.newscientist.com/article/mg20627591.200-the-imperfect-universe-goodbye-theory-of-everything.html.

M. Gleiser, "Theory of Everything... Still Searching?", *13.7 Cosmos & Culture*, 9 March (2011), http://www.npr.org/blogs/13.7/2011/03/09/134373659/theory-of-everything-still-searching.

M. Gleiser, "Enough Already With This 'Theory Of Everything'", *13.7 Cosmos & Culture*, 28 August (2013), http://www.npr.org/blogs/13.7/2013/08/28/216095888/enough-already-with-this-theory-of-everything.

[83] M. Campbell, "What is the point of a theory of everything?", *New Scientist*, 12 October (2013), No. 2938, p. 36. http://www.newscientist.com/article/mg22029380.800-what-is-the-point-of-a-theory-of-everything.html.

[84] A. Noë, "Should We Expect A Theory Of Everything?", *13.7 Cosmos & Culture*, 7 February (2014), http://www.npr.org/blogs/13.7/2014/02/07/273020930/should-we-expect-a-theory-of-everything.

[85] G. Longo, M. Montévil and S. Kauffman, "No entailing laws, but enablement in the evolution of the biosphere", *ArXiv:1201.2069*.

S. Kauffman, "Beyond Reductionism Twice: No Laws Entail Biosphere Evolution, Formal Cause Laws Beyond Efficient Cause Laws", *ArXiv:1303.5684*.

S. Kauffman, "Beyond Entailing Law?", *13.7 Cosmos & Culture*, 20 June, 2011, http://www.npr.org/blogs/13.7/2011/06/20/137296039/beyond-entailing-law.

[86] T. Kuhn, *The Structure of Scientific Revolutions* (Chicago University Press, Chicago, 1970). First edition: 1962.