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SPACE, TIME AND LIFE IN QUANTUM-SEMIOTIC VIEW

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Abstract

The origin of space and time is the deepest question in fundamental physics. This paper addresses it from quantum-theoretic perspective, deriving both concepts from elementary principles. Time appears as a measure for the stream of decision acts, collapsing quantum potentialities of the future to actual reality. Guiding of this construction is identified as fundamental function of life, thus obtaining definition in cybernetic style. This entails specific geometric structure of subjective meaning identical to that of the simplest quantum state, the qubit. Alignment of individual meaning spaces then produces 3-dimensional Euclidean space as biologically fixed format of common sense. The problem of space-time is thereby triangulated with the nature of life, identifying these three concepts as integral sides of the same fundamental phenomenon. The theory opens new prospects for scientific and ethical progress.

Key words

space, time, potentiality, future, meaning, qubit, quantum, life

1 Introduction

Space and time are central to modern scientific worldview. Classical physics postulates that time is linear and space is three-dimensional as we see it with our eyes. Yet human curiosity is never satisfied with such commitments. Why, indeed, do we live in space and time like this?

Few researchers addressed this question explicitly. Great attempt is due to John Archibald Wheeler who linked it with quantumness of nature [Wheeler, 1989]. No space, no time, he said; these concepts and their structure must be not postulated, but derived from deeper physical principle.

Facing this challenge, Wheeler spotted information and meaning as concepts, possibly fitting the job. Meaning, in particular, is seen as a product of question-answer, perception-action cycle of organisms with nature [von Uexküll, 1992]. By staging experimental setups we state meaningful questions to nature, responding by elementary events of yes-or-no type, and vice versa. Crucially, this dialogue not only reveals an objectively pre-existing world, but takes part in its making. Similarly to the open-ended game of 20 questions[1] reality is not pre-given, but constructed by “observer-participants” in dialectic cycle of meaningful action. This construction was supposed to include particles, space, time and laws of nature as we know them [Wheeler, 1986; Jaeger, 2023].

How exactly this is done, however, is left unspecified. Wheeler leaved us with five cues to the puzzle [Wheeler, 1989]:

1. The boundary of a boundary is zero – topological fact illustrating a hope that everything can be derived from nothing, all law from no law.
2. No question? No answer! – a dialectic core of quantum physics [Peres, 1978], ensuring that every knowledge and piece of reality, including space and time, is due to someone’s creative participancy in a special experimental context.
3. “The super-Copernican principle” – warns of self-centrism in the accounts of existence. Sites of observer-participancy are countless and most of them are yet to be found.
4. “Consciousness” – points to the importance of living agents and their subjective mind in construction of meaning [Yolles, 2022]. Consciousness is noted as ingredient, missing in objectified view of nature by classical science [Nagel, 1986].

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[1] A group of people collectively agrees on a secret word. A leader must reveal it by asking no more than twenty yes-no questions to participants. Contrary to this standard version of the game, the group does not define the word beforehand, but each new answer is up to a particular player. These answers, however, must conform with all previous ones, forming a “consistent history” of the game. This turns the process from discovery of a predefined truth to a joint creative quest.

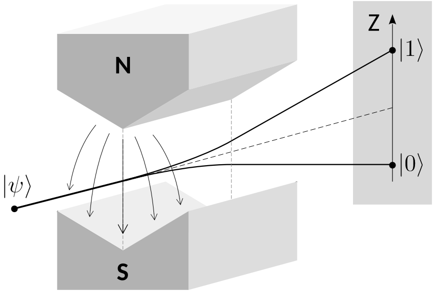

Figure 1. Experiment of Stern and Gerlach [Gerlach and Stern, 1922] with a beam of silver atoms. When passing through an inhomogeneous magnetic field, each atom (of spin-1/2) deflects either along or opposite to the field's gradient, as observed on the screen. Although the outcome of each experiment is unpredictable, its probabilities are described by ascribing atoms with qubit state (1).

5. More is different – indicating that transition from small to large often involves emergent, qualitative changes [Anderson, 1972].

This paper proposes a solution to the Wheeler's challenge, based on the recent models of subjective sense-making. The results are presented in the following order. First, section 2 introduces the basic concept of uncertainty, discriminated to quantum and classical types. Section 3 accordingly develops the concepts of future and time, differing from their classical understanding. Based on that, Section 4 proposes functional definition of life, emphasizing fundamentality of this phenomenon in nature. Section 5 then describes an elementary structure of the subjective meaning in living behavior, giving rise to the standard Euclidean space. Final Section 6 highlights some implications of the theory.

2 Uncertainty

Consider the simplest quantum state called qubit. This state is normally written as

$$|\psi\rangle = \cos\frac{\theta}{2}|0\rangle + e^{i\phi}\sin\frac{\theta}{2}|1\rangle, \qquad (1)$$

where $\theta \in [0, \pi]$ and $\phi \in [0, 2\pi)$ are angular parameters, while $|0\rangle$ and $|1\rangle$ are basis states. For single photons they can be two orthogonal polarizations, for superconducting loops – opposite current directions, while for an atom in the Stern-Gerlach apparatus they are alternative spatial trajectories as shown in Figure 1.

This is formal math used in calculations [Guts, 2008]. But what exactly does it mean? This is the question of interpretation, going beyond objective facts. The logic of this paper is based on the following understanding.

2.1 Two types of uncertainty

State (1) encodes irreducible (objective, ontological, quantum) uncertainty of nature, [Heisenberg, 1958; Jaeger, 2019; Khrennikov and Svozil, 2019], describing the *potential future* of a considered system which cannot be predicted by any algorithm. In Figure 1, for example, $|0\rangle$ and $|1\rangle$ are potential positions of the atom on the screen before it enters the apparatus. The particle would move to one of these states only if the experiment would be actually performed; as per the second Wheeler's clue, without this "question", no answer could be brought to being. In contrast to algorithmic computation, such experiment *creates* a single bit of information, which never existed before. By interaction with the environment (screen in Figure 1) this bit is irreversibly recorded in state of its matter. This resolves quantum uncertainty, "collapsing" state (1) to one of superposed alternatives.

This situation differs from someone's ignorance of the experimental outcome, recorded when nobody was in the lab. Such lack of knowledge is shown in Figure 2A by gray area. It can be eliminated, for example, by means of a camera sending the screen's image to the person's desktop in the office. Like any observation or measurement procedure, of course, this would not change the particle's state being $|0\rangle$ or $|1\rangle$. This bit is already recorded and cannot be erased from nature; a measurement just rewrites it to the form available to the person, eliminating one's subjective (epistemological, classical) uncertainty. The terms "observer" and "measurement" are semantically associated with this passive process, contrasting with the creative change of reality described in the previous paragraph [Bell, 1990].

An elementary macroscopic example is an ignorance about the side of a coin under a sheet of paper, which can be heads (1) or tails (0). As in the classical case above, this information already exists, being recorded in the actual position of the coin's matter and, possibly, in the nervous systems of other people. Notably, this bit also existed a moment before this coin touched the table. The motion still goes on, but final position of the coin is already predetermined by the laws of Newton (except for deliberate interventions in the flight). These laws function as a measuring algorithm, revealing pre-existing information which was initially unknown to the observer.

2.2 Quantum uncertainty at macroscale

The same holds for the whole flight, when the coin's motion deterministically proceeds on a single algorithmic track backward in time up to the moment of tossing. At this point, the process depends on a state of the gambler's nervous system, which at the cellular and molecular levels is sensitive to the quantum uncertainties of the nanoscale. Such are, for example, conformational states of a cytoskeleton being a neural system of each nervous cell [Hameroff, 2003; Hameroff and Penrose, 2014]. A simpler property of the same type is the number of open ion channels in the axons, varying due to atomic-level Brownian motion of chemicals in cellular fluid [Faisal

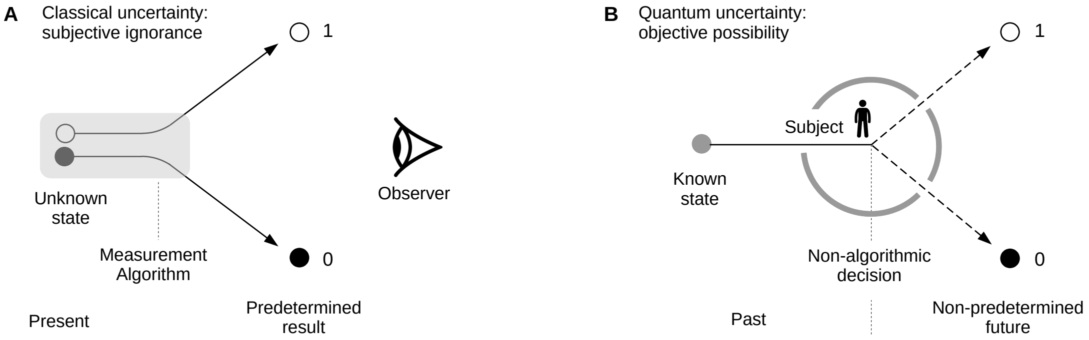

Figure 2. Concepts of quantum and classical uncertainties. Classical uncertainty (A) refers to subjective ignorance about the actual state of nature, shown by gray box. Such uncertainty is eliminated by algorithmic evolution or measurement procedure. Quantum uncertainty (B) refers to alternative potential futures, one of which is actualized by the subject's non-algorithmic decision in particular context (circle). In contrast to passive observation in the classical case, quantum uncertainty resolves by creating genuine novelty as in elementary case of Figure 1.

et al., 2008]. These quantum fluctuations produce uncertainty in neural triggering time and, consequently, duration of subsequent flight. Magnitude of this uncertainty is large enough to change the number of the coin's rotations in the air, defining the final state of heads or tails [Albrecht and Phillips, 2014].

Tossing the coin, throwing the dice, and other tools of randomization thereby access genuine quantum uncertainty of exactly the same type as in elementary physical systems used in quantum random number generators (which probably motivates these practices through ages). The difference from Stern-Gerlach experiment in Figure 1 is the use of a human body, containing both quantum-uncertain particle and experimental apparatus. In each case the result is amplified to the macroscopic level of observable events by mechanical and biological algorithms just mentioned [Jedlicka, 2017; Vinnik, 2020]; initial resolution of the quantum uncertainty at the microscale, however, is not predetermined by any (measurement or evolution) algorithm as noted in the previous section.

Supplemented by algorithmic amplification, temporal ("propensity") understanding of quantum uncertainty [Popper, 1959; Shanks, 1993] validates the use of this concept and corresponding math at macroscopic scales [Khrennikov, 2010]. As seen from previous discussion, it has nothing to do with coexistence of a system in two states at once. The coexistence takes place not in the present actuality, but only among alternative scenarios of potential future. Unlike popular paradoxical views [Marin, 2009], Schrödinger's cat is just a cat pondering, say, whether to go for a mice or not.

Living organisms enter qubit cognitive state (1) each time when some cognitive-behavioral algorithm (of starting new project, making a tea, and so on) must be discarded $|0\rangle$ or brought to execution $|1\rangle$ [Surov, 2023a]. *Decisions* of this type are macroscopic analogs of the physical case shown in Figure 1. Such quantum uncertainty is schematized in Figure 2B.

3 Time

So, superposed states in quantum uncertainty (1) encode alternative futures of the considered system, whether this is a particle in the Stern-Gerlach apparatus, a man at the crossroad, or society at elections.

These statements refer not a future in formal chronometric sense, understood as everything that will exist when the clock hands will move beyond their present position. As seen from the coin case in Section 2.2, such chronometric future can be predetermined by simple mechanical laws with no place for potential choices. The same is true for a train schedule, fixed several months prior to the actual occurrence of events. Reality then unfolds like a film in movie theater, with events rolling in from a fully predetermined future. A filmstrip moving with constant pace then visualizes classical concept of time.

Quantum uncertainty, in contrast, refers to the events which are not just not yet happened, but which are not predetermined to happen. This aligns with the everyday concept of the future as a space for creativity and novelty which is worth of strive and aspiration (like in the game of 20 questions), but differs from time in the aforementioned classical sense.

Contrary to the filmstrip analogy, this "quantum" time cannot be rolled back. Its unidirectionality is the nature of quantum experiments, irreversibly changing the system and recording the results in the environment as noted in Section 2. The pace of this construction is defined by the scale of the quantum uncertainties involved.

3.1 Construction process

Quantum uncertainties of molecular scattering account for their movement up to the following collision a few picoseconds after; within a living body, such a decision might trigger a behavioral act, a spoken or written word, possibly further amplified by a social organism. Algorithms associated with "small" uncertainties define the

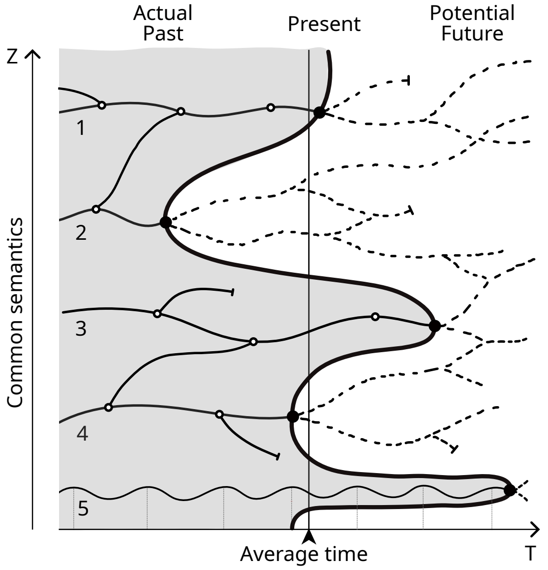

Figure 3. Construction of the actual reality (shaded region, left) through the resolution of quantum uncertainties (1) of the non-predetermined potential future (right). The boundary between the past and the future, consisting of current decision points in multiple algorithmic lines, irreversibly moves from the left to the right. The progress of each algorithm can be measured relative to a periodic clock algorithm shown by line 5. The vertical axis orders the processes in common semantic dimensions of decision-makers (Section 5).

microscopic path of an atom, only registered by neighboring particles; "big" algorithms build the future of humanity for thousands of years.

After triggering by some decision act, each algorithm deterministically unfolds up to the nearest point of quantum uncertainty (Figure 2B), when its "world line" splits like a Y-shaped fork. Non-algorithmic decision then starts on one of the next-step algorithms. The discarded paths (not shown), like empty riverbeds, do not actualize in real events and are no more relevant for the future. In this way reality constructs itself by intermittent actualization of quantum potentiality, consisting of reversible algorithmic transitions and irreversible non-algorithmic decision (bi- or poli-furcation) points [Gabora and Aerts, 2005].

This construction process is sketched in Figure 3. A shaded area is the past, consisting of events along solid algorithmic lines that formed the present state of nature. In special circumstances these lines may merge, end, and split with fusion, death and birth of the corresponding subjects. The future is pierced by algorithms that are not yet actualized, but have potential for that. In Figure 3B this is indicated by dashed lines beyond the decision point. In this potentiality region algorithms merge and split in potential quantum uncertainties of type (1), forming a network of possibilities in non-predetermined future.

In contrast to the fixed past, this potentiality domain is flexible and constantly updating according to the cognition and decisions of subjects. Some algorithmic junctions open up, while others get precluded; amplitudes of the corresponding alternatives evolve in non-local contextual way. As in Stern-Gerlach experiment (Figure 1), decision-makers also define the basis states for present and future quantum uncertainties; what is deterministic in one basis is uncertain in the other. Figure 3 thus sketches a momentary slice of dynamical and multidimensional potentiality matrix, previously associated with multiple (virtual) worlds [Mensky, 2007; Guts, 2012].

Actual reality thus advances in the potential domain through a series of decision acts, filling some of possible futures with real events. The shaded area in Figure 3 then grows like a crystal, absorbing molecules from surrounding gas to vacant positions. The boundary of that area is shown by a thick line, connecting the points of quantum uncertainties under resolution[2]. This frontier between the past and the non-predetermined future delineates "quantum" and "classical" domains (instead of some borderline spatial scale separating classical and quantum physics). As required by the irreversible nature of quantum decision acts, this boundary in Figure 3 moves from left to right in unidirectional way.

Some parts of the boundary between the past and the future can be well ahead of others, as exemplified in Figure 3 by algorithmic line 3. Such are stable algorithms like long-term schedules and seasonal cycles, initiated by correspondingly large-scale decisions. Alternatively, refraining of subjects from decision-making may suspend algorithms at some junction point as shown by line 2. This requires screening of the system from its actualized environment as done in quantum-physical labs[3].

Blank spaces both in past and future regions of Figure 3 are left for clarity. In fact, this space is also filled by algorithmic lines in fractal manner, so that magnification of the plot would reveal pattern of the same type. This algorithmic fractality produces fractality of space-time, used to derive quantum theory from scale relativity prin-

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[2] More precisely, this boundary is a transition belt of finite width, corresponding to the degrees of the actualization (decoherence) process [Zurek, 1991; Zheltikov, 2018].

[3] Removal of such screen puts them in interaction, forcing the system to adopt either of the basis alternatives and collapsing the superposition of type (1). This happens, for example, with a photon from a distant star which encounters a polarization-measuring apparatus after a thousand years of travel. With classical concept of time, such "delayed-choice" experiments appear as acting backwards in time [Wheeler, 1986].

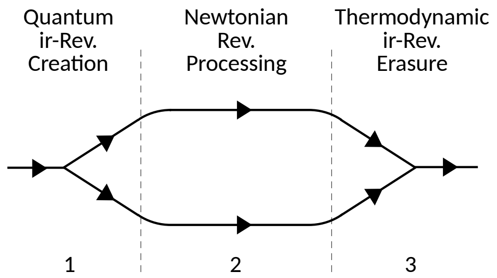

Figure 4. Regimes of algorithmic evolution, producing three concepts of time. Irreversible (ir-Rev.) times emerge from quantum (1) and thermodynamic (3) regimes, creating and erasing information. Information-conserving computation (2) generates reversible (Rev.) Newtonian and Schrödinger's time via deterministic clock algorithms.

ciple[4] [Nottale, 2010].

3.2 Three kinds of time

Evolution of algorithmic lines can be of three types shown in Figure 4, which correspond to different kinds of time.

The first type corresponds to the branching of lines in resolution of quantum uncertainties (Figures 1 and 2). The opposite process fuses different algorithmic lines into a single statistically-preferred macro-line as typical for thermodynamic systems. Both types are irreversible, but for different reasons. Branching creates new information as in the movement of algorithmic front in Figure 3, referred to as active or creative time-duration [Mullarkey and Pearson, 2019; Cortes and Smolin, 2021]. Fusion, in contrast, erases information which was discriminating different algorithmic lines in the past. This erasure, quantified by the growth of entropy, generates irreversible thermodynamic time [Prigogine and Stengers, 2017].

Third type of evolution describes deterministic processes in which information is neither lost nor generated. This is the case of reversible Newtonian dynamics. In both actual and potential domains, such lines neither branch nor fuse as shown in the middle part of Figure 4.

Reversible constant-entropy algorithms of the third type like celestial cycles, mechanical or atomic oscillations are used as clocks. Such process is shown in Figure 3 by algorithmic line 5. Its period provides a unit for measuring the progress of other algorithms by real number, leading to the Newtonian concept of time as reversible movement along a linear dimension[5]. However reliable, though, such algorithms always have windows for disrupting intervention, allowing, for example, shooting down an asteroid to deflect it from the Earth.

3.3 Classical limit

As in solid bodies, continuous boundary between the past and the future is macroscopic approximation. Actually it consists of discrete boundary points shown in Figure 3 by black dots. Following fractal structure of the algorithmic lines (footnote 4), this boundary is itself a fractal. Neglect of this discreteness and fractality is standard, more or less valid approximation (challenged e.g. by the delayed-choice experiments), connecting the developed theory with the classical concept of time as one-way movement along linear dimension. This transition is achieved in three steps:

1. limit on screening and planning, necessary for suspension and advance of algorithms as described in Section 3.1. This would constrain horizontal range of thick line in Figure 3, producing nearly vertical, but discrete and fractal boundary of limited width;
2. approximation of this boundary by continuous line as in transition from microscopic to macroscopic view of the crystals. The result is sharp vertical line, dividing the past from the future;
3. one-way movement of this line with respect to a chosen clock process (line 5 in Figure 3, infinitely prolonged to the future) produces the real-valued progression of classical time.

This limit is naturally approached in thermal equilibrium states like a gas at constant temperature, guaranteeing the absence of long-range correlations. Operating algorithms are then limited to molecular motions in the range of mean free path, which in room conditions is in order of 10^{-10} seconds and 10^{-7} meters. According to the second step above, fuzzy boundary of such temporal width is well approximated by sharp vertical line for most practical purposes. This surface moves to the future with a constant pace of classical clocks.

4 Life

4.1 History of the question

Studies of life faced difficulties since the very beginning of modern science. In contrast to chemistry, mechanics, and astronomy, regularities of life elude formalization in Newton-like laws to this date. Such laws, of course, work for the living bodies, allowing to compute the probability of genetic illness or stress in a bicycle frame; still, living behavior always reveals something else than captured by less or more sophisticated

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[4] Algorithmic fractality in past and future sides are of different kinds: the lines on the left of Figure 3 are (mostly) parallel, while on the right they are highly diverging. This duality of actual and potential is reflected in the Ostrovski theorem, stating that there are only two completions of rational numbers. The first is real continuum $\mathbb{R}$, ordering algorithmic lines in the past, actuality domain. The second is p-adic numbers $\mathbb{Q}_p$, corresponding to the tree-like branching of algorithms in potential domain [Dragovich et al., 2009; Khrennikov, 2000].

[5] For non-actualized properties as in the delayed-choice experiments mentioned above, clock time may be seen as turning imaginary. This transforms diffusion equation to that of Schrödinger [Jaroszkiewicz, 2003], which prescribes clock-like evolution of quantum states in potentiality domain [Wootters, 1984].

algorithms [Weber, 2011]. This subtle something, differing human from machine, constitutes the mystery of life as considered by philosophers in terms of meaning, consciousness, soul, free will, and other concepts. By focusing on discovery of biological mechanics, positive research pushed this core of life to the periphery of scientific worldview.

Physical approach to the puzzle of life emphasizes its ability to maintain ordered structures much longer than expected from statistical laws, driving the system to maximally disordered high-entropy equilibrium [Schrödinger, 1944]. This requires, in particular, stability of genetic structure which is enabled by quantumness of chemical bonds in the DNA (ibid.). This approach is recently refined in quantum-theoretic formalism [Khrennikov, 2022; Khrennikov, 2023].

Among other features of life like movement, respiration, sensitivity, reproduction, growth and so on [Nurse, 2020], entropy is especially valuable due to its clear quantification. Still, like other items of this list, entropic and self-organizational argument explores external attributes of life and not its fundamental nature. Accordingly, such attributes are subject for technological imitation, which opens way for trans-humanistic philosophies alien to most of our cultures. Simple question “what is life?” asks for equally simple answer, resolving the problem.

4.2 The idea

The attempts to find “the law of life” fail simply because there is no such law, biological or otherwise. However intricate laws of neurophysiology, psychology, and genetics only capture mechanics of the psycho-physiological machine. Behind these nuts and bolts of living organisms always resides a subject – a non-algorithmic agency, which eventually breaks any deterministic prediction [von Uexküll, 1992]. This non-algorithmicity of life is fundamentally alien to the deterministic worldview, explaining failure of previous approaches to the problem; same was true for the notion of free will, often omitted from scientific discourse due to the lack of appropriate conceptual basis.

The situation changed with cross-disciplinary digestion of quantum theory. In particular, understanding of quantum uncertainty as that of potential future (Section 2) situates non-deterministic behavior within the scope of natural science [Surov, 2023a]. By definition, such uncertainty excludes possibility for algorithmic resolution; what remains is non-algorithmic decision, exercised by living subjects [Surov and Melnikova, 2024]. Quantum potentiality then provides space for non-algorithmic core of life, absent in deterministic worldview[6].

Since novelty enters the world only by actualization of quantum potentiality (Section 2.1), life is the locus of creativity in nature. This making of novelty is a unique and fundamental function of life, providing a definition understandable to preschool children:

> Life is natural process of creating novelty through non-predetermined decisions.

This definition aligns with the previous views of life as macroscopic instantiation of quantum uncertainty, resolved by means of subjective free will [Wendt, 2015, ch. 7], [Stapp, 2017]. External features like order, growth, cognition, etc. then appear as bio-technological consequences of this fundamental function.

The proposed definition complements the concept of time (Section 3). Since quantum uncertainty resides at the interface between the past and the future, same is location of life as shown in Figure 3 by thick line. Life, then, is equivalently defined as a frontier of actual reality, constantly advancing into the domain of potential future.

Being a part of this unfolding process, an individual rides on a bundle of constantly branching algorithmic lines – the processes under one's control. His fundamental function is guiding of this construction process (Section 3.1): monitoring the course of the controlled activities, recognition of objective possibilities for the future, and resolution of the corresponding quantum uncertainties by his or her discretion.

4.3 All the way up and down

By anchoring life in non-algorithmic decision capacity, the proposed definition properly recognizes it in animals, birds, reptiles, plants, insects, and single-cellular organisms [von Uexküll, 1992; Balázsi et al., 2011]. On the other hand, it rules out the possibility of considering artificial intelligence as alive (as long as it remains within classical computation) [Surov and Melnikova, 2024]. Whether robotically embodied or not, however complex algorithm has no access to genuine decision-making understood as resolution of quantum uncertainty.

The same definition also identifies as living elementary physical systems, capable of carrying quantum states. This weird conclusion, however, resolves the hard question of biology looking for the simplest living thing, sitting precisely at the edge between inert and animate nature [Narby, 2005]. The answer is simple: there is no such boundary at all.

In the present view, life did not spring out of lifeless matter by some mysterious leap of emergence. Life is integral to nature from micro to macro scales and existed always. Down at the atomic scale it would not be bothered even by nuclear apocalypse: as long as quantum mechanics holds true, interaction between particles and fields would involve quantum uncertainty and elementary acts of creative decision. The very existence of

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[6] Schrödinger's deterministic mindset, in particular, rejected quantum uncertainty as important to the nature of life [Schrödinger, 1944, p. 88]. Heisenberg and Wheeler, in contrast, recognized importance of quantum potentiality and approached the concepts of consciousness and life as integral to quantum phenomena [Jaeger, 2023, p. 52].

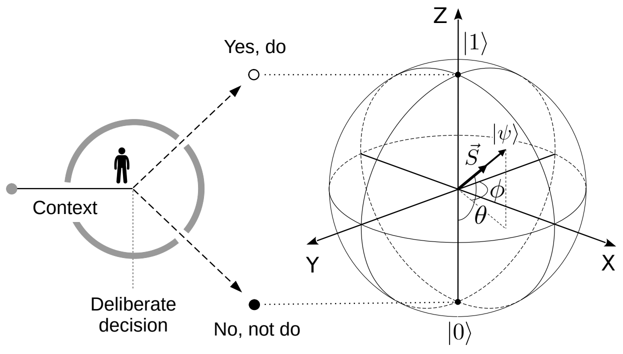

Figure 5. Geometry of the space of qubit states (1)-(2), encoding subjective sense of the context for the basis non-algorithmic decision in Figure 2B [Surov, 2022a; Surov, 2023b].

seemingly inert matter is only possible due to the continuous working of rudimentary forms of life down there.

This conclusion complements modern studies of cognition and life, identifying sentient beings across all scales of nature [Levin, 2022; Doctor et al., 2022]. Following the ancient maxim – as above, so below – the present theory takes these ideas to their logical limit on the new conceptual basis, discriminating genuine life from algorithmic imitations. What changes across different lifeforms is their algorithmic equipment and material substrates, increasing complexity from physical and chemical to cellular and biological systems (ibid.), while the non-algorithmic core of life is the same for all.

After tracing life all the way down to atoms, a natural question would be about the opposite side of the range. What is the highest and most powerful life in our sight? Instinctive response could be human, but science seems to take us off this pleasant position. Any seeming individual is, in fact, a group of individual cells, tissues, and organs, locally operating with their own selves and minds [Levin, 2022; Falandays et al., 2023]. Similarly to biological swarms, proper interaction merges such aggregations into holistic units of larger hierarchical level – a super-organism like human brain and body, ant colony, social system, bio- and noo-spheres [Ünver, 2018; Vidal, 2024].

This merging is possible at the so-called critical regime of interaction, balancing individualist and collective drives [Muñoz, 2018]. Out of this balance, individuals lose the ability to amplify quantum uncertainty to large scales, taking more or less inert structures with regular behavior like solids and gases [Surov et al., 2021]. On the landscape of life, completely inert systems fitting to classical physics occupy deep valleys, whereas biological organisms, including ours, stand as towering peaks.

5 Space

The developed concept of life is roots in the notions of time and uncertainty, but does not mention space – an ordinary three-dimensional continuum in which we seem to live. Classical physics, in contrast, considers space to be as fundamental as time, usually postulating both on the same introductory page. It is therefore expected that space must be integral to the theory, otherwise it should have been added to the scheme artificially.

Such move, which would seriously compromise the approach, is not needed. The concept of space, in fact, is already present in the model. Following intuition of [Wheeler, 1986; Wheeler, 1988], this is shown through the notion of *meaning*[7].

Meaning, or subjective sense, is an inherent feature of life and natural mind as considered from biological and psycho-semiotic perspectives [De Jesus, 2018]. In contrast to objective information – like distribution of pixels on a screen – meaning is what it implies to a reader. For Masha this pattern could mean progress in her research, while for Misha the same thing could be a distraction from some other duty. In contrast to objective data, this subjective meaning is not imported from the outside, but generated from within – in direct analogy with the creation-discovery distinction of Section 2 [Aerts, 2010]. Similarly to resolution of quantum uncertainty, non-algorithmicity of this generation forbids formalization of subjective sense-making [Cosmelli and Ibáñez, 2008; Weber, 2011].

5.1 Geometry of meaning

The question of [Wheeler, 1986] was: "How are we to quantify meaning?". Although the process of subjective sense-making is non-algorithmic, the structure its result is formalized [Surov, 2022a]. In the simplest and most important case this is the qubit state (1) itself, shown in Figure 5 in the Bloch-sphere form.

In generalized form the qubit state is also written as

$$\hat{\rho} = \frac{\hat{\mathbb{I}}}{2} + \frac{1}{2}\begin{bmatrix} x \\ y \\ z \end{bmatrix} \cdot \begin{bmatrix} \hat{\sigma}_x \\ \hat{\sigma}_y \\ \hat{\sigma}_z \end{bmatrix}, \quad x^2 + y^2 + z^2 \leq 1, \qquad (2)$$

where $\hat{\sigma}_k$ are Pauli matrices and real-valued parameters x, y, and z form three-dimensional (Stokes) vector $\vec{S}$, pointing to the volume of unitary sphere as shown in Figure 5. The space of qubit states is thus three-dimensional. Similarity between qubits in that space is quantified by trace-distance metric, being half of standard Euclidean distance between the corresponding Stokes vectors (2) [Nielsen and Chuang, 2010, ch. 9.2].

Function of this semantic space is detailed in papers [Surov, 2022a; Surov, 2023b], showing how qubit states encode meaning of the decision-making situation for a

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[7] Or conceptuality, referring to cognitive-informational nature of potentiality domain [Aerts, 2010]. Wheeler considered meaning as "the joint product of all the evidence available to those who communicate" [Wheeler, 1986, p. 304], which is different from the concept used in the present approach.

subject of the basis uncertainty (1). In short, polar angle θ and vertical axis z quantify subjective evaluation (favorability) of the situation for the basis alternatives: the closer qubit state (1) lies to the north pole, the higher is probability of realization of alternative $|1\rangle$, and vise versa. Azimuthal phase ϕ, in turn, discriminates situations according to their process functions in the life cycle of realization of the alternative $|1\rangle$ (ibid.).

Thus defined semantic space integrates all information, available to the subject and relevant for resolution of the basis uncertainty. We gather visual, sound, and other modalities, while an atom's experience in Stern-Gerlach apparatus is limited to the local magnetic field. In all cases, the resulting subjective sense is represented by the qubit state (1)–(2), which is universal for all living nature [Surov, 2022a; Surov, 2023b]. The difference between humans and other mammals is that we experience this meaning as emotional-affective (psychological, conscious, cognitive) states of specific physiology, demarcating the Bloch sphere (ibid.)[8].

5.2 Semantic fusion

By living in ensembles, individuals – particles, cells, and humans – necessarily interact. Most of such interactions (e.g. of Ising's or Kuramoto's type) stimulate synchronization and alignment of individual states similarly to ferromagnetic effect. In biological systems this mechanism allows for communication and coordinated action as exercised by swarm behavior of cells, insects, fish, birds, and mammals. Such interaction integrates individuals into unitary wholes as noted in Section 4.3.

Natural protocol for such interaction is affective language, in which universal emotional signs are recognized both within and across species [Clynes, 1973; Elfenbein, 2014]. Since major emotional states demarcate individual semantic spaces similarly [Surov, 2022a; Surov, 2022b], affective communication aligns the corresponding Bloch spheres together with their Cartesian axes as shown in Figure 6. One of such axes orders algorithmic lines in Figure 5. Affective alignment thus allows for crystallization of individual meanings in larger and larger coherent clusters. These cluster function as stable semantic environments as necessary for the emergence of other physical properties [Bishop and Ellis, 2020].

Shared semantic space thus arises in a kind of phase transition, establishing long semantic order analogous to ordering of crystals and magnetic media. In line with quantum networking hypothesis [Wheeler, 1988] this process is supposed to originate at the Planck scale (10^{-33} centimeters), where an entangled web of spins is supposedly producing our standard spatial geometry [Penrose, 1971; Fields et al., 2022]. Similar concept is developed in biology, where this primordial soup seen as a field of proto-consciousness [Hameroff, 2003].

In macroscopic biology, affective communication structured nervous systems of its users for many evolutionary epochs. By now, spatial structure of the affective meaning is firmly imprinted in physiology of humans and other complex species [Panksepp, 2011]. Accordingly, our infants are born with this neural hardware, preconfigured for spatial sense-making (in so-called pointer basis [Zurek, 1982]). A commonly accepted norm for subjective experience thus became objective reality, postulated in physical textbooks. Fundamentally, though, it remains to be what it originally was – a natural format of common sense[9].

Dimensionality of the common integrated space coincides with that of original grains, which are the Bloch spheres of subjective meaning shown in Figure 5. This is our familiar three-dimensional space with standard Euclidean metric between qubit states (Section 5.1). Due to the use for great variety of activities, however, the basis-relative nature of meaning is averaged out, while its Cartesian axes acquired absolute meanings of evaluation, activity, and potency [Tanaka and Osgood, 1965]. In Figures 5 and 6 evaluation, for example, corresponds to the vertical axis Z, top and bottom ends of which are cross-culturally associated with good (light, bright, favorable) and bad (dark, heavy, unfavorable) experiences [Surov, 2022a; Surov, 2023b].

5.3 Other semantic spaces

Three-dimensional Euclidean space thus derives from the complex-valued probability model of the simplest binary uncertainty (1). This choice could have been motivated by its unique mathematical features [Müller and Masanes, 2013]. Still, it is theoretically plausible to consider semantic spaces, generated by other kinds of quantum states and possibly maintained by other forms of life.

Adding one more alternative $|2\rangle$ to the two-way uncertainty (1), for example, would change qubit (1) to the qutrit state, defined by four and eight parameters in pure and mixed cases [Goyal et al., 2016]. The dimensionality of the corresponding space grows accordingly. Given the energetic cost of cognition, for such complication of the nervous systems it must provide strong competitive advantages.

This optionality of space is not paralleled by something similar for time, which is not conditioned by particular type of uncertainty. Figure 3 would retain its meaning, for example, with triadic X- type junctions. Space thus appears as secondary to time and life in ontological hierarchy of concepts.

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[8] Definition of life as "sense-making in precarious conditions" [Thompson, 2011] aligns with the definition proposed in Section 4.2 if "precarious condition" is understood as individual's quantum uncertainty, requiring non-algorithmic decision. Sense-making is not a goal by itself, but a means for guiding of this act.

[9] The theory is not relativistic but may have such development as proposed for example in [Aerts, 2018].

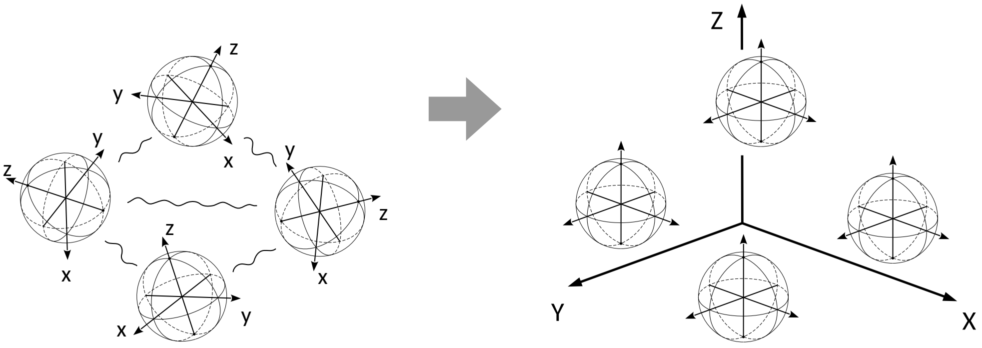

Figure 6. Alignment of the isolated qubit semantic spaces, Figure 5, due to affective interaction of individuals. The result is three-dimensional Euclidean space of standard metric, providing common language for pragmatic communication and coordinated decision-making.

6 Conclusion

Meeting the Wheeler's challenge, this paper sketches the way for refounding space and time on quantum principles. These fundamentals are triangulated by the phenomenon of life, thus recovering integrity of natural science as envisioned in [Kauffman and Gare, 2015; Cortes and Smolin, 2021]. In short,

- Time is pace with which actual reality advents to the domain of potential future due to resolution of quantum uncertainties in acts of decision;
- Life is the way for guiding this construction at branchings of deterministic laws at all scales;
- Space is natural and the most widespread format of subjective sense-making, enabling coordination of individual decisions.

These conclusions slightly depart from the original Wheeler's ideas. Famous "it from bit" [Wheeler and Ford, 2000, ch. 15], [Zeilinger, 2004], for example, implies primacy of information with respect to particles and matter. This favors subjective interpretations of quantum theory and solipsistic philosophy, considering the world as creation of human mind, or even indistinguishable from it. The present model, in contrast, is compatible with balanced ontology of nature, sliding neither to idealistic ("it from bit"), nor to materialistic ("bit from it") side [Aguirre et al., 2015]. As shown above, the concept of meaning (developed well beyond Wheeler's original form) is the origin of space, but neither of life, nor matter and time.

Another difference regards the "no law" dictum, an idea to derive everything from nothing. The fact that qubit resolves in either 1 or 0 is the law; specific structure of the qubit state in another law; the resulting dimensionality and metric of Euclidean space are secondary laws of lower rank. The strive for "no law" thus seems methodologically flawed, and the present approach does not subscribe for this objective.

Nevertheless, the obtained solution aligns with the core of Wheeler's thought:

- "no law" corresponds to non-algorithmicity of choice between potential futures;
- "no space, no time" dictum is fulfilled by deriving both from quantum phenomena;
- "consciousness" agrees with the conclusion that nature is fundamentally alive and sentient;
- "observer-participancy" manifests in active role of individuals in decision- and sense-making;
- "the super-Copernican principle" helped in transcending human-centered conception of meaning and biology-centered conception of life.

The latter point, extending "the super-Copernican principle" to the unprecedented scope, is the main conceptual difference from the works of Wheeler. In this respect, he essentially followed mainstream cultural narrative of the time, monopolizing the privilege of meaningful life to humans. In the realm of meaning our species is then placed to the "Swiss watch-maker" role, which is typical to the anthropocentric worldview, but alien to the spirit of Wheeler's thought.

Weakening of this monopoly is key for the reported progress. By recognizing all nature as rudimentary alive and sentient, the present theory moves the phenomenon of life from the margin to the center of scientific worldview. Going beyond our self-centrism, this opens new paths for ethical and technical progress.

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