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Complex-Dynamical Nanobiotechnology Paradigm and Intrinsically Creative Evolution

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Complex nanosystem dynamics is analysed by the unreduced solution of arbitrary many-body interaction problem, leading to the fundamental dynamic multivaluedness and universal definition of dynamic complexity in terms of the number of system realisations. As shown, the genuine quantum and classical chaos can only be strong for a free-interaction nanoscale system providing exponentially huge, 'magic' efficiency of such unreduced interaction dynamics, which underlies the properties of life, intelligence, and consciousness. Various more or less chaotic regimes of irreducibly complex nanosystem dynamics as well as the rigorously specified transitions between them are reviewed. The obtained unified formalism for description of the unreduced complex nanosystem dynamics is based on the universal symmetry (conservation and transformation) of complexity unifying the extended versions of all usual laws and principles. The main principles of thus obtained new, complex-dynamical nanobiotechnology paradigm are summarised, and as shown, it is the only viable way of further sustainable nanotechnology and society development in the spirit of coevolution of the natural and artificial system complexity.

Складну динаміку наносистем проаналізовано за допомогою нередукованого розв'язку задачі довільної взаємодії багатьох тіл, яка приводить до фундаментальної динамічної багатозначности й універсального визначення динамічної складности у термінах кількости реалізацій системи. Показано, що в системі наномасштабних розмірів справжній квантовий і класичний хаос може бути тільки сильним, зумовлюючи експоненційно величезну, «магічну» ефективність динаміки такої нередукованої взаємодії, яка лежіть в основі властивостей життя, інтелекту та свідомости. Розглянуто різні, більш або менш хаотичні режими нередукованої складної динаміки наносистем, а також строго визначені переходи між ними. Одержано об'єднаний формалізм опису нередукованої складної динаміки наносистем, що ґрунтується на універсальній симетрії (збереженні та перетворенні) складности, яка поєднує розши-

рені версії усіх звичайних законів і принципів. Оглянуто основні засади одержаної таким чином нової парадигми складно-динамічної нанобіотехнології та показано, що це єдиний шлях наступного сталого розвитку нанотехнології і суспільства у дусі коеволюції складности природніх і штучних систем.

Сложная динамика наносистем проанализирована с помощью нередуцированного решения задачи произвольного взаимодействия многих тел, которое приводит к фундаментальной динамической многозначности и универсальному определению динамической сложности в терминах числа реализаций системы. Показано, что в системе наномасштабных размеров истинный квантовый и классический хаос может быть лишь сильным, давая экспоненциально огромную, «магическую» эффективность динамики такого нередуцированного взаимодействия, которая лежит в основе свойств жизни, интеллекта и сознания. Рассмотрены различные, более или менее хаотичные режимы нередуцированной сложной динамики наносистем, а также строго определённые переходы между ними. Полученный объединённый формализм описания нередуцированной сложной динамики наносистем основан на универсальной симметрии (сохранении и превращении) сложности, которая объединяет расширенные версии всех обычных законов и принципов. Рассмотрены основные принципы полученной таким образом новой парадигмы сложно-динамической нанобиотехнологии и показано, что это единственный путь последующего устойчивого развития нанотехнологии и общества в духе коэволюции сложности естественных и искусственных систем.

Key words: dynamic multivaluedness, complexity, chaos, self-organisation, fractal, many-body problem, quantum mechanics, nanobiotechnology, quantum computers.

Ключові слова: динамічні багатозначності, складність, хаос, самоорганізація, фрактал, проблема багатьох тіл, квантова механіка, нанотехнології, квантові комп'ютери.

Ключевые слова: динамические многозначности, сложность, хаос, самоорганизация, фрактал, проблема многих тел, квантовая механика, нанотехнологии, квантовые компьютеры.

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1. INTRODUCTION

While the huge and always growing scale of various nanotechnology applications becomes a major driving force of modern world development, the underlying fundamental science paradigm is mainly limited to traditional (quasi-)*regular* functioning of artificial nanostructures and nanomachines. However, as shown in previous

works [1, 2], the true nanoscale range of interacting system elements inevitably leads to strongly *irregular* dynamic regime of uniform, or global, chaos, as confirmed, in particular, by chaotic structure and dynamics of natural nanomachines in living organisms.

It is important that the difference between the two kinds of dynamics involves the original, qualitatively deep phenomenon of *dynamic multivaluedness* of *any* real interaction process [1–17], with its regular, *dynamically single-valued projection* being but a strongly simplified model of reality that becomes particularly inadequate in the case of ultimately small, nanoscale structures. The visible regularity of usual artificial nanostructures implies either their actually greater, rather microscale characteristic sizes or a very crude approximation in their theoretical description that can lead to essential mistakes and vain hopes. This is the case, for example, of the extremely popular projects of unitary quantum computation, which cannot be realised as such because of the inevitable and purely dynamic chaoticity [2]. On the other hand, the qualitatively different kind of real, chaotic (multivalued) nanosystem dynamics opens other perspectives of surprisingly high, 'magic' operation efficiency actually realised in natural nanostructures [1, 2, 7, 10–13].

In this paper, we provide a broad original review of this real, intrinsically complex nanosystem dynamics, including its rigorous mathematical basis, key features, huge efficiency and applied aspects (section 2). We further argue that our entire universe is essentially based on this kind of complex nanoscale dynamics, which provides the unified solution to various stagnating problems of fundamental physics, cosmology, biology and intelligence–consciousness theory, with numerous important applications (section 3). It follows that we should actively take this way also in artificial nanostructure realisation, using the mentioned huge efficiency of their unreduced complex-dynamical version for creation of qualitatively new kind of machinery with really 'magic' properties (that were often announced, but never realised, with unitary nanostructures). We draw a number of particular perspectives for such complex-dynamical nanotechnology, emphasizing its links to the omnipresent natural universe structure as additional support for the unique efficiency of this way of further nanotechnology development by the only possible harmonious coevolution of natural and artificial structures (sections 3 and 4).

2. UNREDUCED CHAOTIC DYNAMICS OF REAL NANOSYSTEMS AND ITS KEY FEATURES

We start our universal nanostructure description with a general formulation of a problem of arbitrary interaction of many elements,

such as atoms, molecules and elementary particles, in the nanoscale size range. Our system *existence equation* is but a unified Hamiltonian formulation of many-body interaction problem self-consistently confirmed by further analysis, in addition to such popular cases as Schrödinger equation for quantum dynamics and Hamilton–Jacobi equation for classical systems [2, 3, 7–15]:

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

where $h_k\left(q_k\right)$ is the generalised Hamiltonian (expressing a dynamic complexity measure, see below) of the k-th system component with the degrees of freedom q_k, $V_{kl}\left(q_k,q_l\right)$ is the (arbitrary) potential of interaction between the k-th and l-th components, $\Psi(\boldsymbol{Q})$ is the system state-function describing exhaustively its configuration, $\boldsymbol{Q}\equiv\left\{q_0,q_1,\ldots,q_N\right\}$, E is the generalised Hamiltonian eigenvalue, and summations are performed over all (N) system components. This more general timeless form of interaction description and its further analysis covers also the special case of time-dependent interaction (for open systems), where the eigenvalue E on the right is replaced by the partial time derivative.

A more relevant form of existence equation (1) is obtained by separating common system variable(s), $q_0\equiv\xi$ (describing, *e.g.*, system element position or interaction time dependence):

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

where now $\boldsymbol{Q}\equiv\left\{q_1,\ldots,q_N\right\}$, and $k,l\geq 1$ here and below.

If we express the problem in terms of eigensolutions for system components, then the existence equation (2) is transformed, in a standard way, to an equivalent system of equations for the respective state-function components $\psi_n\left(\xi\right)$ [2, 3, 7–15]:

$$\left[h_0\left(\xi\right)+V_{nn}\left(\xi\right)\right]\psi_n\left(\xi\right)+\sum_{n'\neq n}V_{nn'}\left(\xi\right)\psi_{n'}\left(\xi\right)=\eta_n\psi_n\left(\xi\right), \tag{3}$$

where

$$\eta_n\equiv E-\varepsilon_n,\ \ \varepsilon_n\equiv\sum_k\varepsilon_{n_k},\ \ V_{nn'}\left(\xi\right)=\sum_k\left[V_{0k}^{nn'}\left(\xi\right)+\sum_{l>k}V_{kl}^{nn'}\right], \tag{4}$$

$$V_{0k}^{nn'}\left(\xi\right)=\int\limits_{\Omega_Q}d\boldsymbol{Q}\Phi_n^*(\boldsymbol{Q})V_{0k}\left(\xi,q_k\right)\Phi_{n'}(\boldsymbol{Q}), \tag{5}$$

$$V_{kl}^{nn'}=\int\limits_{\Omega_Q}d\boldsymbol{Q}\Phi_n^*(\boldsymbol{Q})V_{kl}\left(q_k,q_l\right)\Phi_{n'}(\boldsymbol{Q}), \tag{6}$$

$$\Phi_n(\boldsymbol{Q}) \equiv \varphi_{1n_1}(q_1)\varphi_{2n_2}(q_2)\ldots\varphi_{Nn_N}(q_N),$$

and $\{\varphi_{kn_k}(q_k)\}$, $\{\varepsilon_{n_k}\}$ are eigenfunctions and eigenvalues of noninteracting system components:

$$h_k(q_k)\varphi_{kn_k}(q_k) = \varepsilon_{n_k}\varphi_{kn_k}(q_k), \tag{7}$$

$$\Psi(\xi, \boldsymbol{Q}) = \sum_{n\equiv(n_1,n_2,\ldots,n_N)} \psi_n(\xi)\Phi_n(\boldsymbol{Q}), \tag{8}$$

with $n \equiv (n_1, n_2, \ldots, n_N)$ running through all eigenstate combinations (starting at $n = 0$ for the ground state).

As we do not want to use any usual approximation for problem solution (killing the essential features of unreduced interaction dynamics), we try to solve the unreduced system of equations (3) by expressing the excited state-function component $\psi_n(\xi)$ $(n > 0)$ through the ground-state component $\psi_0(\xi)$ with the help of standard Green's function technique and substituting the result into the equation for $\psi_0(\xi)$, which leads to the *effective existence equation* for $\psi_0(\xi)$ [2, 3, 7–16]:

$$\left[h_0(\xi) + V_{eff}(\xi;\eta)\right]\psi_0(\xi) = \eta\psi_0(\xi), \tag{9}$$

where the *effective (interaction) potential* (*EP*) $V_{eff}(\xi;\eta)$ is defined as

$$V_{eff}(\xi;\eta)\psi_0(\xi) = V_{00}(\xi)\psi_0(\xi) + \sum_{n,i} \frac{V_{0n}(\xi)\psi^0_{ni}(\xi)\int\limits_{\Omega_\xi} d\xi'\psi^{0*}_{ni}(\xi')V_{n0}(\xi')\psi_0(\xi')}{\eta - \eta^0_{ni} - \varepsilon_{n0}} \tag{10}$$

and includes the eigensolutions $\{\psi^0_{ni}(\xi)\}, \{\eta^0_{ni}\}$ of a truncated system of equations (containing no equations and contributions for $\psi_0(\xi)$ in (3)):

$$\left[h_0(\xi) + V_{nn}(\xi)\right]\psi_n(\xi) + \sum_{n'\neq n} V_{nn'}(\xi)\psi_{n'}(\xi) = \eta_n\psi_n(\xi), \tag{11}$$

with $n, n' \neq 0$ here and below, $\eta \equiv \eta_0 = E - \varepsilon_0$, and $\varepsilon_{n0} \equiv \varepsilon_n - \varepsilon_0$.

The eigensolutions, $\{\psi_{0i}(\xi), \eta_i\}$, of the effective problem formulation (9), (10) are used to obtain other state-function components $\psi_{ni}(\xi)$ and then the total system state function (4) (the general problem solution):

$$\Psi(\xi,Q)=\sum_i c_i\left[\psi_{0i}(\xi)\Phi_0(Q)+\sum_{n>0}\psi_{ni}(\xi)\Phi_n(Q)\right], \qquad (12)$$

where coefficients c_i are determined by state-function matching at the boundary/configuration where interaction vanishes.

The *key point* in the effective description of the unreduced many-body interaction, crucially important for real nanosystem dynamics, is the *explicitly nonlinear* structure of the effective dynamic equation (9), (10), which contains the eigensolutions $(\eta,\{\psi_{ni}(\xi)\})$ to be found. It is not difficult to see that it leads to essential growth of the number of its equally valid solutions, due to the respective growth of the highest power of its characteristic equation for eigenvalues [1–17]. As these solutions, called system *realisations*, are all *equally real* and *mutually incompatible* (due to their physical completeness), they are forced to permanently replace each other in *dynamically random*, or *chaotic*, order thus defined. Any measured quantity, suitably represented by system density $\rho(\xi,Q)$ (given by the squared modulus of the state-function for 'wave-like' levels or the state-function itself for 'particle-like' levels), is obtained as a specific, *dynamically probabilistic sum* of respective quantities for all realisations:

$$\rho(\xi,Q)\equiv\left|\Psi(\xi,Q)\right|^2=\sum_{r=1}^{N_\Re}{}^{\oplus}\,\rho_r(\xi,Q)=\sum_{r=1}^{N_\Re}{}^{\oplus}\left|\Psi_r(\xi,Q)\right|^2, \qquad (13)$$

where $N_\Re$ is the number of realisations (determined by the number of system eigenmode combinations), $\rho_r(\xi,Q)\equiv\left|\Psi_r(\xi,Q)\right|^2$ is the r-th realisation density, and the dynamically probabilistic sum, designated by $\oplus$, describes the mentioned *dynamically random change* of system realisations. In accord with (12), the r-th realisation state-function $\Psi_r(\xi,Q)$ is obtained from the effective problem solution as

$$\Psi_r(\xi,Q)=\sum_i c_i^r\left[\Phi_0(Q)\psi_{0i}^r(\xi)+\right.$$

$$\left.+\sum_{n,i'}\frac{\Phi_n(Q)\psi_{ni'}^0(\xi)\int_{\Omega_\xi}d\xi'\psi_{ni'}^{0*}(\xi')V_{n0}(\xi')\psi_{0i}^r(\xi')}{\eta_i^r-\eta_{ni'}^0-\varepsilon_{n0}}\right], \qquad (14)$$

where $n\neq 0$, c_i^r are matching coefficients giving the generalised Born's rule for realisation probabilities [1] (see below), and $\{\psi_{0i}^r(\xi),\eta_i^r\}$ are the r-th realisations' eigensolutions of effective existence equation (9), (10).

Thus discovered plurality of mutually incompatible, but equally real solutions of the unreduced interaction problem is called *dynamic multivaluedness*, or *redundance*, the property leading to the universally defined, omnipresent dynamic randomness, or chaos, and dynamic complexity [1–17] (see below). The complementary and equally universal feature of the unreduced interaction process is due to the *dynamic entanglement* of interacting system components (or degrees of freedom) described by sums of products of eigenfunctions of different components depending on their respective degrees of freedom in the general solution of unreduced problem (12)–(14). Similar to dynamic multivaluedness, it is absent in usual, *dynamically single-valued* (perturbative or 'model') problem solution and further amplified by ultimately detailed elaboration of the unreduced solution, where the auxiliary, truncated system equations (11) participating in the formulation of the first-level solution (9)-(14) is progressively solved by the same EP method applied to a (finite) series of ever more truncated higher-level auxiliary systems of equations. This leads to the ultimately complete expression of the general solution of the unreduced interaction problem in the form of *probabilistic (multivalued) dynamical fractal* whose hierarchically connected structural levels are made of incompatible, chaotically changing realisations (as opposed to usual, dynamically single-valued and dynamically trivial fractals) [2, 6, 7, 10, 13, 15, 18, 19]:

$$\rho(\xi, Q) = \sum_{r,r',r''\ldots}^{N_{\Re}} {}^{\oplus}\rho_{rr'r''\ldots}(\xi, Q), \qquad (15)$$

where the dynamically probabilistic sum is taken over all realisations of all levels of the dynamical fractal.

The fractally structured dynamic entanglement of interacting degrees of freedom within the chaotically changing system realisations determine the *tangible material quality* of resulting system structure, which is absent in any usual, dynamically single-valued model providing only a schematic, purely abstract, 'immaterial' projection of real system structure and dynamics. This conventional dynamically single-valued projection is also called *unitary* solution and description, as it provides a qualitatively smooth system structure and only formally introduced evolution, without real change and causal time flow (see also below).

The property of dynamic multivaluedness and related randomness naturally includes also the *universal dynamic origin* and *definition* of *probability*, actually referring to (also universally defined) *events* of system realisation *emergence*. Since all elementary realisations are equally probable by origin, the *a priori dynamic probability* α_r of each r-th realisation emergence is given by $\alpha_r = 1/N_{\Re}$, but as in

the general case these elementary realisations are grouped into compound realisations containing dense groups of similar, experimentally unresolved elementary realisations (cf. multivalued self-organisation below), the general expression of dynamic probability (of realisation emergence) is given by

$$\alpha_r = \frac{N_r}{N_{\Re}} \quad \left(N_r = 1, \ldots, N_{\Re}; \sum_r N_r = N_{\Re} \right), \quad \sum_r \alpha_r = 1, \tag{16}$$

where $1 \le N_r \le N_{\Re}$ is the number of elementary realisations within the r-th observed compound realisation. This expression is directly generalised to multilevel fractal structure of the unreduced solution (15), so that the averaged, expectation value of the observed system density, $\rho_{ex}(\xi, Q)$, (for long enough observation times) is given by

$$\rho_{ex}(\xi, Q) = \sum_{r,r',r''\ldots}^{N_{\Re}} \alpha_{rr'r''\ldots} \rho_{rr'r''\ldots}(\xi, Q). \tag{17}$$

Note, however, that the general, dynamically probabilistic sum of system realisations (15) represents the general solution of unreduced interaction problem also for the case of any small number of realisation emergence events and remains valid even before any event occurs at all. It describes the 'living' structure of dynamical fractal permanently probabilistically moving in real time, the property absent in any unitary theory and crucially important for real nanosystem dynamics and efficiency (see below).

The detailed algebraic and geometric analysis of effective problem formulation (9)–(10) revealing the dynamic multivaluedness phenomenon shows [1–16] that in addition to the complete set of $N_{\Re}$ system realisations determining its structure, the unreduced interaction problem solution contains one special realisation with a strongly reduced number of contributing elementary eigenvalues, which describes a transient system state during its transition between those ordinary, or *regular*, structure-forming realisations. We call that transitional state the *intermediate*, or *main*, system realisation and show that it provides the universal and causally complete extension of usual quantum mechanical wave function to *any* system dynamics [2, 3, 10–15]. This *generalised wave function*, or *distribution function*, describes the state of transiently quasi-free system components that *dynamically disentangle* in the realisation change process, which explains the reduced number of eigenvalues and vanishing effective interaction magnitude for that intermediate realisation of generalised wave function. At the lowest, quantum levels of complexity, it provides the realistic extension of usual, abstract wave function, and at higher, classical complexity levels it

gives the physically real version of distribution function.

This causally complete version of generalised wave function in our unreduced interaction description naturally includes the important link to the above concept of dynamic realisation probability (16), in the form of *generalised Born's rule* stating that the wave function magnitude at a given local configuration determines the probability α_r of realisation emergence just around that configuration:

$$\alpha_r = \left|\Psi\left(x_r\right)\right|^2, \tag{18}$$

where $\Psi(x)$ is the generalised wave function, and x_r—the r-th realisation configuration (one may also have here $\alpha_r = \Psi\left(x_r\right)$ for 'particle-like' complexity levels). This physically transparent relation can be rigorously derived from the state-function matching conditions (determining the coefficients c_i^r in (16)) and is practically useful for system description due to the universal dynamical equation for $\Psi(x)$ (the generalised Schrödinger equation, see below) [2, 3, 10–15].

The proposed causal interpretation of the generalised wave function (or distribution function) of any real system and interaction process as the physically real 'realisation probability field' implies also the generalised and causal interpretation of the (originally) quantum-mechanical, probabilistically interpreted '*linear combination' of eigenstates*. It becomes clear now, within the dynamic redundance paradigm [2, 3, 10–15], that the unreduced interaction dynamics consists in *permanent system transitions* between those state-realisations, which are all *really taken* by the system probabilistically (at random, cf. (15)), with probabilities determined dynamically by respective numbers of elementary realisations, in accord with the dynamic probability definition (16) and the above causal Born's rule interpretation (18).

We can finally provide the *universal and rigorous definition of dynamic complexity C* of any real system as a growing function of the number of system realisations or their change rate, equal to zero for the (unrealistic) case of only one realisation [1–16]:

$$C = C\left(N_{\Re}\right),\ dC/dN_{\Re} > 0,\ C(1) = 0, \tag{19}$$

with, for example, $C\left(N_{\Re}\right) = C_0 \ln\left(N_{\Re}\right)$ or $C\left(N_{\Re}\right) = C_0\left(N_{\Re} - 1\right)$. The case of $N_{\Re} = 1$, $C\left(N_{\Re}\right) = 0$ exclusively considered in usual, dynamically single-valued (unitary) theory, including its numerous, inevitably non-universal and contradictory *imitations* of complexity, corresponds only to effectively zero-dimensional, point-like projection of unreduced, multivalued system dynamics, which destroys all its

essential features (see below). The latter are particularly important, as we shall see, for the unreduced nanosystem dynamics, where frequent transitions between various regimes of genuine complex dynamics are inevitable and omnipresent.

Specific features of real nanosystem dynamics are revealed by the detailed analysis of the EP formalism Eqs. (10), (14) taking into account all the unreduced interaction effects. We note, first of all, that contrary to usual, unitary nanoscience models, any real nanosystem dynamics is a dynamically multivalued, chaotic one, with permanent change of system realisations in causally random order. Moreover, we show that, just for the case of nanoscale dynamics, one is usually left with the particularly irregular regime of uniform, or global, chaos, while the opposite case of relatively regular, though always multivalued, self-organisation is a much less evident situation, which can actually emerge with growing characteristic sizes and transition from quantum to classical behaviour [1, 2].

This limiting regime of externally regular multivalued dynamics is obtained in the case of essentially differing characteristic system frequencies, or eigenvalue separations, such as the frequencies of internal element dynamics, $\omega_q = \Delta\varepsilon_n / \mathcal{A}_0$, and inter-element dynamics, $\omega_\xi = \Delta\eta_i / \mathcal{A}_0$, where $\Delta\varepsilon_n$ is the separation of eigenvalues ε_{n0} in (10), (14), $\Delta\eta_i$ the separation of eigenvalues η^0_{ni}, and $\mathcal{A}_0$ is the characteristic action value. If, for example, $\omega_\xi \ll \omega_q$ (or $\Delta\eta_i \ll \Delta\varepsilon_n$), then one can neglect the η^0_{ni} dependence on i in (10), (14), which leads to the local limit for the EP and state-function due to the completeness of eigenfunction set $\{\psi^0_{ni}(\xi)\}$:

$$V_{eff}(\xi;\eta) = V_{00}(\xi) + \sum_n \frac{\left|V_{0n}(\xi)\right|^2}{\eta - \eta^0_{ni} - \varepsilon_{n0}}, \qquad (20)$$

$$\Psi_r(\xi, Q) = \sum_i c^r_i \left[\Phi_0(Q) + \sum_n \frac{\Phi_n(Q) V_{n0}(\xi)}{\eta^r_i - \eta^0_{ni'} - \varepsilon_{n0}}\right] \psi^r_{0i}(\xi), \qquad (21)$$

where the respective averaged values of η^0_{ni}, $\eta^0_{ni'}$ are implied, and the usual case of Hermitian interaction potential is assumed for brevity. It is easy to see that in this case the system performs very frequent transitions between its very similar realisations thus giving the impression of externally regular shapes and trajectories. We therefore call this limiting case *multivalued self-organised criticality* (*SOC*), taking into account also the multilevel (fractal) realisa-

tion hierarchy mentioned above that forms in this limit characteristic (but now intrinsically chaotic) SOC patterns of 'sustainable fluctuations' around the average shape [1–13, 18, 19].

However, this relatively regular regime of 'ordered chaos' can hardly be realised at the smallest scale of genuine nanosystem because in this case the eigenvalue separation and frequencies, related to respective spatial sizes, cannot vary and differ essentially. The genuine nanoscale level dynamics corresponds instead to the opposite limiting case of comparable level separations or frequencies (the situation of resonance), $\Delta\eta_i \simeq \Delta\varepsilon_n$ (or $\omega_\xi \simeq \omega_q$). In that case, different realisation eigenvalues intermingle randomly, and we obtain essentially different realisations replacing each other chaotically with relatively low frequencies comparable to those of their internal motions, which give the evident situation of explicitly irregular, strong chaoticity forming the regime of *uniform, or global, chaos*. Simultaneously, we obtain the true meaning of the *phenomenon of resonance* practically inevitable for nanoscale systems and giving rise to the *onset of global chaoticity*, whose *criterion* acquires the rigorously derived exact expression [1–4, 10–13, 18, 19]:

$$\kappa \equiv \frac{\Delta\eta_i}{\Delta\varepsilon_n} = \frac{\omega_\xi}{\omega_q} \simeq 1\,, \tag{22}$$

where κ is the introduced parameter of *chaoticity*. While κ grows from 0 to 1, system behaviour changes from the global regularity of SOC (at $\kappa \ll 1$) to the global chaoticity (at $\kappa \simeq 1$), where chaoticity increases by a more abrupt step each time κ passes by a higher resonance ($\kappa = m/n$, with moderate integer $n > m \geq 1$). The situation of unreduced many-body nanosystem dynamics corresponds thus to strong chaoticity of $\kappa \sim 1$, which can pass to a more regular SOC regime of $\kappa \ll 1$ (or $\kappa \gg 1$, for a 'complementary', usually less useful system configuration) only with growing characteristic sizes (*e.g.*, in 'measurement' parts).

This dominating regime of strong chaoticity and irregular process configuration for genuine nanosystem dynamics is related also to its essential *quantum* features persisting due to ultimately small, atomic-scale sizes of interacting element configurations. There is the well-known paradox of *quantum chaos* in usual (dynamically single-valued) chaos theory, where truly random dynamics is impossible in Hamiltonian quantum systems due to the absence of 'exponentially diverging trajectories' describing the origin of classical chaoticity. This fundamental limitation creates the unpleasant violation of the even more fundamental correspondence principle imposing a noncontradictory, direct transition between respective quantum and classical features in the classical limit of relatively

small Planck's constant, $\hbar \to 0$. One could also conclude, based on this conventional quantum chaos theory with absent genuine dynamic randomness on quantum scale, that essentially quantum nanosystems (including those used for quantum computation) are basically regular, which would justify their unitary description, including (generally accepted) feasibility of unitary quantum computers.

While conventional theory tries to replace the absent genuine quantum chaos with 'quantum signatures of (classical) chaos', we show in our unreduced, dynamically multivalued description of (arbitrary) Hamiltonian quantum system dynamics [2, 3, 16] that the problem does not even appear in the unreduced theory, since the *genuine quantum chaos* with *truly random* system realisation change is obtained in the same way as in (any) classical dynamics, including the universal criterion (22) of global (genuine) chaos onset. The standard correspondence principle is re-established for any real, truly chaotic dynamics, including the transition (22) between the quasi-regular (self-organised) and essentially chaotic dynamical regimes [2, 3, 16].

The obtained result of genuine dynamic randomness in essentially quantum dynamics changes dramatically the general picture of nanosystem dynamics, especially in combination with the dominating regime of strong chaoticity, as explained above (Eq. (22)). As opposed to basically regular, both quantum and classical dynamics in usual picture, we obtain in reality the *highly chaotic, truly random* quantum and classical dynamics of any unreduced many-body nanosystem, with multiple occasional transitions between dynamical regimes of various regularity, from SOC to global chaos, as described above (in particular, unitary quantum computation in essentially quantum regimes is impossible in principle, even in a totally noiseless system [2]).

This messy, truly complex and permanently changing configuration of real nanoworld structure is further complicated by purely dynamic transitions between essentially quantum and classical (localised) kinds of behaviour readily occurring, according to our theory, just at those *ultimately small* (atomic) scales. Here too, we obtain the crucial difference with respect to standard, unitary theory picture, which relates classical behaviour emergence to sufficiently big, practically macroscopic system size, in particular due to the growing 'decoherence' effects in such greater systems (in the most popular interpretation). While this conventional picture directly contradicts multiple observation results, for both small-scale and larger structures (see [2, 3, 10, 14, 15] for details), and shows multiple conceptual difficulties, there is no other choice in the artificially limited, dynamically single-valued space of usual theory.

If we avoid those artificial restrictions in our unreduced, dynamically multivalued description of an *isolated*, purely quantum (nano)system dynamics, then we naturally obtain the *purely dynamic*, intrinsic *emergence of classical, permanently localised behaviour* in *elementary bound*, also *nanoscopic* systems, such as atoms, even when they are totally isolated from any external interactions [2, 3, 10, 14, 15]. The classical localisation effect for an elementary bound system is due to the truly (spatially) chaotic dynamics of the 'free quantum walk' of its components (starting from the so called quantum beat process for massive elementary particles [2, 3, 10, 14, 15]), so that in their bound state they cannot continue to walk randomly *and* coherently (in the same direction), performing instead a chaotic localised 'dance' around each other, with the probability of greater coherent walk exponentially decreasing with distance. This purely dynamic origin of classical behaviour explains also occasional *revivals of quantum behaviour* of those bound, normally localised systems due to their special interactions with other systems (*e.g.*, during quantum interference or Bose condensation process).

This result means that the diversity of variously (but usually essentially) chaotic regimes of real many-body nanosystems is additionally extended by those occasionally emerging (bound) classical states and interaction-driven revivals of quantum behaviour, revealing the huge genuine complexity of unreduced nanosystem dynamics [1, 2]. This leads to further qualitatively important feature of unreduced nanoworld dynamics, the *(exponentially) huge efficiency of unreduced complex dynamics*, explaining the observed 'magic' properties of life, intelligence and consciousness (which remain otherwise always 'mysterious' in the framework of the unitary theory) [1, 2, 7, 10–13, 18, 19].

We first recall the rigorously derived universal structure of the complete interaction problem solution in the form of dynamically probabilistic (multivalued) fractal (see Eq. (15)), which efficiently *adapts* its permanently chaotically changing branches to the environment and its own emerging structure. We obtain thus the important universal property of *dynamic adaptability* of natural structures, essentially based on the *dynamically multivalued search* process automatically performed by its chaotic realisation change and explaining the optimal performance of natural structure growth and dynamics (for a given level of complexity).

The latter can be characterised quantitatively by the mentioned effect of exponentially huge power of unreduced many-body interaction dynamics as compared to its usual, dynamically single-valued models [1, 2, 7, 10–13, 18, 19]. The maximum operation power, P, of a real complex system is proportional to the total number $N_{\Re}$ of

its realisations given by the number of combinations of its $N = N_{\rm unit} n_{\rm link}$ (essential) interaction links (where $N_{\rm unit}$ is the number of interaction elements and $n_{\rm link}$ —the average number of links per element):

$$P \propto N_{\Re} \simeq N! \simeq \sqrt{2\pi N}(N/e)^N \sim N^N . \qquad (23)$$

Since for many real systems with macroscopic total size and nanoscopic operative structure N is already a large number (*e.g.*, $N \geq 10^{12}$ for brain or genome interactions [7, 10, 18]), we obtain 'exponentially huge', practically infinite P values just due to arbitrary interaction link combinations in the dynamically multivalued interaction search process. By contrast, any usual, dynamically single-valued (basically regular) operation mode or model for the same system size can only produce the power P_0 growing as N^{β} $(\beta \sim 1)$, so that $P/P_0 \sim N^{N-\beta} \sim N^N \to \infty$, which provides the rigorously substantiated quantitative explanation for the underlying 'magic' efficiency and properties of *life*, *intelligence* and *consciousness* (as well as for the persisting *in*efficiency of their usual, unitary modelling) [7, 10, 18].

We conclude this section with *applied aspects* of the revealed complex (multivalued) and essentially chaotic dynamics of real nanosystems. Note, first of all, that one may see certain contradiction between thus revealed character of unreduced interaction dynamics and the dominating nanotechnology paradigm and models based on essentially regular behaviour (*e.g.*, nanoscopic elements of computer chips and many other artificial structures). This contradiction is easily resolved by noting that this *quasi*-regular behaviour is possible due to the realised regime of SOC, far from the global chaos onset condition (22), *i.e.*, at $\kappa \ll 1$, according to the above unified classification of dynamic regimes. This situation can be realised especially for larger structures of the nano-microscale, showing predominantly classic behaviour, but also in a specially fixed, effectively one-dimensional (sequential) configuration, which is very far from arbitrary, unreduced nanosystem structure (*e.g.*, in natural nanobiosystems).

However, this 'easy regularity' of usual nanotechnology (which can never be absolute!) is obtained at the expense of losing the huge efficiency (23) of the unreduced, essentially chaotic dynamics, together with the ensuing 'magic' properties of (genuine) life, intelligence and consciousness, becoming increasingly important for practical applications. On the other hand, various attempts to realise unreduced nanomachines at ultimately small scales and in essentially quantum regimes within the same, unitary nanotechnology paradigm easily lead to fundamentally wrong directions and vain illu-

sions of 'magic' efficiency. This is the case of unitary 'quantum computation', which has grown to a vast field of theoretical research, but in fact cannot be realised in principle, due to the inevitable quantum chaos condition (22), in accord with our genuine quantum chaos concept (absent in usual, basically regular quantum dynamics) [2]. One can realise instead the highly complicated, mixed, but indeed hugely efficient multivalued dynamics of unreduced many-body nanosystems described above. This extended, complex-dynamical nanotechnology paradigm has deep technological and social implications related to the necessary real, unreduced sustainability of further civilisation development (see section 4 below).

Detailed realisation of complex-dynamical nanotechnology concept should rely on the universal laws of complex dynamics of real structures reviewed in the next section.

3. REAL NANOSYSTEM COMPLEXITY AS A BASIS FOR THE UNIVERSE STRUCTURE DEVELOPMENT AND LAWS

We have seen in the previous section that the unreduced many-body nanoscale system dynamics exceeds essentially any its usual, dynamically single-valued (or unitary) version by the richness of the complete, dynamically multivalued behaviour with a variety of dynamic regimes of permanently chaotically changing system realisations. In order to properly understand the emerging multilevel, fractally structured system dynamics one must rely on the fundamental laws of the unreduced universal complexity (19) of this multivalued interaction dynamics.

In accordance with the universal nature of dynamic complexity introduced above, there is the single, unified law defining its dynamics and evolution, the *universal law of conservation and transformation, or symmetry, of complexity*, which also generalises and extends various particular dynamical laws and principles [2–13, 18, 19]. It starts from the fact that universal dynamic complexity $C\left(N_{\Re}\right)$ is determined by the number of system realisations $N_{\Re}$ (Eq. (19)) depending only on the number of element eigenmode combinations, which does not change during system evolution and interaction development. However, if the total system complexity C does not change in its structure formation process, it does change its form, passing from the latent, potential form of *dynamic information*, I, at the start of interaction process development (initial system configuration giving rise to the existence Eq. (1)) to the explicit, unfolded complexity form of *dynamic entropy*, S, so that their sum, *total complexity* C, remains unchanged:

$$C = I + S = \text{const},\ \Delta C = \Delta I + \Delta S = 0,\ \Delta S = -\Delta I > 0\,, \qquad (24)$$

where the last inequality reflects the unstoppable interaction development process (irreversible realisation change), giving the generalised second law (entropy growth) [2–13, 18, 19]. Both complexity forms, dynamic information I and entropy S, as well as the total complexity $C = I + S$, are determined by the same universal equation (19), but whereas system realisations are only 'planned' in the initial state $I = C$, $S = 0$, they really emerge and replace each other in further system structure evolution $I < C$, $0 < S < C$, until its final state of fully developed realisations (in the form of dynamically probabilistic fractal, Eq. (15)) $I = 0$, $S = C$.

In order to transform the basic expression (24a) of the symmetry of complexity to a dynamic equation, we need to introduce the notions of *emerging real space and time* at each complexity level (where the most fundamental levels of 'physical' space and time are obtained in this way at the lowest complexity levels of elementary particles, see below). The element of *dynamically discrete, or quantised, space*, Δx, is determined by the explicitly found eigenvalue separation of the unreduced EP Eq. (9), (10), $\Delta x = \Delta\eta_i^r$, where the *elementary length* λ is given by neighbouring realisation separation, $\lambda = \Delta x_r = \Delta_r \eta_i^r$, and the *elementary size* (of real space 'point') r_0 emerges as eigenvalue separation within the same realisation, $r_0 = \Delta x_i = \Delta_i \eta_i^r$ (index r stands for realisation number). Emerging space quantisation is thus due to the fundamental dynamic discreteness of the underlying realisation formation and change process, while the *tangible, physically real* character of this emerging space is determined by the *fractal dynamic entanglement* of the interacting degrees of freedom (section 2).

The *elementary time interval*, Δt, of a given complexity level emerges as *intensity*, actually measured by *frequency*, ν, of rigorously (and universally) defined *events* of *incompatible* realisation formation and change, $\Delta t = \tau = 1/\nu$. The *irreversible, unstoppable time flow* is thus due to the same fundamental phenomenon of dynamic multivaluedness and *randomness* of any real interaction process and resulting system structure, which is inevitably absent in any usual, dynamically single-valued theory or model, leading to the famous, unsolvable (we now know why) 'problem of time' or rather *absence* of real, irreversible time flow in unitary science framework [2–13, 18, 19]. The concrete value of real time interval $\Delta t = \tau$ can be obtained also from the above quantised space interval $\lambda = \Delta x_r$ (of the same complexity level) and the velocity v_0 of signal propagation in the material of interaction components (necessarily known from this lower complexity level dynamics), $\tau = \lambda / v_0$. This purely *dynamic* link between equally real space and time is not reduced, however, to any their real 'mixture' within a 'space-time' entity (introduced in unitary theory): while space is a tangible 'ma-

terial' entity dynamically 'woven' from interacting components, equally real time is not a tangible entity and describes only *permanent chaotic* (and therefore irreversible) *change* of material space structure elements.

Since universal dynamic complexity $C = C(N_{\Re})$ is determined by the number $N_{\Re}$ of permanently changing system realisations, Eq. (19), while the emerging space and time elements specify the same process development, it becomes evident that the basic, *universal*, *integral measure of complexity* is provided by the simplest linear combination of (independent) space and time elements, known as *action* $\mathcal{A}$ (now *extended* to *any* system dynamics and its intrinsic nonlinearity):

$$\Delta\mathcal{A} = p\Delta x - E\Delta t\,, \tag{25}$$

where all *dynamic* increments are determined by real system leaps between realisations, coefficients p and E are recognised as *momentum* and *energy*, now generalised as *universal differential measures of complexity*,

$$p = \frac{\Delta\mathcal{A}}{\Delta x}\Big|_{t=\text{const}} \simeq \frac{\mathcal{A}_0}{\lambda}\,, \tag{26}$$

$$E = -\frac{\Delta\mathcal{A}}{\Delta t}\Big|_{x=\text{const}} \simeq \frac{\mathcal{A}_0}{\tau}\,, \tag{27}$$

and $\mathcal{A}_0$ is the characteristic action magnitude at the complexity level in question (x and p should be understood as vectors if necessary).

With irreversible time flow ($\Delta t > 0$) and positive energy ($E > 0$) action $\mathcal{A}(x,t)$ is a decreasing function of time, $\Delta\mathcal{A} < 0$ (see Eq. (27)). This permanently decreasing integral form of complexity is therefore directly associated with dynamic information I introduced above, after which the main law of the universal symmetry of complexity, Eq. (24), takes a more dynamically sensible form:

$$C = \mathcal{A} + S = \text{const},\ \Delta C = \Delta\mathcal{A} + \Delta S = 0,\ \Delta S = -\Delta\mathcal{A} > 0\,. \tag{28}$$

In addition to the absolute universality of this law eventually unifying the extended versions of all usual dynamical laws and 'principles' (now properly understood, see below), we note the natural unity within one law of energy/complexity conservation and transformation laws (the extended first and second laws of thermodynamics respectively), so that the *balance*, or symmetry, of total complexity (or energy) conservation is maintained by its 'suitable' *transformation* from dynamic action-complexity (information) to dynamic

entropy-complexity, where 'symmetry' is not different from 'conservation' (as opposed to unitary theory) [2–13, 18, 19].

The differential, dynamically important form of the universal symmetry of complexity is obtained by division of the last equality (28) by real time increment $\Delta t\big|_{x=\mathrm{const}}$:

$$\frac{\Delta\mathcal{A}}{\Delta t}\Big|_{x=\mathrm{const}} + H\left(x, \frac{\Delta\mathcal{A}}{\Delta x}\Big|_{t=\mathrm{const}}, t\right) = 0\,,\ H = E > 0\,, \tag{29}$$

where the *generalised Hamiltonian*, $H = H(x, p, t)$, is a differential form of dynamic entropy-complexity, $H = (\Delta S/\Delta t)\big|_{x=\mathrm{const}}$, in accord with Eqs. (26), (27). We obtain thus the generalised, *universally valid* and *rigorously derived* version of the *Hamilton–Jacobi equation* plus the generalised differential version of the second law (first and second parts of Eq. (29), respectively). In the basic case of a closed system, the Hamiltonian does not depend on time explicitly and we obtain a simpler version of the generalised Hamilton–Jacobi equation:

$$H\left(x, \frac{\Delta\mathcal{A}}{\Delta x}\Big|_{t=\mathrm{const}}\right) = E\,. \tag{30}$$

The ultimately extended version of the 'second law' or the 'arrow of time' in (29), $H = E > 0$, is obtained by introduction of the *generalised Lagrangian*, L, defined as the total (discrete) time derivative of action-complexity $\mathcal{A}$:

$$L = \frac{\Delta\mathcal{A}}{\Delta t} = \frac{\Delta\mathcal{A}}{\Delta t}\Big|_{x=\mathrm{const}} + \frac{\Delta\mathcal{A}}{\Delta x}\Big|_{t=\mathrm{const}} \frac{\Delta x}{\Delta t} = p\upsilon - E = p\upsilon - H\,, \tag{31}$$

where $\upsilon = \Delta x/\Delta t$ is the (global) system motion speed, and the obvious vector version of these relations is implied if necessary. Intrinsic randomness of plural realisation choice gives entropy-complexity growth or the equivalent action-complexity decrease (see (28)), *i.e.*

$$L < 0,\quad H, E > p\upsilon \geq 0\,, \tag{32}$$

which is reduced to a simpler version, $H, E > 0$, of the same generalised second law (time arrow in the direction of entropy-complexity growth) for $\upsilon = 0$.

Returning now to the generalised wave function $\Psi(x, t)$ of the intermediate system realisation (introduced in section 2, see Eq. (18)), we can complete the unified Hamilton–Jacobi expression of the symmetry of complexity (29), (30) for regular, localised realisations by the corresponding equation for the distributed realisation

of the system wave function. This is achieved with the help of the *generalised, causal (dynamic) quantisation rule*, extending usual postulated Dirac quantisation in quantum mechanics and expressing complexity conservation in one cycle of transition between two regular system realisations through the main realisation of the wave function [2, 3, 10–15, 18, 19]:

$$\Delta\left(\mathcal{A}\Psi\right) = 0\,,\ \Delta\mathcal{A} = -\mathcal{A}_0\,\frac{\Delta\Psi}{\Psi}\,, \tag{33}$$

where $\mathcal{A}_0$ is a characteristic action value that may include a numerical constant depending on the detailed nature of the complexity level considered (quantum, classical, wave-like, corpuscular, *etc.*).

Using unified quantisation (33) in the universal Hamilton–Jacobi equation (29), (30), we obtain the *generalised Schrödinger equation* for the generalised wave function (or distribution function) [2, 3, 10–15, 18, 19]:

$$\mathcal{A}_0\,\frac{\Delta\Psi}{\Delta t}\Big|_{x=\text{const}} = \hat{H}\left(x, \frac{\Delta}{\Delta x}\Big|_{t=\text{const}}, t\right)\Psi(x,t)\,, \tag{34}$$

$$\hat{H}\left(x, \frac{\Delta}{\Delta x}\Big|_{t=\text{const}}\right)\Psi(x) = E\Psi(x)\,, \tag{35}$$

where the Hamiltonian operator, $\hat{H}(x,\hat{p},t)$, is obtained from the Hamiltonian function $H(x,p,t)$ of Eq. (29) by replacement of the momentum variable $p = \left(\Delta\mathcal{A}/\Delta x\right)\big|_{t=\text{const}}$ with the corresponding momentum operator, $\hat{p} = \mathcal{A}_0(\Delta/\Delta x)\big|_{t=\text{const}}$. One should add here the generalised Born's rule (18) relating system wave function (or distribution function) with realisation probability distribution. Note that this complex-dynamic origin of the generalised Schrödinger equation provides also the causally complete interpretation of usual quantum-mechanical Schrödinger equation at the corresponding lowest levels of complexity, with $\mathcal{A}_0 = i\hbar$ [2, 3, 14, 15] (just relevant for real nanosystem dynamics, see also below).

We thus finally obtain the *unified Hamilton–Schrödinger formalism* of arbitrary many-body system dynamics, Eqs. (29)–(35), (18), expressing the universal symmetry of complexity at its any given level. It is supposed that both the generalised Hamilton–Jacobi equation for regular realisations and Schrödinger equation for the generalised wave function are further analysed by the same unreduced EP method (section 2) giving plural realisations of emerging new complexity (sub)levels. This is especially important for real nanosystem dynamics represented, as we have seen above (see the

end of section 2), by a dense, permanently changing and highly chaotic mixture of lowest quantum and classical complexity levels. At the same time, emergence of greater complexity steps in system structure development towards superior levels of complexity is better described by explicitly discrete form of the symmetry of complexity (28).

Note finally that the universal symmetry of complexity and the ensuing Hamilton–Schrödinger formalism (28)–(35) underlie and unify the extended versions of all known (correct) laws, equations and principles, including the Hamiltonian form of our starting existence equation (1), thus self-consistently confirmed. One can specify this unified origin of various dynamic equations by inserting the Hamiltonian expansion in powers of p into our universal Hamilton–Jacobi and Schrödinger equations:

$$H(x,p,t)=\sum_{n=0}^{\infty}h_n(x,t)\,p^n\,, \tag{36}$$

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

$$\mathcal{A}_0\,\frac{\Delta\Psi}{\Delta t}\Big|_{x=\text{const}}=\sum_{n=0}^{\infty}h_n(x,t)\left(\frac{\Delta}{\Delta x}\Big|_{t=\text{const}}\right)^n\Psi(x,t)\,, \tag{38}$$

where $h_n(x,t)$ can be arbitrary functions. In the limit of usual derivatives, the last two equations become as follow:

$$\frac{\partial\mathcal{A}}{\partial t}+\sum_{n=0}^{\infty}h_n(x,t)\left(\frac{\partial\mathcal{A}}{\partial x}\right)^n=0\,, \tag{39}$$

$$\mathcal{A}_0\,\frac{\partial\Psi}{\partial t}=\sum_{n=0}^{\infty}h_n(x,t)\,\frac{\partial^n\Psi}{\partial x^n}\,, \tag{40}$$

thus, including, in a truncated form, many ‘model’ equations. Their scope grows even more, if we take into account various models for nonlinear dependencies in the unreduced EP formalism (9), (10) used for solution of universal equations (29), (30), (34), (35).

The universal symmetry of complexity (28), following rigorously from the dynamic multivaluedness of any real interaction process, leads to the intrinsically unified, causally complete description of entire world structure and dynamics in the form of multilevel dynamically probabilistic fractal, Eq. (15) (section 2) [2, 6, 7, 10, 13, 15, 18, 19]. Progressive levels of this unified complex-dynamical world structure are properly specified by the detailed analysis of respective interaction processes, starting from the lowest levels of elementary particles and fields, together with physically real fun-

damental space and time (see above in this section), their intrinsic properties, dynamically unified fundamental interactions, quantum, emerging classical and relativistic behaviour [2, 3, 13–16]. These fundamental and now causally complete results are particularly important for proper understanding and design of real nanosystem dynamics, already because it belongs just to these lowest, dynamically entangled complexity levels [1, 2]. While the natural world evolution and dynamics can be causally understood within the dynamic redundance paradigm [1–19], the emerging new stage of its artificial, man-made coevolution *necessitates* practical application of the same causally complete understanding, if we want to obtain the intrinsically creative, sustainable world development. By contrast, usual, unitary theory models containing essential 'mysteries', 'unsolvable' problems, omnipresent ruptures, contradictions, and many 'invisible' or 'dark' entities (matter, energy, dimensions, elementary species) are not suited for the full-scale nano interaction description, including the particularly popular case of (unitary) 'quantum computers' [2].

Our intrinsically unified, complete and realistic world structure starts from the unreduced (attractive) interaction in the *simplest possible* configuration of two initially homogeneous, physically real media, the electromagnetic protofield, giving rise to directly observed particles, and the gravitational protofield, eventually identified as directly unobservable quark condensate [2, 3, 14, 15]. Due to the intrinsic dynamic instability, this initially homogeneous configuration gives rise to local emergence of essentially nonlinear local self-oscillation process called *quantum beat* (periodic local protofield squeeze and extension) and constituting the essential, causal dynamic structure of a simplest (massive) *elementary particle*, such as the electron. The dynamically multivalued quantum beat character accounts for *non-zero dynamic complexity* of even such simplest objects and leads to *spatially chaotic* permanent wandering of the squeezed (corpuscular) state of virtual soliton, which provides the *universal dynamical definition of inertial (and eventually gravitational), relativistic mass-energy*, without any additional entity, such as the Higgs field in usual, dynamically single-valued theory [2, 3, 14, 15]. While the number of forming elementary particles grow, the protofield tension increases and finally no new quantum beat process can emerge (which is the *self-tuned universe* feature and respective unitary problem solution). After that, only *massless photons* with quasi-regular dynamics can appear and disappear because of protofield and massive particle interaction.

One obtains also equally transparent dynamic origin of other intrinsic properties and their observed features, including *electric charge* and *spin*, and of the number and character of *fundamental*

interactions transmitted by the two protofields and now intrinsically, dynamically *unified* from the start. Elementary particle interactions then lead to emergence of higher complexity sublevels, in the form of compound elementary particles (represented by hadrons) and *elementary bound states*, such as atoms. The latter represent also the elementary *classical*, permanently localised states, due to internal chaotic dynamics of their components (obtained without evoking any other 'decoherence', see section 2) [2, 3, 10, 14, 15]. Genuine quantum chaos (dynamic randomness) and quantum measurement are other characteristic cases of elementary quantum object interaction (in the Hamiltonian and weakly dissipative system configurations respectively), naturally emerging within the same, unreduced analysis of dynamically multivalued interaction processes, thus overcoming the 'hard' limitations of usual theory [2, 3, 16]. As mentioned above, the unreduced natural or artificial *nano(bio)system dynamics* is a highly entangled, irregular and permanently changing *mixture* of these characteristic kinds of lower-level *complex dynamics* (quantum and classical chaos, emerging classicality and quanticity revivals, quantum measurement, collapse and extension). Therefore, it can be properly understood and managed in applications only within the described causally complete, dynamically multivalued picture (including the important property of *exponentially huge power* of unreduced interaction dynamics, Eq. (23)).

In a more general vision, the entire Universe dynamics and structure is largely determined by the same unreduced interaction processes that locally give rise to the full-scale, 'living' nanobiosystem dynamics, and therefore the former can be seen now as macroscopic, astrophysical manifestations of living complex-dynamical (multivalued) structure development, generally governed by various manifestations of the universal symmetry of complexity (28)–(40). Therefore, proper understanding of the self-tuned Universe dynamics, without 'mysteries', 'dark' entities, 'hidden' dimensions and 'invisible' particle species (the main content of usual science picture), is obtained within the *same* analysis and dynamical picture as the causally complete description of Universe's local nanostructures, in their extended, complex-dynamical, or 'living', version (with the mathematically exact definition of the properties of life and related intelligence and consciousness [2, 3, 10, 14, 15]). Indeed, we show that macroscopic living, intelligent and conscious systems are obtained as superior levels of unreduced dynamic complexity (with exponentially huge interaction power, Eq. (23)), where essential components are provided already at nanoscale complexity sublevels. This is of direct importance for respective applications of artificial intelligence, machine consciousness, advanced robotics,

intelligent computer systems and communication networks, reliable genomics, and integral medicine [2, 3, 6–13, 18, 19].

4. COMPLEX-DYNAMICAL NANOBIOSCIENCE PARADIGM AND UNIFIED PRINCIPLES OF NANOSYSTEM DYNAMICS

The rigorously specified laws of unreduced complex dynamics and their outlined applications to the unreduced nano(bio)system dynamics (section 3) lead to the ultimately extended *paradigm of complex, multivalued nanosystem dynamics*, governed by the universal symmetry (conservation and transformation) of complexity, Eqs. (28)–(40). While the detailed system dynamics and evolution is governed by these equations, their applications provide also certain *general principles* of real, complex-dynamical interaction process development, which can be useful as such for the unreduced nanosystem design and management (while being consequences of the same universal symmetry of complexity) [2, 3, 11–13, 18, 19].

One may start with the basic *complexity development principle* as the guiding line for complex system design and dynamics. This is simply the applied version of the symmetry of complexity (24), (28) stating that any real system dynamics is governed by the permanent transformation of its initial dynamic information I (expressed by action-complexity $\mathcal{A}$) to the equal amount of dynamic entropy-complexity S, so that their sum of total complexity $C = \mathcal{A} + S$ remains unchanged (with any complexity form being determined by the system realisation number, Eq. (19)). The process details are irregular, highly unpredictable and generally extremely numerous (due to the exponentially huge efficiency, Eq. (23)) and therefore, contrary to usual design and programming, cannot be followed and designed exactly, one by one. Instead of detailed step-by-step programming, one should use here suitable arrangement and adjustment of potential action-complexity through system configuration, while the detailed ways of complexity development are found by the unreduced complex dynamics itself, spontaneously and with the exponentially huge efficiency (23). One can call this approach *complex-dynamical programming*.

Close to it, it is the *complexity correspondence principle*, according to which most efficient interaction with ‘interesting’ (creative) results takes place for interacting components of comparable unreduced complexity. In particular, higher-complexity participants tend to control and determine the behaviour of lower-complexity units (generalised self-organisation principle), while lower-complexity component or system *cannot* efficiently control or simulate higher-complexity behaviour. It is especially this latter manifestation of the complexity correspondence principle that has im-

portant practical applications in various fields of usual, unitary science and technology, which tends to neglect the unreduced complexity effects. First of all, it clearly expresses the basic general deficiency of usual, dynamically single-valued (zero-complexity) science paradigm being applied to understanding of real, dynamically multivalued (complex) system and interaction dynamics (especially at higher complexity levels). A particular application becoming extremely popular in the last decades, *unitary quantum computation*, appears now *impossible* as such, irrespective of technical details, because here the lowest, essentially quantum complexity levels are supposed to efficiently solve, reproduce or simulate much higher, classical complexity processes and tasks (even apart from the real quantum chaos obstacle, section 2) [2]. By contrast, it is the unreduced, complex-dynamical (and thus inevitably chaotic) nanosystem operation that can indeed show 'magic', exponentially huge efficiency (see Eq. (23)) characteristic of living and intelligent behaviour.

The *complex-dynamical control principle* implies optimal system *complexity development* (from dynamic information to dynamic entropy) as the unified real control purpose, as opposed to usual control purpose of making system behaviour 'more regular' (in the predetermined shape or direction), including various pseudo-complexity features of 'synchronisation' *etc.* As the unreduced interaction analysis explicitly shows, real, dynamically multivalued system behaviour, including thus *any* 'control' scheme, can never be really, internally regular (section 2), and therefore relying on usual 'total control' approach in the unitary control paradigm can actually produce higher, catastrophic deviations from the desired stability, than lower-control influences. What can be truly reliable in real, highly chaotic nanosystem design is the *creative*, rather than restrictive, control principle, using proper system development between dynamically multivalued, internally chaotic SOC regimes (see section 2). One can generally speak here about *sustainable control* (and design) principle, where *global stability* is obtained with the help of *local creativity*. Suitable transitions between now clearly defined regimes of strong chaos and self-organisation (section 2, Eq. (22)) can be efficiently used here for system configuration and dynamics management.

Finally, the *unreduced (free) interaction principle* separately emphasizes the huge power of unreduced, essentially chaotic interaction dynamics (Eq. (23)), variously used also in the other principles. Only the general purpose of optimal entropy-complexity growth can be fixed, while the detailed nanosystem evolution remains highly chaotic and largely unknown, where this intrinsic chaoticity is a normal and *useful* system operation regime (see also the above com-

plexity development principle). The magic, exponentially huge power (23) of unreduced complexity can also be described as the genuine, interactive *parallelism* of multivalued fractal dynamics. The entire free-interaction nano- and biosystem dynamics can be described thus as constructive alternation of strong-chaos and multivalued SOC regimes realising the optimal combination of efficient chaotic search and ordered creation respectively.

In summary, the rigorously substantiated picture of the unreduced nanoscale interaction dynamics, sections 2–4, opens new perspectives for the full-scale, free-interaction nanobiosystem design and control, actually realising the *coevolution* of natural and artificial complex-dynamical, living and intelligent systems, organisms and communities. One obtains thus the new *paradigm of unreduced complex-dynamical nanobioscience and technology*, necessitating the corresponding *complexity transition (or revolution)* with respect to the dominating dynamically single-valued, unitary models and approaches [1–3]. Various aspects and details of this new paradigm have already been specified and confirmed in a number of applications to living and intelligent complex system design [6–13, 18, 19], demonstrating its unrestricted potentialities and the objective necessity of complexity transition at the current stage of intrinsically globalised interactions beyond the recently transgressed *complexity threshold*.

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