

Schrödinger's cat versus Darwin

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Abstract

Sun Wu-k'ung, an immortal Monkey-King of Chaos learns modern physics from the Patriarch Bodhi and questions the Darwinian evolution. He finds that the modern physics indicates towards the intelligent design as a vastly more probably origin of humans than the random evolution by mutations and natural selection.

1 Preface

Я не знаю, Земля кружится или нет,
Это зависит, уложится ли в строчку слово.
Я не знаю, были ли моими бабушкой и дедом
Обезьяны, так как я не знаю, хочется ли мне сладкого или кислого.
Но я знаю, что я хочу кипеть и хочу, чтобы солнце
И жилу моей руки соединила обшая дрожь.
Но я хочу, чтобы луч звезды целовал луч моего глаза,
Как олень оленя (о, их прекрасные глаза!).
Но я хочу, чтобы, когда я трепещу, общий трепет приобшился вселенной.
И я хочу верить, что есть что-то, что остается,
Когда косу любимой девушки заменить, например, временем.
Я хочу вынести за скобки общего множителя, соединяющего меня,
Солнце, небо, жемчужную пыль.

Велимир Хлебников, 1909.

I do not know, the Earth turns or not,
This depends how the words will fit the line.
I do not know, whether my grandmother and grandfather were
Monkeys, since I don't know do I want sweet or sour.
But I do know that I want to boil and I want the Sun
And the vein of my hand to be connected by the common trembling.
But I do want the ray of the star to kiss the ray of my eye,
As deer to deer (oh, their excellent eyes!).
But I want when I quiver the general trembling of the universe
to join my trembling.
And I want to believe that there is something which remains,
When the braid of the dear girl is faided away, for example,
by the time.
I want to take out of brackets the common factor, which connects me,
the Sun, pearl dust, and the sky.

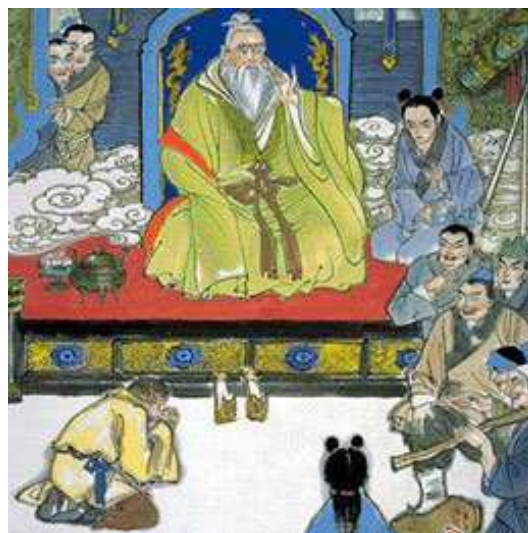
Velimir Khlebnikov, 1909.

2 Introduction

The most beloved story in China is the book “Monkey” written by Wu Cheng-En in the sixteenth century and it is about an immortal Monkey-King of Chaos Sun Wu-k’ung [1, 2].



Sun Wu-k’ung was born of primordial Chaos in a remote island from a stone impregnated by the sky. The other monkeys honored him as their king but soon in search of immortality he left the island and traveled on a raft to civilized lands. Acquiring human speech and manners, he decided to become the disciple of a Buddhist Patriarch Bodhi. Bodhi was initially reluctant about this but was impressed by monkey’s determination and brilliant abilities.



In three years Wu-k’ung learned perfectly well magical transformations, cloud dancing, and martial arts. Soon he was able to leap thousands of miles with one somersault. Of course, these marvelous abilities were not acquired without learning modern physics and the next chapter describes what he learned in physics from the Patriarch Bodhi.

3 Wu-k'ung learns modern physics

The glorious building of modern physics is based on three elephants (or whales according to another scientific school to which Bodhi is antagonistic). The elephants stand on the back of a gigantic tortoise which by itself swims in a world ocean of dark energy.



We know very little about the tortoise (Grand Unification, Theory of Everything), or about the dark energy, but the elephants are studied perfectly well and these elephants are

- gauge symmetry
- special relativity
- quantum mechanics

– Let us take a closer look at them – said the Patriarch to Wu-k'ung.

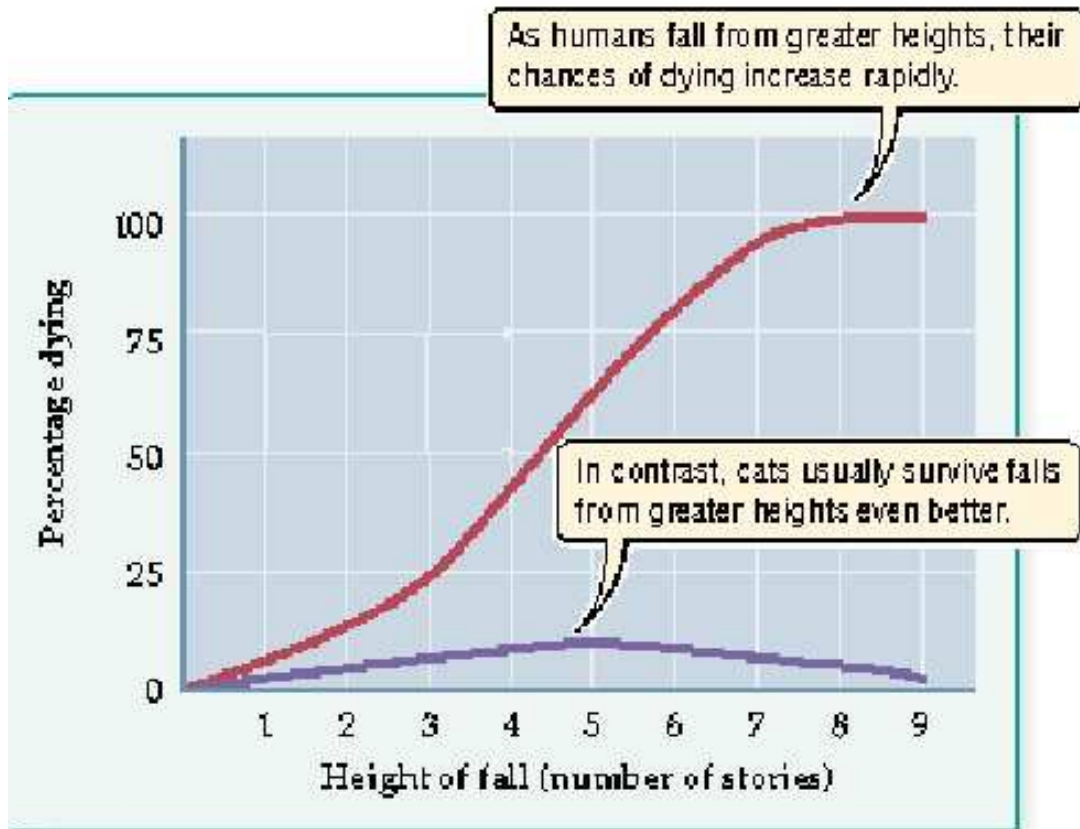
3.1 Gauge symmetry

– It's better to learn gauge theory by observing falling cats – began Bodhi his narrative. In the middle ages Europeans were not very fond of cats because cats were considered as devil creatures. At holidays people used to go on cat hunting. They catch these poor creatures and tormented them in all wicked ways: roasted them alive, whipped to death, or threw them into a boiling water [3].

– Oh, my Master, – cried Wu-k'ung – what a stupid brutality of ignorant and rude people thinking themselves as pious!

– They just considered cats as demons, – calmly continued the Patriarch – and they had a good proof for the cat's devil nature. One favorite amusement at that days was to through down the cats from a church tower, and pretty often the cats survived safe this sure death adventure. Why not a proof of cat's supernatural resistance against inevitable death and hence her devil nature?

In more enlightened age, two veterinarians Wayne Whitney and Cheryl Mehlhaff studied the so called “feline high-rise syndrome” in 1987. They had their veterinary clinic in Manhattan where cats often fall from New-York skyscrapers. Their findings are schematically shown in the figure below [4, 5].



– Quite a remarkable finding – said Wu-k’ung, surprised a bit – contrary to humans whose chance to die from the falling accident steadily increases with height and approaches 100% above a height of about seven floors, the mortality of cats initially rises to 10% and then falls down to about 5%! Incredibly, cat’s prospects of survival improve with height! Surely there is some explanation of this queer fact?

– Yes, of course, – replied the Patriarch – one can imagine the following explanation [5, 6]. Cats reach a terminal velocity of about 100 km/h after flying about 30 meters in air. After this moment the air resistance balances the pull of earth’s gravity and cat’s velocity ceases to grow. At first sight, one expects the height to be no longer important for cat’s survival after the terminal velocity is reached. However, then the acceleration disappears the cat probably relax and extends its limbs horizontally, flying like a flying-squirrel from this moment. This increases its effective transverse area and hence air resistance, reducing the terminal velocity.

– But more important for us is the one particular ingredient of cat’s enduring power of survival, – continued the Patriarch – it’s their ability to change the body’s orientation in the free fall. After all cats always land on their feet, no matter how they were dropped, is not it? Look at this picture of the cat dropped upside down. Within less than half a second it turns around its longitudinal axis and land on its feet unharmed.

– But I’m surprised, – begin Wu-k’ung – I know the conservation of momentum precludes the center of mass of a system to be moved by inner forces. There was a guy, it seems Baron Münchhausen was his name, who claimed that he once escaped from a swamp by pulling

himself up by his own hair. But he is notorious liar, is not it? And what about the conservation of angular momentum? Does not it precludes the cat to change its orientation if cat's initial angular momentum was zero?

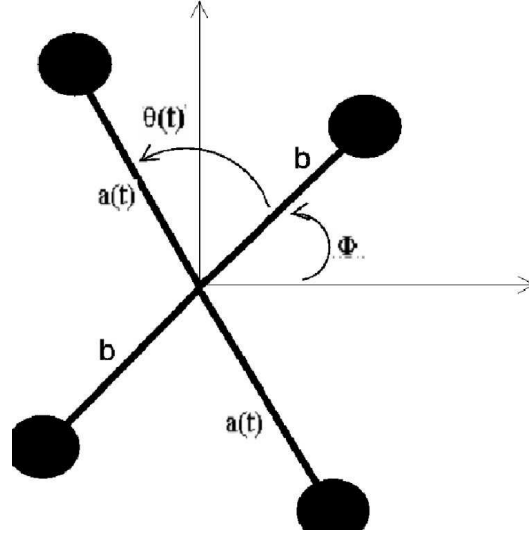


– The cat just uses the conservation of angular momentum in a clever way [3] – smiled the Patriarch. – Look at the picture. In a first stroke the cat pulls the front legs tightly against the body and stretches the hind legs perpendicular to the longitudinal axis of the body away. Thus it increases the moment of inertia of the rear part of the body and lowers the moment of inertia of its front part. But the angular momentum equals to the product of the moment of inertia over the angular velocity. Therefore, when the cat turns its head and the front body quickly downward, the rear part rotates in the counter direction but with much less angular velocity, in complete agreement with the angular momentum conservation law. As a result, the rotation angle of the front part may be near 180° while the counter rotation angle of the rear part will be much smaller. Then the cat repeats the maneuver in reverse order: now it stretches the front legs from the body away and pushes the rear ones to the body. This allows the cat to rotate the rear part of the body downward with only

small swing of the front part and hence to eliminate the twist of its body at the end of this two step flip-flap.

– Really ingenious! – said Wu-k’ung – you know monkeys as close relatives of humans are vice-kings of Nature and I always largely regarded cats as inferior creatures, but now I’m beginning to change my opinion. However, how can we describe cat’s somersaulting mathematically?

– Good question – answered the Patriarch – and this is the heart of the matter. But to explain what I have in mind we need some simple model of a cat. And here is one, inspired by [7].



We have two dumbbells of identical mass $2m$ on the common pivot. The “cat” can control the angle $\theta(t)$ between the dumbbells, as well as the half-length $a(t)$ of one dumbbell. Cat’s goal is by manipulating a and θ to change its orientation specified by the angle Φ . We can regard (a, θ) as polar coordinates in the cat’s shape space which in our case is just a plane. Any somersaulting of the cat is described in the shape space by some curve γ which connects its initial and final shapes. If the cat restores its shape after performing a flip, the curve γ will be a closed loop.

We can calculate the angular momentum of the “cat” very simply

$$L = 2m(a^2 + b^2)\dot{\Phi} + 2ma^2\dot{\theta},$$

where b is the half-length of the dumbbell with fixed length. If the angular momentum was initially zero so it will remain all the time as the cat does not experience any external torque. This enables us to connect time derivatives of angles Φ and θ as follows

$$\dot{\Phi} = -\frac{a^2}{a^2 + b^2} \dot{\theta}.$$

Using this relation, for the turning angle of the cat we get

$$\Delta\Phi = \int_0^T \dot{\Phi} dt = \int_{\gamma} \left[-\frac{a}{a^2 + b^2} ad\theta + 0 da \right] = \int_{\gamma} \vec{A} \cdot d\vec{l},$$

where γ is the path in the (a, θ) plane which describes consecutive changes in the shape of the cat. Besides we have for the “vector potential” \vec{A} and for the line element $d\vec{l}$ the following expressions in polar coordinates

$$\vec{A} = -\frac{a}{a^2 + b^2} \vec{e}_\theta, \quad d\vec{l} = da \vec{e}_a + a d\theta \vec{e}_\theta.$$

As we see the time parametrization have dropped from the equation. The only thing that matters as far as the total rotation of the cat is concerned is the geometry of the change. The speed at which a and θ change does not matter and only the curve γ in the cat’s shape space, that is a succession of cat’s shapes, uniquely determines the total rotation.

– However, you can not have any doubts that cats perform this exercise very quickly, – remarked the Patriarch. – As the American physiologist Donald McDonald found in 1960 by using modern high-speed camera, for the full motion cascade cat only needs one-eighth of a second, that is it is properly turned after only the first eight centimeters of the free fall when dropped upside down [3].

But let us return to the formula for the total rotation angle. By using Stokes’ theorem, we can rewrite it as follows

$$\Delta\Phi = \oint \vec{A} \cdot d\vec{l} = \iint_S \vec{B} \cdot d\vec{S},$$

where

$$\vec{B} = \nabla \times \vec{A} = -\frac{2b^2}{(a^2 + b^2)^2} \vec{e}_z, \quad d\vec{S} = a da d\theta \vec{e}_z.$$

An analogy with a gauge theory can be made even more apparent if we compare the formulas obtained for $\Delta\Phi$ to the formula of electron’s phase shift in the Aharonov-Bohm effect [8]

$$\Delta\Phi = \frac{e}{\hbar c} \oint \vec{A} \cdot d\vec{l} = \frac{e}{\hbar c} \iint_S \vec{B} \cdot d\vec{S},$$

where now \vec{A} is a genuine vector potential and \vec{B} is the corresponding magnetic field.

– In connection with the Aharonov-Bohm effect – mentioned Wu-k’ung – I just remembered the Arnold principle: *If a notion bears a personal name, then this name is not the name of the discoverer*, which is said to be so awfully general that being applicable even to itself (the Berry principle) [9]. Ten years before [8], Ehrenberg and Siday in their studies of electron microscopy [10] already obtained the main results of [8]. However their work went completely unnoticed. As remarked by Chambers, who one of the first experimentally verified the Aharonov-Bohm effect, Ehrenberg and Siday “perhaps did not sufficiently emphasize the remarkable nature of their result” [11].

– This is amusing, of course, – said the Patriarch – however the importance of contribution of Aharonov and Bohm is beyond any question.

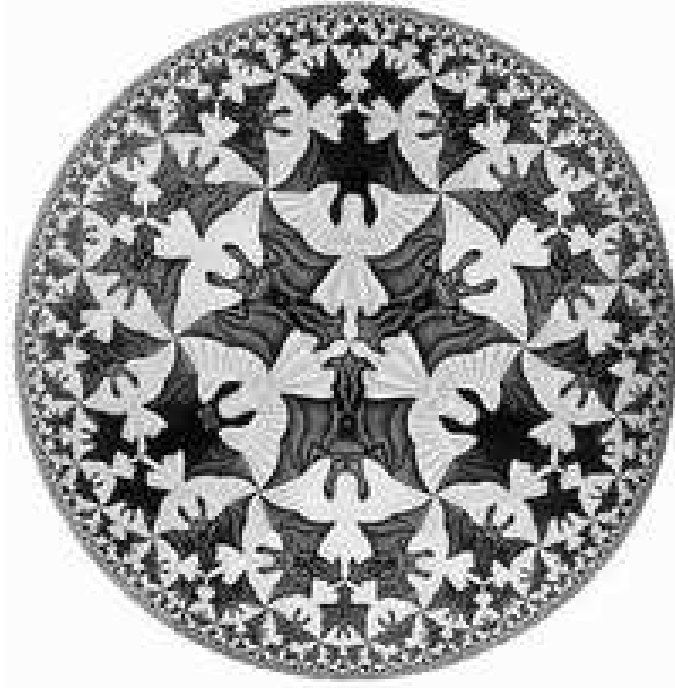
– With some caveat to the Arnold principle, – continued he – I should say that Guichardet was the first who made explicit a connection between gauge fields and falling cat [12]. Then important contributions by Wilczek and his PhD student Shapere followed [13, 14]. They also showed that gauge fields are a natural language to describe self-propulsion of microorganisms at low Reynolds number [15] (a very nice description of life at low Reynolds number was given by Purcell [16]). Montgomery in his influential papers [17, 18] investigated the question

how cats can perform their maneuvers efficiently (and you can't have even slightest doubt that they do this very efficiently). It turns out that for this goal cats should "solve" almost the same Wong's equations that describe the motion of a colored quark in a Yang-Mills field [19]. You can consult a review article [20] for additional information.

3.2 Special relativity

After Wu-k'ung mastered gauge theory, the time has come to speak about special relativity.

– The essence of special relativity – begin solemnly the Patriarch – can be expressed by one sentence: *the geometry of empty space-time is Minkowski geometry.*



– But I suspect – humbly remarked Wu-k'ung – to duly appreciate the meaning of this sole sentence we need a deep insight into the nature of geometry.

– That's right – said the Patriarch – and what is geometry? You surely know about Euclidean geometry and know that the points of the Euclidean plane can be represented by complex numbers. The distance between two points represented by complex numbers z_1 and z_2 is given by

$$d^2(z_1, z_2) = (z_2 - z_1)(\bar{z}_2 - \bar{z}_1),$$

where the bar means complex conjugation. This is called parabolic linear measure for reasons you will understand after you scrutinize this folio – the Patriarch transferred to Wu-k'ung some of Klein's papers [22, 23, 24].

– But I also heard about non-Euclidean geometries of Lobachevsky and Riemann – got excited Wu-k'ung.

– For monkey you are well versed in mathematics – praised the Patriarch. In Lobachevsky geometry (hyperbolic linear measure) the distance is given by

$$\sinh^2 d(z_1, z_2) = \frac{(z_2 - z_1)(\bar{z}_2 - \bar{z}_1)}{[1 - z_2\bar{z}_2][1 - z_1\bar{z}_1]}$$

and in Riemann or elliptic geometry (elliptic linear measure) by

$$\sin^2 d(z_1, z_2) = \frac{(z_2 - z_1)(\bar{z}_2 - \bar{z}_1)}{[1 + z_2\bar{z}_2][1 + z_1\bar{z}_1]}.$$

– Complex numbers are obtained by adding to the real numbers a special element i which is a solution of the quadratic equation $i^2 = -1$. But why this particular quadratic equation? What is special about it? – asked Wu-k’ung.

– Nothing special – answered the Patriarch – On equal footing we can assume a special element e to be a solution of the general quadratic equation $Ae^2 + Be + C = 0$. In fact, in this way we get three different types of generalized complex numbers $a + eb$. If the discriminant $D = B^2 - 4AC$ is negative, we get the ordinary complex numbers $a + ib$ and one can assume without loss of generality that $i^2 = -1$. Indeed, if $Ae^2 + Be + C = 0$ and $D < 0$ then

$$i = \frac{B}{\sqrt{-D}} + \frac{2A}{\sqrt{-D}} e$$

just have this property $i^2 = -1$ and every hyper-complex number $a + eb$ can be rewritten as $a' + ib'$.

If the discriminant is zero, we get the so called dual numbers $a + \epsilon b$ and one can assume that $\epsilon^2 = 0$. And if the discriminant is positive, we get the double numbers $a + eb$ with $e^2 = 1$ [21].

– If now we change complex numbers in the above formulas – guessed Wu-k’ung – we get other types of geometry?

– Absolutely right, – the Patriarch seemed satisfied by Wu-k’ung’s insight. – For hyperbolic linear measure, double numbers lead to de Sitter geometry and dual numbers lead to co-Minkowski geometry. For elliptic linear measure, double numbers correspond to anti-de Sitter geometry and dual numbers to co-Euclidean geometry. At last, for parabolic linear measure, dual numbers imply Galilean geometry and double numbers lead to Minkowski geometry. On the whole, we have nine so called Cayley-Klein geometries of the plane (more details can be found in [25]).

measure of angles	measure of lengths		
	Hyperbolic	Parabolic	Elliptic
Hyperbolic	Doubly hyperbolic (de-Sitter)	Minkowski	co-Hyperbolic (anti de-Sitter)
Parabolic	co-Minkowski	Galilean	co-Euclidean
Elliptic	Hyperbolic (Lobachevsky)	Euclidean	Elliptic (Riemann)

– However, – remarked Wu-k’ung, – special relativity is not a merely geometric theory, but a physical one and it includes concepts like causality, reference frames, inertial motion, relativity principle.

– Absolutely right again, – said the Patriarch. Let us see what geometry will arise if we stick to these physical notions.

It is intuitively appealing to suppose that meter sticks do not change their lengths when gently set in uniform motion – continued the Patriarch. – However, this is not quite obvious and we simply admit a more general possibility, instead of supposing unchanged lengths. Accordingly, we change the Galilean transformations, which describe a transition from one inertial frame to another, by

$$x' = \frac{1}{k(V^2)} (x - Vt),$$

where the scale factor $k(V^2)$ accounts for the possible change in the length of the meter stick when it is set in motion with velocity V . It can depend only on the magnitude of the relative velocity V , because the Relativity Principle and the isotropy of space is assumed to be valid.

Due to the Relativity Principle, the same relation holds if unprimed coordinates are expressed through the primed ones, with V replaced by $-V$. Therefore,

$$x = \frac{1}{k(V^2)} (x' + Vt') = \frac{1}{k(V^2)} \left[\frac{1}{k(V^2)} (x - Vt) + Vt' \right].$$

Solving for t' , we get

$$t' = \frac{1}{k(V^2)} \left[t - \frac{1 - k^2(V^2)}{V} x \right].$$

Now we are in a position to derive the velocity addition rule,

$$v'_x = \frac{dx'}{dt'} = \frac{dx - Vdt}{dt - \frac{1-k^2}{V} dx} = \frac{v_x - V}{1 - \frac{1-k^2}{V} v_x}.$$

By using the Relativity principle, it will be convenient to write down it in the form

$$v_x = \frac{v'_x + V}{1 + \frac{1-k^2}{V} v'_x} \equiv F(v'_x, V).$$

F must be an odd function of its arguments $F(-x, -y) = -F(x, y)$, because If we change the signs of both velocities v'_x and V it is obvious that the sign of the resulting velocity v_x will be also changed.

Consider now three bodies A , B and C in a relative motion. Let V_{AB} denote the velocity of A with respect to B so that $V_{BA} = -V_{AB}$. Then we will have

$$F(V_{CB}, V_{BA}) = V_{CA} = -V_{AC} = -F(V_{AB}, V_{BC}) = -F(-V_{BA}, -V_{CB}) = F(V_{BA}, V_{CB}).$$

Therefore F is a symmetric function of its arguments and then $F(v'_x, V) = F(V, v'_x)$ immediately yields

$$\frac{1 - k^2(V^2)}{V} v'_x = \frac{1 - k^2(v'^2_x)}{v'_x} V,$$

or

$$\frac{1 - k^2(V^2)}{V^2} = \frac{1 - k^2(v'^2_x)}{v'^2_x} \equiv K,$$

where K is a constant.

If $K > 0$, we can take $K = \frac{1}{c^2}$ and introduce a dimensionless parameter $\beta = \frac{V}{c}$. As a result, we get the Lorentz transformations

$$\begin{aligned}x' &= \frac{1}{\sqrt{1 - \beta^2}}(x - Vt), \\t' &= \frac{1}{\sqrt{1 - \beta^2}}\left(t - \frac{V}{c^2}x\right),\end{aligned}$$

and, hence, Minkowski geometry. In this case, velocity addition rule indicates that c is an invariant velocity. If $K = 0$, we recover the Galilean transformations and the geometry behind the corresponding space-time is Galilean geometry. Note that Galilean geometry can be considered as a limiting case of Minkowski geometry when $c \rightarrow \infty$. The case $K < 0$ corresponds to Euclidean space-time which does not allow us to define an invariant time order between events, that is to distinguish future from past and introduce causality (see [25] for more details).

– As I see – Wu-k'ung seemed a bit puzzled, – if we stick to the Relativity principle, space isotropy and inertial reference frames, the only space-time geometry which emerges is Minkowski geometry along with its rather singular limit of Galilean geometry. And what about other Cayley-Klein geometries?

– In fact, – answered the Patriarch, – the existence of inertial reference frames is, in general, not obviously guaranteed. Therefore we can consider the boost transformations in a more general context as not necessarily representing transitions from one inertial frame to another. This opens a possibility to generalize special relativity by deforming its underlying symmetry structure - the Poincaré algebra [26].

The symmetry group of special relativity is the ten-parameter Poincaré group. Ten basis elements of its Lie algebra are the following: the generator H of time translations; three generators P_i of space translations along the i -axis; three generators J_i of spatial rotations; and three generators K_i of pure Lorentz transformations, which can be considered as the inertial transformations (boosts) along the i -axis. The commutation relations involving J_i have the form

$$[J_i, H] = 0, \quad [J_i, J_j] = \epsilon_{ijk}J_k, \quad [J_i, P_j] = \epsilon_{ijk}P_k, \quad [J_i, K_j] = \epsilon_{ijk}K_k.$$

We can not change these commutation relations without spoiling the spatial isotropy. However, other commutation relations

$$[H, P_i] = 0, \quad [H, K_i] = P_i, \quad [P_i, P_j] = 0, \quad [K_i, K_j] = -\epsilon_{ijk}J_k, \quad [P_i, K_j] = \delta_{ij}H$$

are less rigid and can be deformed as they depend on the interpretation of inertial transformations (boosts) which we want to change.

If we demand the parity and time-reversal invariance, the only possible deformations of these commutation relations will have the form [26]

$$[H, P_i] = \epsilon_1 K_i, \quad [H, K_i] = \lambda P_i, \quad [P_i, P_j] = \alpha \epsilon_{ijk}J_k, \quad [K_i, K_j] = \beta \epsilon_{ijk}J_k, \quad [P_i, K_j] = \epsilon_2 \delta_{ij}H.$$

The Jacobi identities

$$[P_i, [P_j, K_k]] + [P_j, [K_k, P_i]] + [K_k, [P_i, P_j]] = 0$$

and

$$[P_i, [K_j, K_k]] + [K_j, [K_k, P_i]] + [K_k, [P_i, K_j]] = 0,$$

are satisfied only if

$$\alpha - \epsilon_1 \epsilon_2 = 0, \quad \text{and} \quad \beta + \lambda \epsilon_2 = 0.$$

After the deformation, the Poincaré group is replaced by the so called kinematical group – the generalized relativity group of nature. As we see, the structure of its Lie algebra is completely determined by three real parameters ϵ_1 , ϵ_2 and λ . Note that the overall sign of the structure constants is irrelevant as the sign change of all structure constants can be achieved simply by multiplying each infinitesimal generator by -1 . Therefore we can assume $\lambda \geq 0$ without loss of generality and by a scale change it can be brought either to $\lambda = 1$ or $\lambda = 0$.

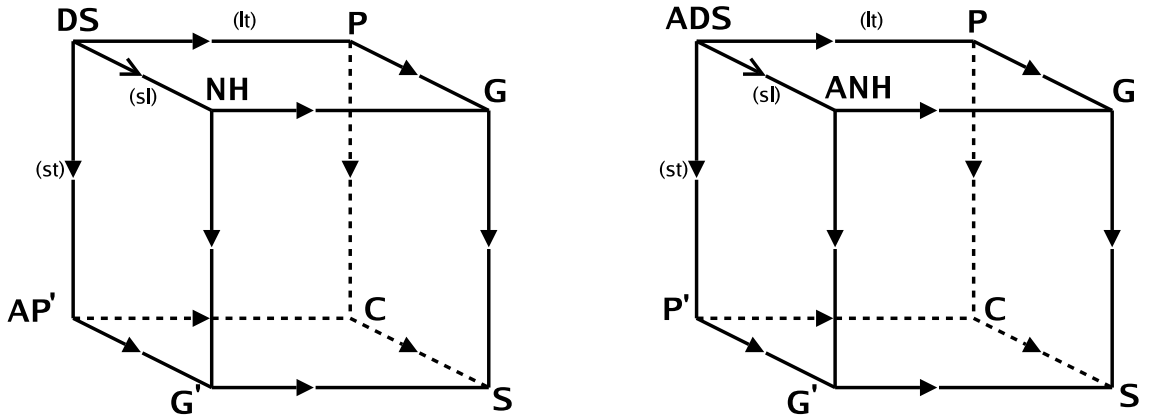
If $\lambda = 1$, every kinematical group has its underlying Cayley-Klein geometry as the geometry of the corresponding space-time. We have the following possibilities (more details can be found in [25]):

- $\epsilon_2 < 0$ - the inertial transformations form a compact group and it is not possible (like Euclidean space-time) to introduce a causal order between events. Such space-times, if they exist at all (the formation of a Euclidean region in the center of a black hole might be a possible outcome of gravitational collapse [27]), are, however, not kinematical as they, in fact, are timeless Nirvanas.
- $\epsilon_1 > 0, \epsilon_2 > 0$ - de Sitter kinematics (**DS**) with doubly-hyperbolic geometry.
- $\epsilon_1 < 0, \epsilon_2 > 0$ - anti de Sitter kinematics (**ADS**) with co-hyperbolic geometry.
- $\epsilon_1 = 0, \epsilon_2 > 0$ - Poincaré kinematics (**P**) with Minkowski geometry.
- $\epsilon_1 > 0, \epsilon_2 = 0$ - Newton-Hook kinematics (**NH**) with co-Minkowski geometry.
- $\epsilon_1 < 0, \epsilon_2 = 0$ - anti Newton-Hook kinematics (**ANH**) with co-Euclidean geometry.
- $\epsilon_1 = 0, \epsilon_2 = 0$ - Galilean kinematics (**G**) with Galilean geometry.

The case $\lambda = 0$ gives rise to five more possibilities of rather exotic kinematics of limited physical significance as they correspond to space-times with absolute space:

- $\epsilon_1 = 1, \epsilon_2 = 1$ - anti para-Poincaré kinematics (**AP'**) with Euclidean geometry.
- $\epsilon_1 = -1, \epsilon_2 = 1$ - para-Poincaré kinematics (**P'**) with Minkowski geometry.
- $\epsilon_1 = 1, \epsilon_2 = 0$ - para-Galilei kinematics (**G'**) with Galilean geometry.
- $\epsilon_1 = 0, \epsilon_2 = \pm 1$ - Carroll kinematics (**C**) with Galilean geometry.
- $\epsilon_1 = 0, \epsilon_2 = 0$ - static kinematics (**S**) with trivial geometry.

– All these kinematical groups along relations between them are shown in the figure below, – said the Patriarch, – and you, Wu-k'ung, should consult the literature ([25, 26]) to better understand the nature of these relations between various kinematical groups. Then you will find out that all corresponding relativity theories are in fact limiting cases of the de Sitter or anti de Sitter space-times.



– I see – exclaimed Wu-k’ung – “there exists essentially only one way to generalize special relativity, namely, by endowing space-time with some constant curvature” [26].

– That’s right – answered the Patriarch – and it is not surprising that, as the recent astrophysical observations indicate, we live actually in the de Sitter space-time, not Minkowski. However, the cosmological constant which measures the curvature of this de Sitter space-time is incredibly small - by about 120 degrees of magnitude smaller than expected on some “natural” grounds! Just this incredible smallness of the cosmological constant renders the special relativity to the extremely good approximation to reality and, therefore, to one of the most trustworthy elephant upon which the whole building of modern physics rests.

3.3 Quantum mechanics

At last Wu-k’ung was prepared to study quantum mechanics.

– Normal people (that is not physicists) usually consider the quantum mechanics as the subject extremely vague and far from the common sense – smiled the Patriarch as the time came for Wu-k’ung to study quantum mechanics.

– This is partly really so – readily answered Wu-k’ung. – Here is a notorious story about the famous mathematicians Russell and Whitehead [28]. One of them was the speaker at a seminar, and the other was the Chairman of that seminar. The talk was devoted to the foundations of quantum mechanics. At the end not only the seminar participants were already on the throat satisfied by the report, but so was the Chairman. It was extremely difficult, confused and unclear. When the report ended, the Chairman felt that he ought to comment on the report. So he said only one sentence which at the same time was both polite and truthful. He simply said: “We should be thankful to the speaker for what he did not obfuscate further this already sufficiently obscure subject.”

– An amusing history indeed, – remarked the Patriarch – but in reality the quantum mechanics is not at all obscure and far from everyday experience contrary to beliefs of the average man. Suppose an electron has to move from one point to another. How it can do this?

– One has to know forces that act on the electron. Then you can apply Newton’s second law and find the trajectory – replied Wu-k’ung.

– Forget about forces – interrupted the Patriarch. – Do you remember the Aharonov-Bohm effect? Besides, force is a vague notion borrowed from politics. “In the Newtonian theory of the solar system, the sun seems like a monarch whose behests the planets have to

obey” [29]. In fact, “ $F = ma$ is formally empty, microscopically obscure, and maybe even morally suspect” [30]. To follow the classical trajectory an electron has to solve second order differential equation which the Newton’s second law is. How on earth it can perform this if it is brainless? Simply the electron is too tiny to have any brain. It needs a very simple instruction to be able to follow it, and the simplest instruction is: “Explore all paths” [31].

– But how can the electron reach any particular destination if all paths you can imagine are equivalent? – exclaimed Wu-k’ung.

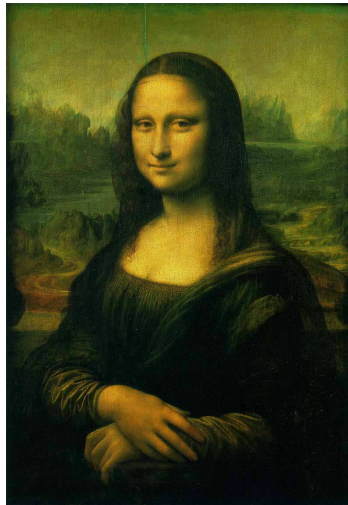
– They are not completely equivalent – was the Patriarch’s reply. – They differ in a subtle way. A complex number called the amplitude is prescribed to each path. All paths are equivalent in a sense that all these complex numbers have unite magnitude, but their phases may be different. To find out the probability that the electron will reach some particular destination you sum up amplitudes of all paths leading to this particular point and the squared magnitude of the resulting complex number gives you the desired probability. You will be surprised, Wu-k’ung, but all the quantum mechanics is based on these simple principles just described [32].

– But this seems crazy! – Wu-k’ung was really surprised.

– You are not alone in your bewilderment – smiled the Patriarch. – Freeman Dyson recollects: *Thirty-one years ago, Dick Feynman told me about his “sum over histories” version of quantum mechanics. “The electron does anything it likes,” he said. “It just goes in any direction at any speed, forward or backward in time, however it likes, and then you add up the amplitudes and it gives you the wave-function.” I said to him, “You’re crazy.” But he wasn’t* [33].

– But quantum mechanics is extremely strange, isn’t it? – asked Wu-k’ung. – for example take the superposition principle. Is it really not strange that a quantum system can be in a superposition of classically mutually exclusive states? This clearly does not fit in our everyday experience.

– Look at the figure below – said the Patriarch in answer.

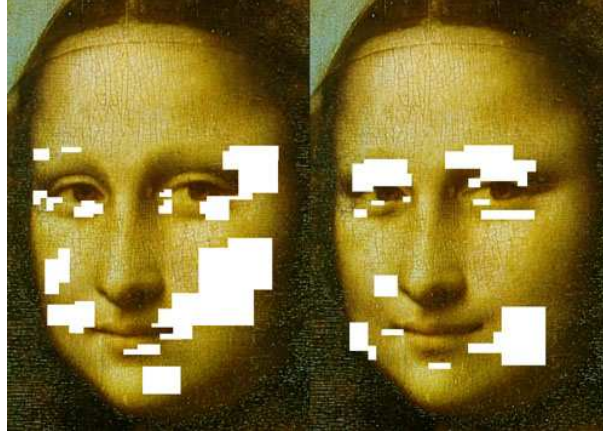


– This is the famous portrait of Mona Lisa by Leonardo da Vinci. – At that time Wu-k’ung was pretty well educated in art.

– But why this portrait is often regarded as enigmatic, mysterious and incomprehensible? – asked the Patriarch.

– Some say the portrait looks different every time we look at it – Wu-k’ung was thoughtful. Then he continued – “Sometimes she seems to mock at us, and then again we seem to catch something like sadness in her smile. All this sounds rather mysterious and so it is” [34].

– And an analogy with quantum mechanics can help us to disentangle the enigma [34] – the Patriarch showed Wu-k’ung a couple of figures.



– Incredible! – uttered Wu-k’ung. – The woman on the left is definitely sad and the one on the right unquestionably cheerful!

– You see, Wu-k’ung, – the Patriarch looked triumphant – quantum mechanics is not at all as queer as it seems at first sight. Even such an unusual notion as the superposition of different states has its counterpart in art. Symbols of art, being macroscopic classical objects, have to obey the laws of classical physics. However, “their meaning need not to be constrained by this theory. They could be organized in a way that corresponds to quantum logic. This would be difficult, but it is not impossible. The art offers great many possibilities for doing that since there are no limits on its expressive power. The piece of art can lead us to some well organized world which has nothing in common with the one of our everyday experience” [34].

– But how about the amazing quantum non-locality? – asked Wu-k’ung – does it contradict to special relativity? I heard in 1935 Einstein, Podolsky and Rosen (EPR) wrote a paper [35] where it was claimed that quantum mechanics fails to provide a complete description of physical reality because it predicts things “no reasonable definition of reality could be expected to permit” [35]. What’s all the fuss about?

– Imagine a linearly polarized photon flying in some direction and a polarizing filter such that the photons either pass through or are absorbed by the polarizing filter [36]. Let $|H\rangle$ be a polarization state of the photon such that it always passes a horizontal filter but is guaranteed to be absorbed by a vertical filter. Analogously we define $|V\rangle$ with the roles of the horizontal and vertical filters interchanged. Quantum mechanics allows the following two-photon state (which is called the twin state in [36])

$$|\Psi\rangle = \sqrt{\frac{1}{2}} \left(|V\rangle |V\rangle + |H\rangle |H\rangle \right).$$

The photons in this state are entangled: if the first photon passes through a horizontal polarizing filter, the second photon is guaranteed to pass through another filter similarly oriented, and if the first photon is absorbed, so does the second photon. Therefore, by

measuring the polarization of the first photon we instantly will know the polarization of the second photon also, regardless the spatial separation between photons.

– I do not find this surprising in any obvious way – said Wu-k’ung. – There are “many examples of similar correlations in everyday life. The case of Bertlmann’s socks is often cited. Dr. Bertlmann likes to wear two sock of different colours. Which colour he will have on a given foot on a given day is quite unpredictable. But when you see that the first sock is pink you can be already sure that the second sock will not be pink. Observation of the first, and experience of Bertlmann, gives immediate information about the second. There is no accounting for tastes, but apart from that there is no mystery here. And is not the EPR business just the same?” [37]. Or take the example of identical twins who had been separated at birth [38]. They had many of their tastes and habits identical not to speak of their exactly alike appearance. This possibly struck many people including the twins themselves if they ever meet as a very surprising correlation. But in this case we have a ready ‘hidden-variable’ explanation: they have the same DNA. Maybe someday we will find analogous hidden-variable explanations of various quantum mechanical phenomena which at present we find puzzling.

– Be careful, Wu-k’ung – smiled the Patriarch. – Dr. Bertlmann himself finds the affairs rather puzzling, realizing their fundamental importance [39]. I think you do not question that the colour of the first sock preexisted before your saw it. Neither will doubt you that if the colour of the first sock allows to predict instantly that the other sock has a different colour then you are bound to conclude that this latter colour also preexisted and was predefined before your colour “measurement” with the first sock. And this is exactly the logic of EPR.

– Fine logic. And you want to say that something is wrong with it?

– Nothing wrong with the logic. But quantum mechanics somehow evades it. Can you imagine a quantum sock with no predefined colour? In some coherent mixture of pink and green, say? Probably you can if you remember ineffable smile of Mona Lisa. This is a strange but rather routine business in quantum world. The entangled photons in the EPR thought experiment do not have predefined polarizations according to quantum theory. Only after the measurement the wave function collapses towards a sharply defined polarization state. The trouble is buried in the fact that the wave function of the entangled photons is not equal to the product of wave functions of two individual photons. It is inseparable quantity and collapses as the whole even for photons widely spaced apart. Do you feel now a problem? How the second photon instantly “knows” to what polarization state to collapse after the measurement is done with the first photon, say, in another galaxy?

– I admit this is rather puzzling – mused Wu-k’ung. – And what is wrong with EPR reasoning?

– The logic behind the EPR reasoning is so fine that the result can be formulated as a theorem: *If the predictions of quantum mechanics are correct (even for systems made of remote correlated particles) and if physical reality can be described in a local (or separable) way, then quantum mechanics is necessarily incomplete: some “elements of reality” exist in Nature that are ignored by this theory* [40]. Nobody questions the validity of the theorem. Therefore, the question is whether the nature is indeed non-local as quantum mechanics suggests or the latter is only an incomplete description of reality. Note that physics was always non-local except some 10 years beginning from about 1915 when Einstein’s general relativity removed at last “spooky actions at a distance” from Newtonian gravity. But the local paradise, for which Newton so longed, ended in about 1925 with the advent of quantum

mechanics which reintroduced non-locality, albeit quite in a different and subtle way than in Newtonian gravity [41].

– But why quantum mechanics cannot prove to be incomplete? – asked Wu-k’ung. – After all so many physical theories turned out to be incomplete. Even special relativity is incomplete as it does not describe gravity. And some think both the special and general relativities are emergent low-energy phenomena [42]. Why quantum mechanics is considered to be more fundamental than these venerable theories?

– Let us return to the twin state photons [36], – begin the Patriarch. – Suppose the photon polarizations indeed do have predefined values as required by local realism, like Bertlmann’s socks. That is we are supposing that the source of these photons, whatever it is, produces with probability λ_1 the combination of photon polarizations $|V\rangle|V\rangle$, and with probability λ_2 the combination $|H\rangle|H\rangle$, while never $|H\rangle|V\rangle$ or $|V\rangle|H\rangle$, so that $\lambda_1 + \lambda_2 = 1$. Suppose further that the two polarizing filters, which analyze the polarization state of photons, are tilted by angles θ_1 and θ_2 , respectively, with respect to the vertical. And here is a good problem to test your advance in physics, Wu-k’ung: what is the odds of getting the same result on both sides (either both photons transmitted or both absorbed)?

– If the photon’s polarization is $|V\rangle$, it has $\cos^2\theta$ probability, according to the Malus’ law, to be transmitted by the polarizing filter inclined by the angle θ , and $\sin^2\theta$ probability to be absorbed by it. For the $|H\rangle$ polarization, probabilities are $\sin^2\theta$ and $\cos^2\theta$ respectively. The probability both photons to be transmitted is, therefore, $P_T = \lambda_1 \cos^2\theta_1 \cos^2\theta_2 + \lambda_2 \sin^2\theta_1 \sin^2\theta_2$, as the probabilities of $|H\rangle|H\rangle$ and $|V\rangle|V\rangle$ combinations are λ_1 and λ_2 . Similarly, the probability both photons to be absorbed is $P_A = \lambda_1 \sin^2\theta_1 \sin^2\theta_2 + \lambda_2 \cos^2\theta_1 \cos^2\theta_2$.

- That’s right – the Patriarch encouraged Wu-k’ung. – And then?
- The probability you asking me is clearly

$$P_{LR} = P_T + P_A = \cos^2\theta_1 \cos^2\theta_2 + \sin^2\theta_1 \sin^2\theta_2.$$

- Fine. And what is the answer according to quantum mechanics?
- I think the answer is

$$P_{QM} = |\langle\theta_1|\langle\theta_2|\Psi\rangle|^2 + |\langle\pi/2 - \theta_1|\langle\pi/2 - \theta_2|\Psi\rangle|^2.$$

And to calculate this, we can decompose $|\theta\rangle = \cos\theta|V\rangle + \sin\theta|H\rangle$ to get

$$\begin{aligned} \langle\theta_1|\langle\theta_2| &= \langle V|\langle V| \cos\theta_1 \cos\theta_2 + \langle H|\langle H| \sin\theta_1 \sin\theta_2 + \\ &\quad \langle V|\langle H| \cos\theta_1 \sin\theta_2 + \langle H|\langle V| \sin\theta_1 \cos\theta_2. \end{aligned}$$

It remains to do a simple algebra and trigonometry to obtain $P_{QM} = \cos^2(\theta_1 - \theta_2)$.

– You see the answers are different – remarked the Patriarch. – Do you find this surprising?

– Not at all – answered Wu-k’ung. – After all quantum mechanics is a different theory. Why should I be surprised that it gives a different result than the local-realistic classical expectation?

– The problem is not that quantum mechanics gives a different result – smiled the Patriarch. – The problem is that it gives *incomprehensible* result. Dr. Herbert invented the

general idea [43] which I will use to explain to your why the answer of quantum mechanics is incomprehensible. The argument goes as follows [36, 44, 45].

Suppose the source of twin photons emits some sequence of polarized photons with either horizontal or vertical polarizations. Were the polarizing filter oriented horizontally, the observer near it would register some sequence of either transmitted photons (T) or the absorbed ones (A), say

$$S(0) = \{A, T, T, A, A, T, A, T, A, T, T, T, A, T, A, A, A, A, T, A, T, T, A, T\}.$$

The same sequence will be registered by the horizontally oriented polarizing filter on the other side of the source because for twin photons their polarizations are 100% correlated like Bertlmann's socks colours. Now if we rotate one of the polarizing filter by some angle θ , it will register another sequence of transmitted or absorbed photons, say

$$S(\theta) = \{A, T, T, T, A, T, A, T, A, A, T, A, A, T, T, A, T, A, T, A, T, T, T, T\}.$$

Now the correlation between $S(0)$ and $S(\theta)$ is not 100%, of course. There are some mismatches, highlighted below

$$\begin{aligned} S(0) &= \{A, T, T, \mathbf{A}, A, T, A, T, A, \mathbf{T}, T, \mathbf{T}, A, T, \mathbf{A}, A, \mathbf{A}, A, T, A, T, T, \mathbf{A}, T\} \\ S(\theta) &= \{A, T, T, \mathbf{T}, A, T, A, T, A, \mathbf{A}, T, \mathbf{A}, A, T, \mathbf{T}, A, \mathbf{T}, A, T, A, T, T, \mathbf{T}, T\} \end{aligned}$$

– According to the formula $P_{LR} = P_T + P_A = \cos^2 \theta_1 \cos^2 \theta_2 + \sin^2 \theta_1 \sin^2 \theta_2$ your obtained, Wu-k'ung, we expect the probability of getting the same result on both sides to be in this case $\cos^2 \theta$ and hence the mismatch probability $\sin^2 \theta$. You observe six mismatches from twenty four events. Therefore the mismatch probability is about 1/4 which indicates the inclination angle $\theta = 30^\circ$, although this is not essential for subsequent considerations.

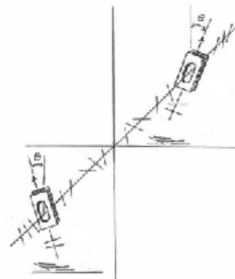
If we rotate the polarizing filter not by the angle θ , but $-\theta$, the mismatch probability should remain the same $\sin^2 \theta$ according to your formula, Wu-k'ung, although the sequence of results registered in this case will be of course different, say

$$S(-\theta) = \{A, T, A, A, A, T, T, T, A, T, T, T, A, T, A, T, T, A, T, A, T, A, T, T\}.$$

We still have about six mismatches although at different places:

$$\begin{aligned} S(0) &= \{A, T, \mathbf{T}, A, A, T, \mathbf{A}, T, A, T, T, T, A, T, A, \mathbf{A}, \mathbf{A}, A, T, A, T, \mathbf{T}, \mathbf{A}, T\} \\ S(-\theta) &= \{A, T, \mathbf{A}, A, A, T, \mathbf{T}, T, A, T, T, T, A, T, A, \mathbf{T}, \mathbf{T}, A, T, A, T, \mathbf{A}, \mathbf{T}, T\} \end{aligned}$$

And what will happen if one polarizing filter is rotated by the angle θ and the another, on the opposite side, by the angle $-\theta$ as indicated in the figure below?



What you can say about the mismatch rate in this case?

– Well, – begin Wu-k’ung – as the filters are well separated as I understand, they cannot influence each other. So I expect one filter to register the sequence $S(\theta)$ and the another one - the sequence $S(-\theta)$. The mismatch rate cannot exceed $2 \sin^2 \theta$ because there are some cases where both $S(\theta)$ and $S(-\theta)$ disagree with the result at zero angle $S(0)$ and, therefore, agree with each other. Indeed, there are only eight mismatches between $S(\theta)$ and $S(-\theta)$:

$$\begin{aligned} S(\theta) &= \{A, T, \mathbf{T}, \mathbf{T}, A, T, \mathbf{A}, T, A, \mathbf{A}, T, \mathbf{A}, A, T, \mathbf{T}, \mathbf{A}, T, A, T, A, T, \mathbf{T}, T, T\} \\ S(-\theta) &= \{A, T, \mathbf{A}, \mathbf{A}, A, T, \mathbf{T}, T, A, \mathbf{T}, T, \mathbf{T}, A, T, \mathbf{A}, \mathbf{T}, T, A, T, A, T, \mathbf{A}, T, T\} \end{aligned}$$

No wonder this observation is consistent with the formula $P_{LR} = P_T + P_A = \cos^2 \theta_1 \cos^2 \theta_2 + \sin^2 \theta_1 \sin^2 \theta_2$ I derived for the coincidence rate. Indeed, when $\theta_1 = \theta$ and $\theta_2 = -\theta$, we get $P_{LR} = \cos^4 \theta + \sin^4 \theta = 1 - 2 \sin^2 \theta \cos^2 \theta$. Therefore the expected mismatch rate is $2 \sin^2 \theta \cos^2 \theta$ and this clearly does not exceed $2 \sin^2 \theta$. By the way, for $\theta = 30^\circ$, the mismatch probability is $3/8$ and, therefore, we expect nine mismatches between $S(\theta)$ and $S(-\theta)$. In reality we observe eight mismatches, but this is just a play of statistics. Everything seems coherent for me.

– My congratulations, Wu-k’ung, – the Patriarch was very serious. – You have just discovered a simple-minded version of Bell’s inequality which all local-realistic models must satisfy [46]. In fact Bell’s inequalities can be considered as examples of George Boole’s mid-nineteenth century ‘Conditions of Possible Experience’ that the relative frequencies of logically connected events must satisfy [47]. There are just the logic and common sense behind them. This brings any theory which violates Bell’s inequalities “on the edge of a logical contradiction” [47]. And quantum mechanics is just such a theory! Remember what you get as the quantum mechanical prediction for the coincidence rate in our twin photon business? For $\theta_1 = \theta$ and $\theta_2 = -\theta$, the prediction is $P_{QM} = \cos^2(2\theta)$. Therefore quantum mechanics predicts the mismatch rate $1 - P_{QM} = \sin^2(2\theta) = 4 \sin^2 \theta \cos^2 \theta$ and this does not exceed $2 \sin^2 \theta$ only if $\cos^2 \theta \leq 1/2$. For example, if $\theta = 30^\circ$ then $1 - P_{QM} = 3/4$ which is *grater* than $2 \sin^2 30^\circ = 1/2$. The Bell’s inequality you obtained is clearly violated here!

– But how! – exclaimed Wu-k’ung, – What the hell is going here! How this simple result of logical reasoning can be violated by the theory which is overwhelmingly tested? I’m confused.

– “Anybody who is not bothered by Bell’s theorem has to have rocks in his head” [48] – replied the Patriarch. – And here is the answer on your question “why quantum mechanics cannot prove to be incomplete”. It cannot prove to be incomplete in the EPR business because simply experiments confirm that the Bell’s inequalities are indeed violated in some circumstances with complete agreement with the quantum mechanical predictions [49]. We are forced to accept a strange view of reality quantum mechanics offers us. “Before Bell’s discovery, one could still imagine that a local reality lurked beneath the experimental facts, after 1964, one could blissfully believe in a strictly local world only by hoping that quantum theory was wrong in its predictions concerning photons in the twin state” [44]. But it was not wrong.

– And what about special relativity? How can it swallow this “spooky actions at a distance”? – Wu-k’ung seemed perplexed.

– Quantum mechanics and relativity can co-exist peacefully because the non-local correlations described above does not allow faster-than-light signaling [41]. However, all of this looks very subtle and the legitimate question still is whether relativity or quantum mechanics can be considered complete. Sometimes it is even claimed that “with the presently available

models we have the alternative: Either the conventional understanding of relativity is not right, or quantum mechanics is not exact” [50]. Frankly speaking, I should admit that “the violation of the Bell-inequality implies that the relation between quantum mechanics and special relativity is more subtle than customarily assumed” [51].

Some think quantum mechanics is more fundamental than relativity. To explain what they have in mind and as another example of the magic of art with profound physical meaning consider the following figure.



– A face of the beautiful girl, – said Wu-k’ung – I appreciate her beauty but what a physical meaning on earth does it have?

– Upon inspecting the figure closely, – answered the Patriarch – you probably will find no face at all whatever beautiful or not in the figure. All what remain are some flowers and butterfly. The face of the beautiful girl is an emergent phenomenon: it exists when things are inspected at some scale but disappears at finer scales. And the crucial thing is that this hierarchical architecture pervades the Nature, being the outstanding principle of its functionality [52, 53]. The whole very often is not merely more than but entirely different from the sum of its parts. The following passage from [52] only at first sight seems like a joke but it actually hints very deep meaning: “Marx said that quantitative differences become qualitative ones, but a dialog in Paris in the 1920’s sums it up even more clearly:

FITZGERALD: The rich are different from us.

HEMINGWAY: Yes, they have more money. “

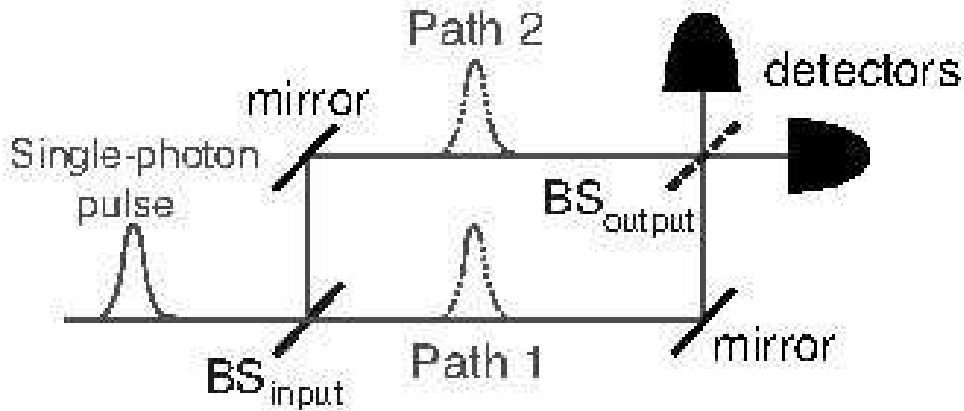
We routinely have emergent physical phenomena and the organizing principles which regulate them make sense only at the corresponding scale. They simply do not exist outside the context established by this scale. Besides, these higher organizing principles are insensitive to fine details of underlying micro-physics [53]. That’s why biologists and chemists can do their science without knowing nuclear physics or theory of elementary particles. Owing to this remarkable property of Nature’s organization science acquires its main strength: it can operate and progress in a modular manner [54].

It is quite possible that relativity is also an emergent phenomenon [42, 55, 56]. Towards this possibility hints the fact that there are some condensed matter systems where electron transport is essentially governed by the Dirac equation and a kind of effective relativity arises [57, 58]. For example, in graphene, a mono-layer of carbon atoms, charge carriers mimic relativistic particles with zero mass and the effective Lorentz invariance emerges with limiting velocity of about 10^6 m/s which is much smaller than the light velocity in vacuum [57]. In these condensed matter examples quantum mechanics is the fundamental

theory governing the underlying micro-physics while the effective relativistic behaviour is an emergent phenomenon valid only in the low-energy sector.

However, let us return to quantum non-locality. I see you are impressed by it. Surprisingly, the majority of physicists does not bother much about it. They become used to oddities of quantum mechanics. You surely think Bell’s proof exploded “like a bombshell in the corridors of science” [44]. In reality, however, Bell’s paper [46], published in a not-mainstream short-lived journal, was largely ignored for five years and fallow physicists were not at all impressed by it [38, 44]. You know “the majority of physicists are phenomenalists – whose professional world is circumscribed by phenomena and mathematics. A phenomenalist perceives science as advancing in two directions: 1. new experiments uncover novel phenomena; 2. new mathematics explain or predict phenomena in original ways. Since it proposes no new experiments and derives no new phenomena-relevant mathematics, but merely puts certain constraints on an invisible reality, Bell’s proof lies outside the fashionable formula for success in science and is generally dismissed by scientists as ‘mere philosophy’ “ [44].

Therefore, to convince you finally how strange the quantum world view is I tell you about Wheeler’s delayed-choice experiment. Consider the following experimental arrangement [59]:



A single-photon pulse is split by a first beam-splitter BS_{input} and it travels through two arms of a Mach-Zehnder interferometer until being recombined by a second beam-splitter BS_{output} . The photon is then detected by one of the two detectors D_1 and D_2 with equal probabilities. However, if we induce a phase shift ϕ between the two arms and vary it, the detection probabilities at ports D_1 and D_2 will be no longer equal. Instead they will be modulated as $\cos^2 \phi$ and $\sin^2 \phi$ respectively.

– This is an interference phenomenon familiar from Young’s double-slit experiment, – remarked Wu-k’ung.

– That’s correct, – said the Patriarch. – Interference appears because we can’t tell which way from the two possibilities the photon arrived by to the detector which it fired. However, we can remove the second beam-splitter BS_{output} so that each detector D_1 or D_2 is uniquely associated to a given path of the interferometer. In this case we expect the interference to disappear and the experiment, of course, confirms our expectation.

In the first case light behaves as a wave and in the second case as a particle. The famous wave-particle duality. As Bohr would say “the behavior of a quantum system is determined by the type of measurement performed on it” [59].

– You said people got used of it – smiled Wu-k’ung.

– However, – remarked the Patriarch, – our classical picture that either light goes through the both arms of the interferometer like a wave, or makes a choice to follow a definite path like a particle, depending what type of measurement we decide to perform on, is too naive. J. A. Wheeler proposed the famous ‘delayed-choice’ Gedankenexperiment in which the choice remove or not the second beam-splitter BS_{output} is made after the photon has already passed the first beam-splitter BS_{input} .

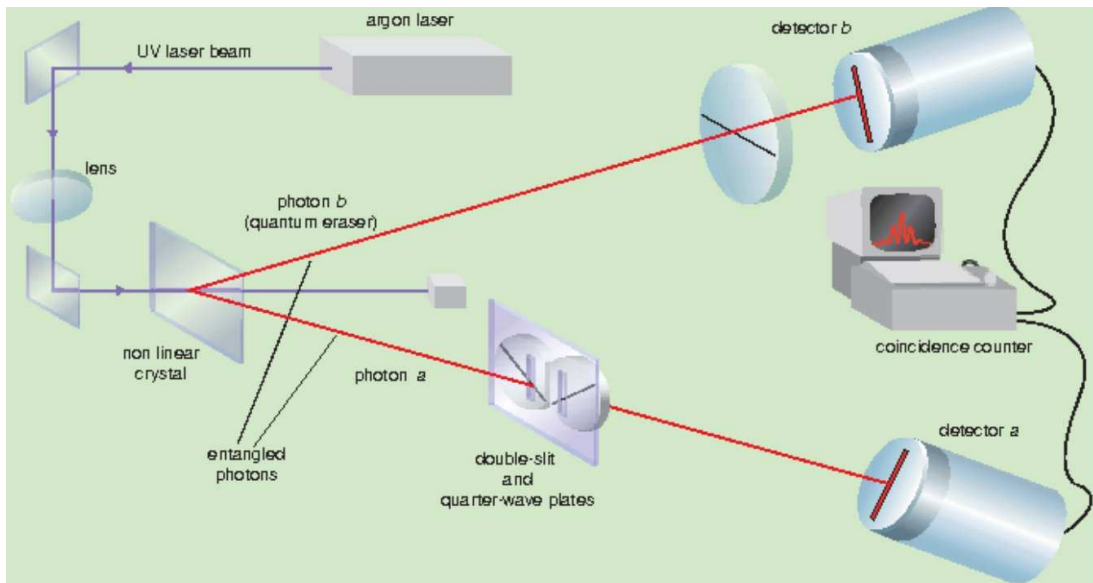
A real experiment very close in spirit to the Wheeler’s original suggestion was performed [59]. In this experiment, the clock that triggers the single-photon emission simultaneously generates a random choice of the interferometer configuration (with BS_{output} or not) by means of specially designed random number generator and the fast electro-optical modulator (EOM) along with some other optical equipment. With no voltage applied to the EOM, one effectively has BS_{output} removed, and it can be effectively brought back within 40 ns by fast switching on the appropriate voltage on the EOM. The random number generator was located close to the output of the interferometer while BS_{input} was some 48 meters away. This configuration guarantees, assuming no faster-than-light signaling, that the photon can not get any information about the made choice between interferometer configurations before it reaches BS_{input} . Actually, such an information might be available for the photon when it is about halfway in the interferometer, long after passing BS_{input} [59].

– And what was the results? – Wu-k’ung was intrigued.

– They found that “Nature behaves in agreement with the predictions of Quantum Mechanics even in surprising situations where a tension with Relativity seems to appear” [59] – answered The Patriarch. – It was demonstrated “beyond any doubt that the behavior of the photon in the interferometer depends on the choice of the observable which is measured, even when that choice is made at a position and a time such that it is separated from the entrance of the photon in the interferometer by a space-like interval” [59].

– Interesting, – said Wu-k’ung. – But I feel I’m becoming used to the strange world of quantum mechanics.

– Wait a moment, – smiled the Patriarch. – By the use of entangled photons we can make the previous situation even more surprising. Now the experimental arrangement looks like this [60]:



An ultraviolet argon laser creates entangled photons through the so called spontaneous parametric down conversion process when it illuminates a beta-barium borate (BBO) crystal. The polarizations of the entangled photons are strictly correlated: if photon a is detected to have a vertical polarization then the polarization of the photon b will be necessarily horizontal and vice versa. Signal photons (a) pass through the double slit and the interference fringes can be observed by the corresponding detector D_a , while idler or passive photon b goes to another detector D_b .

Now in front of each slit we place a quarter-wave plate (QWP), an optical device which transforms linearly polarized light into circularly polarized light. The quarter-wave plates are set so that horizontally polarized a -photon acquires left circular polarization if it goes through the first slit and right circular polarization if it goes through the second slit. For vertically polarized a -photon the circular polarization outcomes after the passage through QWP covered slits are reversed. Note that now a -photons are marked: by measuring their circular polarization we can tell which slit they passed through provided the linear polarization of the a -photon is known before the quarter-wave plates. This latter information is encoded into the polarization of the entangled b -photon.

– According to quantum mechanics – said Wu-k’ung in excitement – this which-way information should destroy the interference and the interference fringes must go away. Is this really so?

– You can’t have any doubt that experiment confirms this expectation, – answered the Patriarch. – It is not necessary to actually measure the polarizations of a - and b -type photons to destroy the interference pattern. The principal possibility of performing such measurements does suffice.

– How do these photons then know that we could find out which slit the a -photon went through? – exclaimed Wu-k’ung. – And I suspect we can change the polarization of the b -photon before it strikes the detector D_b and, therefore, erase the which-way information for the a -photon. What happens then?

– Such a possibility of quantum erasure was recognized in 1982 by Scully and Druhl [61]. In our experimental set-up we can place a polarizer in the b -beam oriented so that both horizontally and vertically polarized b -photons have an equal chances to pass it. After the b -photon passed the polarizer it no longer bears the information about the polarization of the a -photon. Therefore, the which-way information has been erased and we expect interference fringes to reappear in the coincidence counts between detectors D_a and D_b . This is really what is observed in experiment [60]. A particularly impressive situation can be obtained if the quantum erasure is combined with Wheeler’s delayed choice. We can simply place detector D_b with polarizer in front of it far away so that photon a is registered first and then its companion photon b . The experiment clearly demonstrates that reappearance of the interference fringes does not depend on the order a and b photons are detected in [60].

– What the miracles! – Wu-k’ung did not hide his surprise. – It seems we are in a position to change the past!

– This is not correct, – replied the Patriarch. – We can not change the past. Our detection of the photon b does not change the point photon a had hit the detector D_a earlier. “For entangled photons it is misleading and incorrect to interpret the physical phenomena in terms of independent photons” [62]. “Of course, one might try to go beyond the minimalistic interpretation and give additional ontological meaning to Ψ , thereby accommodating some philosophical preconceptions or other personal biases. In doing so, one should however

remember van Kampen’s caveat” [63]:

Everybody is free to speculate, but whoever endows Ψ with more meaning than is needed for computing observable phenomena is responsible for the consequences. He has the duty to show that his speculations do not lead to contradictions, and preferably that they are of some use (other than agreement with preconceived philosophical views). If he does not succeed he should not blame quantum mechanics [64].

– But are you indeed comfortable with Wheeler’s suggestion that “the past has no existence except as it is recorded in the present?” – asked Wu-k’ung. – Do you really think that the photon during its journey in the interferometer is “a great smoky dragon which is only sharp at its tail (at the beam splitter 1) and at its mouth where it bites the detector?” [65]. I heard Bohmian mechanics offers an alternative explanation of these strange delayed choice experiments [66, 67], maybe more comfortable with the common sense, but at the expense of introducing mysterious pilot-wave. In any case, do you really not find that the world view quantum mechanics suggests us is very strange?

– “we always have had (secret, secret, close the doors!)” – answered the Patriarch, – “We always have had a great deal of difficulty in understanding the world view that quantum mechanics represents. At least I do, because I’m an old enough man that I haven’t got to the point that this stuff is obvious to me. Okay, I still get nervous with it. And therefore, some of the younger students . . . you know how it always is, every new idea, it takes a generation or two until it becomes obvious that there’s no real problem. It has not yet become obvious to me that there’s no real problem. I cannot define the real problem, therefore I suspect there’s no real problem, but I’m not sure there’s no real problem” [68].

4 Wu-k’ung doubts Darwinian evolution

Wu-k’ung’s progress in physics was really impressive and the Patriarch was glad and very proud of his pupil. But things began to change when time came to study Darwinian evolution.

– “It is settled, as well as anything in science is ever settled, that the adaptations of living things on Earth have come into being through natural selection acting on random undirected inheritable variations” [69]. – The Patriarch was about to lose his temper after repeatedly trying to convince Wu-k’ung in Darwinian evolution.

– How can you, – persisted Wu-k’ung – how can you, a wise man, to believe that one species can be obtained from others through random mutations? A simple estimate shows that this is impossible [70]. A genome represents an ordered set of about $N = 3 \times 10^9$ nucleotides. The nearest neighboring species have $N_1 \approx 0.01N$ different nucleotides. There are $C_N^{N_1} = \frac{N!}{N_1!(N-N_1)!}$ possibilities to choose N_1 locations from N available in the genome and only one is the right one. Besides, you need to have right nucleotides at those locations. We have four nucleotides used in the genetic code. Therefore for each nucleotide in the old genome at N_1 locations we have three variants to change it by a different nucleotide and only one is what we want. This means there is $(\frac{1}{3})^{N_1}$ probability that all replaced nucleotides turn out to be right ones. In overall, the probability that a pure chance transforms a valid genome into another valid genome is

$$p = \frac{1}{3^{N_1}} \frac{N_1!(N-N_1)!}{N!}.$$

You can already suspect that it is an exceedingly small number, but let us estimate it [70]

by using Stirling's formula $\ln(N!) \approx N \ln N - N$, valid for large numbers. The result is $\ln p \approx -2 \times 10^8$. Therefore the probability that our reckless reliance on chance succeeds is negligibly small, $p \approx \exp(-2 \times 10^8)$. Is it not too foolish to assume that the proliferation of diversity we observe in biota was created in this manner? In fact there is some variation of genomes within one species with characteristic distance $N_2 \approx 0.001N$ between subspecies. Therefore we have somewhat underestimated the probability p , but only slightly [70], and this can not help either.

– Such estimates are too simplistic and misleading, – the Patriarch turned crimson with fury. – Much more elaborated arguments of this kind were given by Fred Hoyle [71]. And what? Darwinians simply dismissed these arguments stating that “Hoyle's objections were frankly silly, reflecting an embarrassing misunderstanding of Darwinian logic” [72].

– It's a pity that Darwinians simply ignored Hoyle's arguments, – replied Wu-k'ung. – I find them at least thought provoking. Take, for example, his histone-4 story. Histone-4 is an important eukaryotic protein that binds and folds DNA and is necessary for chromosome condensation during cell division. It has about one hundred amino acids in its structure and remains remarkably unchanged during known history of evolution: although plants and animals are separated by more than one billion years of evolution their histone-4 molecular sequences differ in only two amino acids [73]. The fact that evolution has not produced many different functional forms of histone-4 during billion years possibly indicates that the molecular sequence of histone-4 is essentially unique and can not be changed without destroying its biological function. However, then we face a difficult question how evolution had found this unique sequence of amino acids in the first place. The probability for the right sequence of one hundred amino acids to appear suddenly by mere chance is very small you can guess, and Hoyle claims that the histone-4 protein could never be produced by evolution in small steps either because all intermediate steps are non-functional.

– You are again hasty in your logical conclusions, – retorted the Patriarch. – Histone-4 is not as stable as you think. Some time ago histone-4 sequences from thirteen species of ciliates were analyzed and it was found that they differ from one another at as many as 46% of their amino acids [74]. It is true that in most other eukaryotes this protein has highly conserved character. This can be explained as an example of purifying selection. Most proteins require a thermodynamically stable suitable three-dimensional structure to function. Protein folding depends crucially upon its amino-acid sequence. Many mutations destabilize rather than stabilize histone-4 structure. It is not surprising, therefore, that this structure was conserved during evolution in light of histone-4's important role in cell division. Compared with other eukaryotes, ciliates have two functionally distinct genomes in within and one of micro-nucleus is transcriptionally inactive. This presence of two functionally distinct genomes may allow more rapid evolution of histone-4 genes in ciliate lineages [74]. It is true that determining factors of protein evolution rates demand serious studies and an integrated view of protein evolution is only emerging now [75].

As for evolution, “it is absolutely safe to say that if you meet somebody who claims not to believe in evolution, that person is ignorant, stupid or insane (or wicked, but I'd rather not consider that)”. “We are not talking about Darwin's particular theory of natural selection. It is still (just) possible for a biologist to doubt its importance, and a few claim to. No, we are here talking about the fact of evolution itself, a fact that is proved utterly beyond reasonable doubt” [76].

– My dear Master, – begin Wu-k'ung, – I don't question evolution. The question is how

to explain it. Darwinian evolution rests upon the following main principles [77]

- Undirected, random variation is the main process that provides the material for evolution.
- Evolution proceeds via natural selection by fixation of the rare beneficial variations and elimination of deleterious variations.
- The beneficial changes that are fixed by natural selection are 'infinitesimally' small, so that evolution is gradual and proceeds via the accumulation of these tiny modifications.

It would be quite remarkable if these simple principles really explain the observed diversity and complexity of life but do they?

– And why do you doubt? – asked the Patriarch. – “Time is in fact the hero of the plot. The time with which we have to deal is of the order of two billion years. What we regard as impossible on the basis of human experience is meaningless here. Given so much time, the ”impossible” becomes possible, the possible probable, and the probable virtually certain. One has only to wait: time itself performs the miracles” [78].

– I think the supposition that time makes it possible the ”impossible” to become possible is seductive but fallacious, – answered Wu-k’ung. – Take, for example, the typing monkeys parable. Do you really think ”that a half-dozen monkeys provided with typewriters would, in a few eternities, produce all the books in the British Museum? Strictly speaking, one immortal monkey would suffice” [79], so I can try this enterprise after I learn from you how to become immortal. However, I doubt strongly I can ever succeed. For simplicity let us take only one aphorism, allegedly attributed to Francis Bacon, from the treasure of the British Museum: “Atheism is a thin layer of ice over which one person may cross, but a whole people would fall into an abyss.” If my count is correct, it contains 109 letters, punctuation marks and spaces. A typewriter has about 50 keys. Therefore there are $50^{109} \approx 1.5 \times 10^{185}$ different combinations of keys which are 109 characters long and I will have a probability of about 10^{-185} to type the correct one just by chance. Even if you take 10^{80} immortal monkeys (10^{80} is the number of baryons in the visible universe) each of them producing a variant of our 109-character string in every 10^{-23} seconds (which is the characteristic time of strong interactions) you still will need about 10^{82} s $\approx 3 \times 10^{74}$ years to type this sole sentence with certainty. Do their typewriters endure such a time span? Possibly not. Due to quantum tunneling, on a time scale of 10^{65} years even the most rigid materials behave like a liquid [80]. Therefore, atoms constituting the typewriters will spread around like the molecules of water. Besides, protons are expected to be unstable due to (at least) quantum gravity effects with a typical lifetime of about 10^{45} years [81] and in 10^{74} years all 10^{80} baryons in the visible universe will decay. There is no way for monkeys to substitute Shakespeare!

– But this is not at all required! – the Patriarch was seemingly angry. – Using your typing monkeys analogy, more realistic picture of evolution might be the following. You offer a string of text (already meaningful in real evolution) to a herd of monkeys which duplicate the string although with some mistakes. After a generation an invisible hand of natural selection inspects the output and selects the string with greatest “fitness” (the meaning of fitness depends on the concrete situation. In computer simulation [82] the phrase with greatest resemblance with the target phrase was selected – the situation more akin to artificial selection). This slightly improved phrase is again offered to the herd for duplication. Generation after generation the fitness increases and it was demonstrated [82] that such

“artificial selection” reaches the target phrase in reasonable time from even meaningless start-up. Of course, this example is given only to demonstrate the power of cumulative selection over the random search and is not a realistic model of evolution. But it indicates that the evolution driven by natural selection, after all, might be not as improbable process as you stupid probabilities indicate.

– Very good, – replied Wu-k’ung. Realistic or not you have portrayed some model of evolution. Why not elaborate it a bit more and try on computer? Some earlier computer simulations of this kind led to conclusions that “it seems to require many thousands, perhaps millions, of successive mutations to produce even the easiest complexity we see in life now. It appears, naively at least, that no matter how large the probability of a single mutation is, should it be even as great as one-half, you would get this probability raised to a millionth power, which is so very close to zero that the chances of such a chain seem to be practically non-existent” [83].

– An accurate computer simulation of the evolution process is extremely difficult, – answered the Patriarch. – Too many uncontrollable factors are involved in real evolution. The computer simulations you mention were intended as merely the zeroth approximation to the problem. They modeled only mitosis in absence of sexual reproduction and really showed that the expected progress was much too slow. “However, and most biologists realize it anyway, the Darwinian mechanism together with mixing of genes accelerate enormously the rate of acquiring new ”favorable” characteristics and leave the possibility of sufficiency of the orthodox ideas quite open” [84]. Anyway, fossil evidence of evolution is enormous and indicates that it really has occurred. We see continual change and increase in complexity if fossils are arranged according to their age.

– That’s true, – agreed Wu-k’ung. – But I do not think this fact proves Darwinian evolution beyond any doubt. Consider, for example, the following analogy [85]. Take my programs of magnetic field calculation which I develop while studying classical electrodynamics. You can not deny that they have many similarities and show a steady increase in complexity over time. Initially these programs were able to deal with only some simple two-dimensional problems. Over the years many new capabilities have appeared to mention among others an ability to crack difficult three-dimensional problems and fancy curved coil configurations, as well as a development of user-friendly interactive interface and graphical tools. Any of these changes have not happened gradually but appeared suddenly in new versions. These improvements required hundreds of interrelated new lines in the program and I never could produce them would I so foolish to try do this by a trial-and-error method without advance planning. In fact any “point mutations” is deleterious and catastrophic in the case of programming languages because “no currently existing formal language can tolerate random changes in the symbol sequences which express its sentences. Meaning is almost invariably destroyed. Any changes must be syntactically lawful ones.” I can not see any reason why the language of DNA programming should be different in this respect. “I would conjecture that what one might call ”genetic grammatically” has a deterministic explanation and does not owe its stability to selection pressure acting on random variation” [86].

– Frankly speaking, – continued Wu-k’ung, – I’m pretty sure that Darwinian version of evolution is quite dead in light of modern findings. None of the three main principles underlying Darwin’s approach withstand close inspection. Darwin considered ‘infinitesimal variation’, or point mutations in modern terms, as the main process that provides the material for evolution. The real finding, however, is that point mutations due to chemical and

physical insults to the genome are almost always deleterious and catastrophic. This fact can hardly come as a big surprise for computer scientists and software engineers with their highly rigid programming languages. However, for proponents of Darwinian evolution “it has been a surprise to learn how thoroughly cells protect themselves against precisely the kinds of accidental genetic change that, according to conventional theory, are the sources of evolutionary variability” [87].

It seems Darwin considered gradualism as very important for his theory. In chapter six of his famous *On the Origin of Species* he states “If it could be demonstrated that any complex organ existed, which could not possibly have been formed by numerous, successive, slight modifications, my theory would absolutely break down” [77]. But now we know that evolution is anything but gradual and is better described as ‘punctuated equilibrium’. For most of the time sexually reproducing species experience very little if any change as witnessed by fossil record. Then abruptly new species appear rapidly in rare events usually associated with some natural catastrophe. The rise and fall of the dinosaurs is a good example.

A study of tetrapod footprints and skeletal material revealed that large theropod dinosaurs appeared less than 10,000 years after the Triassic-Jurassic boundary and less than 30,000 years after the last Triassic taxa, synchronous with a terrestrial mass extinction which wiped out at least half of the species living on Earth at that time [88]. The presence of an iridium anomaly and a fern spore spike suggests that a bolide impact was the possible cause [88]. The time scale of the appearance of large theropod dinosaurs is the blink of an eye in geological terms. Then dinosaurs dominated on Earth for next 135 million years until another bolide impact ended the reign of dinosaurs 65 million years ago and marked the rise of mammalian age.

Now about natural selection which according to Darwin is the main driving force of evolution. “Evolutionary-genomic studies show that natural selection is only one of the forces that shape genome evolution and is not quantitatively dominant, whereas non-adaptive processes are much more prominent than previously suspected” [77]. The picture that emerged is far more complex and pluralistic than Darwin could imagine at his time. “In addition to point mutations that can be equated with Darwin’s ‘infinitesimal changes’, genome evolution involves major contributions from gene and whole genome duplications, large deletions including loss of genes or groups of genes, horizontal transfer of genes and entire genomic regions, various types of genome rearrangements, and interaction between genomes of cellular life forms and diverse selfish genetic elements” [77].

– Science is not a religion, – answered the Patriarch, – and it does not stick dogmas. Of course modern science shows that evolution is much more complex than previously thought. However, “the emerging landscape of genome evolution includes the classic, Darwinian natural selection as an important component” [77]. As for the ‘punctuated equilibrium’, this is precisely what you can expect in analogy with phase transitions in physics [89]. “The theory of punctuated equilibrium is a minor gloss on Darwinism, one which Darwin himself might well have approved if the issue had been discussed in his day” [82].

“Depicting the change in the widest strokes possible, Darwin’s paramount insight on the interplay between chance and order (introduced by natural selection) survived, even if in a new, much more complex and nuanced form, with specific contributions of different types of random processes and distinct types of selection revealed. By contrast, the insistence on adaptation being the primary mode of evolution that is apparent in the *Origin*, but especially in the Modern Synthesis, became deeply suspicious if not outright obsolete, making room

for a new worldview that gives much more prominence to non-adaptive processes” [77].

An interplay between chance and order can produce quite remarkable and strange outputs those origins are difficult to explain in retrospect. Take, for example, a bizarre mating behaviour of praying mantis. “If you have got a female mantis alone in a cage, and put in a male, that male instantly freezes. The praying mantis, like a lot of other animals, such as frogs, don’t seem to be able to see anything unless it moves. The male knows that, and he is watching the female very carefully. If she looks away for a moment, he takes a hasty few steps forward. Then he freezes again as soon as she looks back. This can go on for hours. If the male is fortunate, he reaches the female, mounts her, and goes through a normal copulation. Incidentally, once an American male mantis starts copulating, the female never bothers him. It’s our better standard of living. But often the female sees him first. With that, she grabs him, always by the head. Then she begins to eat him, always starting with his head. As soon as she has eaten off the head, the male goes into a very interesting pattern of behavior. He plants his front feet squarely and begins to circle around them, meanwhile going through violent copulatory motions, because once the male loses his head, the copulatory center is released. In this way such a headless male will frequently succeed in mounting the female and going through a normal copulation” [90].

– Yes, – said Wu-k’ung, – real evolution is full of mysteries. Another enigmatic example of evolution is the origin of bats [91]. There are two distinct groups of these flying mammals, namely megabats and microbats. The question is whether these two groups originated from a common flying ancestor or they have separate origins. Megabats share many features of brain organization with primates and these features are absent in microbats. This fact suggests a common ancestor for megabats and primates. But if true, this scenario implies that wings evolved twice, once very early in microbats and then again later in a branch of primates leading to megabats [91]. Another alternative is that microbats and megabats are monophyletic and the primate brain features evolved twice, once in primates and once in megabats [91]. In either case we have to face the fact that evolution has found the same solution twice which is difficult to expect from the random process.

– I think, – continued Wu-k’ung, – “there are far more unresolved questions than answers about evolutionary processes, and contemporary science continues to provide us with new conceptual possibilities” [87]. Especially interesting are indications that all cells possess biochemical abilities for cutting and splicing of their DNA molecules into new sequence arrangements. Cells perform some kind of genetic engineering! “In other words, genetic change can be massive and non-random. Some organisms, such as the ciliated protozoan *Oxytricha*, completely reorganize their genetic apparatus within a single cell generation, fragmenting the germ-line chromosomes into thousands of pieces and then reassembling a particular subset of them into a distinct kind of functional genome” [87]. The picture that emerges is quite different from the Darwinian view of evolution, but is far more fascinating and realistic. If the natural genetic engineering [87, 92] is the main driving force of evolution then it is not impossible that nearly all ingredients of Lego-like genome architecture were already present billions of years ago in first living cells known to us. Complexity has not been increased during evolution, it became only apparent, like the complexity of an aircraft which is hidden in technical blueprints and documentation but becomes apparent during the construction. “Together with the realization that genome contraction is at least as common in evolution as genome expansion, and the increase of genomic complexity is not a central evolutionary trend, the concept of non-adaptive genome evolution implies that the idea of

evolutionary progress can be safely put to rest” [77].

– “Most biologists now agree that natural selection is the key evolutionary force that drives not only evolutionary change within species but also the origin of new species. Although some laypeople continue to question the cogency or adequacy of natural selection, its status among evolutionary biologists in the past few decades has, perhaps ironically, only grown more secure “ [93], – answered the Patriarch indignantly. – “The status of natural selection is now secure, reflecting decades of detailed empirical work. But the study of natural selection is by no means complete” [93]. I think any doubt in natural evolution will wither with time, although I do not exclude that maybe we need somewhat broader view of natural selection including genetic engineering and other modern findings. However, “no one seriously doubts that natural selection drives the evolution of most physical traits in living creatures - there is no other plausible way to explain such large-scale features as beaks, biceps and brains” [93].

– I seriously doubt that natural selection drives the evolution, – replied Wu-k’ung. – But now I’d like to speak about another conundrum recognized by Erwin Schrödinger many years ago [94]. In statistical physics order emerges from disorder because number of particles are huge. On the background we always have the chaos of thermal motion. The expectation of the ‘naive physicist’, according to Schrödinger, is that an organism and all the biologically relevant processes must have extremely many-atomic structure to be safeguarded against haphazard single-atomic events attaining too great importance. In reality, however, “incredibly small groups of atoms, much too small to display exact statistical laws, do play a dominating role in the very orderly and lawful events within a living organism” [94].

I think the resolution of this enigma how do cells manage to function incredibly reliable and regular manner under constant Brownian bombardment, lies in the fact that cells are dynamic, integrated systems. No part of the cell makes sense outside the context established for the whole cell. Cells are holistic systems and their parts show extreme cooperation and coordination, accompanied with the extraordinary smart proofreading and error correction systems. Cells continually monitor their external and internal environment, perform information processing and make decisions how to react on various challenges. Impressive picture, is not it?

Just one small example that biological information processing is a reality [92]. The bacterium *E. coli* can discriminate between glucose and lactose and it can control the expression of the lactose metabolic proteins so that they are only synthesized once glucose is no longer available. In fact cells execute the following logical instruction: “IF lactose present AND glucose not present AND cell can synthesize active LacZ and LacY, THEN transcribe lacZYA from lacP” which involves many molecules and compartments of the cell, not just DNA and DNA binding proteins [92].

One naturally expects the devices capable to perform such complicated tasks to be irreducibly complex. They are bound to have some minimal complexity in order to function reliably under a thermal environment. This is just simple statistical physics. There are good indications that LUCA, the Last Universal Common Ancestor from which every living cell on the planet has descended, was as complex as any present-day bacterium. And how this miraculously complex first cell come into existence over three billions years ago?

– This is the origin of life problem, – replied the Patriarch, – different from the problems of evolution.

– It is, – agreed Wu-k’ung. – But let us return to the problem of cooperation in the cell.

Why not to go one step further. Why not to expect that bacterial and microbial colonies also use cooperative behaviour to cope environmental hazards?

– I must admit that you are true, – said the Patriarch. – “To face changing environmental hazards, bacteria resort to a wide range of cooperative strategies. They alter the spatial organization of the colony in the presence of antibiotics for example. Bacteria form complex patterns as needed to function efficiently. Bacteria modify their colonial organization in ways that optimize bacterial survival. Bacteria have collective memory by which they track previous encounters with antibiotics. They collectively glean information from the environment, communicate, distribute tasks, perform distributed information processing and learn from past experience” [95].

– In this case, – said Wu-k’ung, – we have to conclude that “the take-home lesson of more than half a century of molecular microbiology is to recognize that bacterial information processing is far more powerful than human technology” [96].

– I suspect, – continued Wu-k’ung, – this cooperative behaviour in its essence is not a result of evolution but was present from the very beginning, at the time of LUCAs. Combined with natural genetic engineering and horizontal gene transfer, this primordial biological information processing, perhaps, paved a way for subsequent evolution according to some in-built templates. “Such gradual refinement through the horizontal sharing of genetic innovations would have led to the generation of a combinatorial explosion of genetic novelty, until the level of complexity, as exemplified perhaps by the multiple levels of regulation, required a transition to the present era of vertical evolution” [97]. It is true that most fellow scientist today are hero worshipers, and Darwin is undoubtedly their hero. Quite deservedly, I think, because historically Darwin’s theory had a tremendous impact on science. But in the long run, hero-worship makes no good and harms the science. Thus, I “regard as rather regrettable the conventional concatenation of Darwin’s name with evolution, because there are other modalities that must be entertained and which” some scientists “regard as mandatory during the course of evolutionary time” [97].

5 Wu-k’ung reflects on intelligent design

The Patriarch was indignant at Wu-k’ung’s stubbornness not to accept Darwinian view of life.

– I see you are inclined towards the intelligent design theory, – said he loweringly to Wu-k’ung.

– If LUCA was really as complex as modern bacteria, not to speak about the alleged cooperative behaviour of these first microorganisms with in-built evolutionary templates, which quite may turn as mere my fantasy, – begin Wu-k’ung his answer, – I see no way how it can emerge from inanimate matter without intelligent designers behind.

– And who were these designers? – asked the Patriarch sarcastically. – I admit, “an honest man, armed with all the knowledge available to us now, could only state that in some sense, the origin of life appears at the moment to be almost a miracle, so many are the conditions which would have had to have been satisfied to get it going” [98]. But this gives no excuse to plunge into religious insinuations. Or maybe you prefer Crick and Orgel’s directed panspermia theory? They speculated that the LUCA, “the primitive form of life was deliberately planted on the Earth by a technologically advanced society on another planet” [99]. Cute theory. But actually it does not solve the origin-of-life problem, except enlarging

the available resources involved from Earth to, maybe, entire cosmos. The problem is the origin of these aliens which seeded the Earth. This remembered me a notorious story. *A well-known scientist (some say it was Bertrand Russell) once gave a public lecture on astronomy. He described how the earth orbits around the sun and how the sun, in turn, orbits around the center of a vast collection of stars called our galaxy. At the end of the lecture, a little old lady at the back of the room got up and said: "What you have told us is rubbish. The world is really a flat plate supported on the back of a giant tortoise." The scientist gave a superior smile before replying, "What is the tortoise standing on?" "You're very clever, young man, very clever," said the old lady. "But it's turtles all the way down!"* [100]. How can you escape this infinite reduction puzzle?

– Were I human, – answered Wu-k'ung, – I probably would say that intelligence and spirituality are primordial properties of Cosmos, and apply to God as the ultimate origin of life. But I'm humble monkey, without in-built religious instincts. So I'm bound to answer that I don't know.

However, – continued Wu-k'ung, – “as biochemists discover more and more about the awesome complexity of life, it is apparent that its chances of originating by accident are so minute that they can be completely ruled out. Life cannot have arisen by chance” [101]. “Although the tiniest bacterial cells are incredibly small, weighing less than 10^{-12} grams, each is in effect a veritable micro-miniaturized factory containing thousands of exquisitely designed pieces of intricate molecular machinery, made up altogether of one hundred thousand million atoms, far more complicated than any machinery built by man and absolutely without parallel in the non-living world” [102]. How can I believe that this marvelous thing, a living cell, aroused by chance?

– Science is not about beliefs, – answered the Patriarch sternly, – it's about facts. You can not expect science to give an immediate answer to all your questions. “Just as most of the weird Cambrian monsters eventually went extinct, many current hypotheses in evolution will also wither over time. Those that survive, however, will be inestimably powerful for explaining the natural world” [103]. The origin of life is a difficult problem for science today, I admit, but maybe tomorrow we will find the clue. You should just wait. And if you want not to passively wait but participate in the exciting process of scientific exploration, you must first learn a lot of already established facts and not plunge into a bad philosophy. One of the virtues of Darwinism is that it removed teleology from our thinking.

– That's the problem, – said Wu-k'ung, – “orthodox scientists are occupied by a fight against religion instead of finding the truth” [101]. I prefer more sober-minded position about religion. It's true that Darwin was successful in eliminating religious motives not only from biology but from social life also, but I doubt that the spreading of nihilistic outlook that followed is a progressive thing. It's an empirical fact that humans have hardwired religious instinct. You can argue about the origin of this instinct, but It's the fact that It's here. And once it's here, it should be important, because in even your version of genesis omnipotent natural selection picks up only important things. Therefore, religion must have some important regulatory function and it is not wise to throw it away. We monkeys do not have any religion but are we wiser than men? Or do you like human social life to be organized in the manner monkeys do? Carl Gustav Jung once remarked, “Among all my patients in the second half of life, that is, over thirty-five, there has not been one whose problem in the last resort was not that of finding a religious outlook on life. It is safe to say that every one of them fell ill because he had lost that which the living religions of every age

have given their followers, and none of them has really been healed who did not regain his religious outlook” [104].

“Rather than accept that fantastically small probability of life having arisen through the ‘blind’ forces of nature, it seems better to suppose that the origin of life was a deliberate intellectual act. By ‘better’ I mean less likely to be wrong” [105] – concluded Wu-k’ung.

– I do not like your attitude towards biology in general and evolution in particular, – declared the Patriarch. – “Like entropy, which perpetually increases, educational standards perpetually worsen. And like entropy, which increases inevitably because of the policies of physics, education worsens inevitably because of the policies of educators. Instead of teaching being properly confined to the rote-learning of facts and well-proven techniques, pupils are confused nowadays by the teaching of meanings that they cannot comprehend” [105]. But you know I adhere to the high educational standards of the past and do not tolerate premature vain attempts of illiterate pupils to engage themselves into dubious and precarious theorizing. Unfortunately, this is precisely what you are doing now. Instead of studying well established biology, you are trying to answer questions which cannot be answered without profound knowledge in biology and other sciences.

– However, – continued the Patriarch, – you have mastered physics quite well. So let me indicate to you that modern physics suggests a world view in which even most unlikely events will eventually happen. I mean, of course, eternal inflation theory [106].

As a poetic metaphor, this world view is already present in the 1941 short story of Jorge Luis Borges *The Library of Babel*. “The Library is unlimited and cyclical. If an eternal traveler were to cross it in any direction, after centuries he would see that the same volumes were repeated in the same disorder (which, thus repeated, would be an order: the Order)” [107].

– I could also quote this book to support my position, – remarked Wu-k’ung in delight. He was very smart in literature in contrast to biology. – “The Library exists *ab aeterno*. This truth, whose immediate corollary is the future eternity of the world, cannot be placed in doubt by any reasonable mind. Man, the imperfect librarian, may be the product of chance or of malevolent demiurgi; the universe, with its elegant endowment of shelves, of enigmatical volumes, of inexhaustible stairways for the traveler and latrines for the seated librarian, can only be the work of a god. To perceive the distance between the divine and the human, it is enough to compare these crude wavering symbols which my fallible hand scrawls on the cover of a book, with the organic letters inside: punctual, delicate, perfectly black, inimitably symmetrical” [107].

– In less poetic terms, – the Patriarch paid no heed to Wu-k’ung’s remark, – eternal inflation looks no less fantastic [106, 108]. Eternal inflation theory is Copernican view of the world pushed to its extreme. Before Copernicus, it was thought the Earth was the center of the universe. Now we know that the Earth is just one of nine planets orbiting the Sun. The Sun itself is quite an ordinary star from the Milky Way galaxy which contains 100 billion other stars. The Milky Way belongs to the Virgo cluster of galaxies and lies at its periphery. The Virgo cluster by itself is a fairly average cluster that unifies a few hundred members. There are trillions of other galaxies out there in the universe. And now the eternal inflation theory tells us that there are infinite number of other universes similar to our own universe, the so called \mathcal{O} regions [109], and many more that does not support life. However, this is not the strangest thing about the eternal inflation theory. After all many universes, or multiverse, is just a huge extrapolation of the Copernican logic. The strangest thing is that while the

number of \mathcal{O} regions is infinite, the number of possible coarse-grained macroscopic histories in each of these universes is finite albeit very large [109]. An inevitable strange conclusion from this is, for example, that another macroscopically identical copy of you is located at some $10^{10^{29}}$ m away [108] having the same life history up to the present point. Besides, if one assumes, as is usually done, that every history consistent with exact conservation laws has a non-vanishing probability and will eventually occur, then “some amusing situations can be entertained where distant copies of ourselves play all sorts of different roles. Some readers will be pleased to know that there are infinitely many \mathcal{O} -regions where Al Gore is President and - yes - Elvis is still alive” [109].

Implications of the eternal inflation theory, sometimes called also ‘many worlds in one’ (MWO) model [109], for the origin-of-life problem were considered by Koonin [110]. Below I will try to summarize main points of this investigation.

The hardest problem in all of biology is the origin of replication and translation systems. Any biological evolution is impossible without sufficiently fast and accurate genome replication. However, the replication and translation systems of even the simplest living cells are based on the molecular machinery of tremendous complexity. This system appears to be the hardest example of ‘irreducible complexity’ [111] and no one knows how such a system could evolve.

– I remember, – said Wu-k’ung, – that the problem of self-replication from the quantum mechanics perspective was considered by Wigner long ago [112]. Wigner assumed that the self-replication process of an organism under its interaction with the nutrient is described by some unitary “collision matrix” S and showed that if S is a random matrix then the number of equations which describe the transformation is so much greater than the number of unknowns that “it would be a miracle” [112] if the transformation equations were satisfied. Wigner himself finds the argument “not truly conclusive” [112] and so do others [113, 114, 115]. However, such considerations clearly indicate that even moderately complex self-replication organisms are not quite trivial objects expected to be found at every corner of the universe. Some even claim that “for all physics has to offer, life should never have appeared and if it ever did it would soon die out” [116].

– Yes, – said the Patriarch, – chance emergence of a sufficiently complex biochemical system is very improbable but not impossible in MWO model. Hoyle once remarked that the chance that life could have been started in this way is comparable with the chance of a tornado sweeping through a junkyard might assemble a functional Boeing-747, ready to fly, from the materials therein [101]. Nevertheless, “the MWO model not only permits but guarantees that, somewhere in the infinite multiverse - moreover, in every single infinite universe, - such a system would emerge” [110].

– But what about the second law of thermodynamics? – exclaimed Wu-k’ung. – “The law that entropy always increases - the second law of thermodynamics - holds, I think, the supreme position among the laws of nature. If someone points out that your pet theory of the universe is in disagreement with Maxwell’s equations - then so much the worse for Maxwell’s equations. If it is found to be contradicted by experiments - well, these experimentalists do bungle things sometimes. But if your theory is found to be against the second law of thermodynamics I can give you no hope; there is nothing for it but to collapse in deepest humiliation” [117]. I, of course, know that the second law applies to the closed systems only. “But the second law of thermodynamics - at least the underlying principle behind this law - simply says that natural forces do not cause extremely improbable things to happen, and it is

absurd to argue that because the Earth receives energy from the Sun, this principle was not violated here when the original rearrangement of atoms into encyclopedias and computers occurred” [85].

– In the MWO model – replied the Patriarch – extremely improbable things do happen. This of course violates the second law. But the second law of thermodynamics is statistical in its nature. Molecules do not gather in a one half of the vessel not because this is absolutely forbidden by exact conservation laws but because such fluctuation is extremely improbable, much less improbable than a Shakespearean sonnet typed by a monkey. However, in the infinite multiverse, as I already said, every event with non-zero probability will eventually happen no matter how small the probability is. I can not say that I easily swallow this. As the origin-of-life problem is concerned, “a crucial aspect of the framework developed here is brought about by a disturbing (almost nightmarish) but inevitable question: in the infinitely redundant world of MWO, why is biological evolution, and in particular, Darwinian selection relevant at all? Is it not possible for any, even the highest degree of complexity to emerge by chance? The answer is ‘yes’ but the question misses point. Under the MWO model, emergence of an infinite number of complex biotas by chance is inevitable but these would be vastly less common than those that evolved by the scenario that includes the switch from chance/anthropic selection to biological evolution” [110].

– Do you consider such explanation of the origin-of-life problem, “which would require happenings every bit as miraculous as the views of religious fundamentalist” [105], as really scientific? – asked Wu-k’ung. – I have a feeling that some trickery could be always invoked when infinities come into the game, like the cunning Devil striping us our money in a nefarious underground bar through an infinite number of transactions during which the amount of our money continuously increases but nothing at all is left when the super-transaction is over in a finite time [118].

– Frankly speaking, – answered the Patriarch, – I hope some less extravagant explanations, like RNA world [119], will eventually prove to be correct.

– However, – said Wu-k’ung, – eternal inflation hypothesis is taken too seriously and is actively discussed in physics, if not in biology. You know, these theoretical “physicists behave a lot more like ‘bosons’ which coalesce in large packs” [120] towards fashionable ideas. But if you accept one aspect of the theory you have to accept its other consequences also. Therefore, I can not see why we can not use MWO model in biology if in physics it is considered to be so successful. But if we accept MWO model as the solution of the origin-of-life problem, an immediate inference, I’m afraid, would be that life on the planet Earth is almost certainly the result of intelligent design.

The argument is quite simple. Human civilization is at the dawn of nanotechnology. And no doubt in many pocket universes of the MWO model its twin civilizations already reached the level of nanotechnology which allows a production of artificial living organisms. Sooner or later our civilization, or more precisely your civilization, because I do not expect monkeys to participate appreciably in this process, except maybe some distinguished specimens like me, sooner or later human civilization also will reach this level in nanotechnology and will be able not only to reproduce any living organism ever present on Earth, but to create new life forms. I admit, at present, “such a project would be quite beyond our practical ability, but not beyond our comprehension. Indeed we are nearer to understanding what would be involved in it than a dog is to understand the construction of a power station” [105].

However, as soon as we realize that MWO model inevitably predicts the existence of

infinitely many advanced civilizations capable to create artificial life, it becomes clear that then we find a life at some particular place in the universe it is vastly more probable this life to be a product of nanotechnology of some advanced civilization than the product of primordial miracle due to quantum fluctuations like Hoyle's Boeing-747 emerging in one stroke of hurricane from the junkyard.

I conclude, therefore, that the intelligent design is a vastly more probably origin of humans than the random evolution by mutations and natural selection. This is an inevitable conclusion of modern science if we take MWO argument seriously and not as a merely "turtles all the way down" type hand-waving. – Wu-k'ung smiled and disappeared in a somersault. However he returned soon to continue his speech.

– In fact, – said he, – I'm curious about the nature of logical thinking. Why the MWO model is considered as scientific and more logical than the religious picture of the world if it predicts happenings vastly more miraculous than described in the Bible?

– Carl Gustav Jung has an interesting observation about the nature of logical thinking, – answered the Patriarch. – He tells the following story. "Two anklets were found in the stomach of a crocodile shot by a European. The natives recognized the anklets as the property of two women who, some time before, had been devoured by a crocodile. At once the charge of witchcraft was raised, for this quite natural occurrence, which would never have aroused the suspicions of a European, was given an unexpected interpretation in the light of one of those presuppositions which Lévy-Brühl calls 'collective representations'. The natives said that an unknown sorcerer had summoned the crocodile and had bidden it to bring him the two women. The crocodile had carried out the command. But what about the anklets in the beast's stomach? The natives maintained that crocodiles never ate people unless bidden to do so. The crocodile had received the anklets from the sorcerer as a reward" [104].

For us these conclusions of aborigines seem strange and absolutely illogical. But are they really so? In fact, "it only strikes us in this way because we start from assumptions wholly different from those of primitive man. If we were as convinced as he is of the existence of sorcerers and of mysterious powers, instead of believing in so-called natural causes, his inferences would seem to us perfectly reasonable. As a matter of fact, primitive man is no more logical or illogical than we are. His presuppositions are not the same as ours, and that is what distinguishes him from us" [104].

– Interesting observation indeed, – agreed Wu-k'ung. – Another interesting observation of this kind, which shows how subtle and fragile human's ability to think logically is, can be found in the Sylvia Nasar's masterpiece [121], a splendid biography of John Forbes Nash, the mathematical genius and Nobel Prize winner. At the top of his scientific career, he went insane and struggled for years that followed with schizophrenia which almost destroyed both his career and his marriage. While ill, he has suffered increasingly bizarre delusions that he was the Prince of Peace and the Emperor of Antarctica, and believed that aliens were trying to contact him through the *New York Times* newspaper. Nasar describes how Nash, while in the mental hospital, explains to a colleague his acceptance of strange ideas which for 'normal' people appears utterly illogical.

John Forbes Nash, Jr. – mathematical genius, inventor of a theory of rational behavior, visionary of the thinking machine – had been sitting with his visitor, also a mathematician, for nearly half an hour. It was late on a weekday afternoon in the spring of 1959, and, though it was only May, uncomfortably warm. Nash was slumped in an armchair in one corner of the hospital lounge, carelessly dressed in a nylon shirt that hung limply over his unbelted trousers.

His powerful frame was slack as a rag doll's, his finely molded features expressionless. He had been staring dully at a spot immediately in front of the left foot of Harvard professor George Mackey, hardly moving except to brush his long dark hair away from his forehead in a fitful, repetitive motion. His visitor sat upright, oppressed by the silence, acutely conscious that the doors to the room were locked. Mackey finally could contain himself no longer. His voice was slightly querulous, but he strained to be gentle. "How could you," began Mackey, "how could you, a mathematician, a man devoted to reason and logical proof...how could you believe that extraterrestrials are sending you messages? How could you believe that you are being recruited by aliens from outer space to save the world? How could you...?" Nash looked up at last and fixed Mackey with an unblinking stare as cool and dispassionate as that of any bird or snake. "Because," Nash said slowly in his soft, reasonable southern drawl, as if talking to himself, "the ideas I had about supernatural beings came to me the same way that my mathematical ideas did. So I took them seriously" [121].

– But the power of scientific method, – said the Patriarch – its real strength that gives the science profound depth and reliability, lays in the fact that real science relies on experimental method. "Without experimentalist, theorist tend to drift" [122] and dwell in wild fantasies. So you beloved Intelligent Design hypothesis will remain a mere fantasy until you can give some clues how it can be unambiguously checked by facts.

– It is difficult to indicate facts that unambiguously indicate towards Intelligent Design, it is very difficult – answered Wu-k'ung. – I can only point to some plausible consequences of intelligent design. First of all if the evolution was predefined by some intelligent design, I would expect the primordial cells and viruses to constitute parts of a well-thought-out and well balanced system aimed to produce increasingly complex living forms by genetic engineering. Natural selection, I think, could be used in some form by these intelligent designers to polish required traits, but it cannot be the main driving force. Simply the algorithm of genetic engineering and the mechanism to accomplish it, as well as some meaningful simpler building blocks of genetic code, were already present in the primordial assembly of cells and viruses. I have no idea how this primordial assembly was produced by intelligent designers, but after all parts of the system is in place it perhaps can function autonomously, without further need from the side of the intelligent designers to interfere.

I see it plausible random search algorithms to be a part of the system. But the natural selection, by its accent on competition, not cooperation, is not the most powerful random search algorithm. Social behavior is ubiquitous in the animal kingdom. Darwinians, of course, try to explain this by various advantages it gives for survival, and proudly stop at that. However, two intelligent scholars had have a deeper insight that "once again nature has provided us with a technique for processing information that is at once elegant and versatile" [123]. They were driven by the philosophy "that allows wisdom to emerge rather than trying to impose it, that emulates nature rather than trying to control it, and that seeks to make things simpler rather than more complex" [123]. As a result a powerful and simple random search algorithm, Particle Swarm Optimization (PSO), emerged. A key idea of this algorithm is illustrated by reference to fish schooling. "In theory at least, individual members of the school can profit from the discoveries and previous experience of all other members of the school during the search for food. This advantage can become decisive, outweighing the disadvantages of competition for food items, whenever the resource is unpredictably distributed in patches" [124].

So, – continued Wu-k'ung, – if something like PSO is used in evolution, I expect orches-

trated mutations to appear when, for example, bacteria develop drug resistance. I mean favorable mutations which appear simultaneously at different places of the bacterial colony after some cell in it randomly finds the correct combination of genetic code via genetic engineering. I think such mutations are hard to explain in Darwinian paradigm because they are not random but deterministic and require information sharing between cells.

– Orchestrated mutations, – said the Patriarch thoughtfully, – you at least are making some experimentally testable prediction which you think is associated with Intelligent Design. This is good. Normal science works just in this way. A bad thing with you Intelligent Design theory is, however, that nobody has ever seen these orchestrated mutations in bacterial drug resistance studies.

– Maybe because nobody looked for them? – answered Wu-k’ung. – By the way we can further extend this line of thought and assume that the whole biosphere should show signs of tight interconnections, fine tuning, high level of optimization and stability if it owe its existence to Intelligent Design. Picturesquely we can say that the Earth with its biosphere is one big self-regulating living system where every part has its specific function and predestination. An interesting question is what role was predestined in this system for humans with their yet restricted intelligence and knowledge dangerously coupled to increasing awesome ability to upset the biosphere. The only hope for monkeys is that probably the wise Intelligent Designers had anticipated a protection from fools, and reckless humankind will be not allowed to destroy the life on Earth. The perspective for humans, I’m afraid, is not very good if all this is true and humans fail to correctly understand their predestination - they can simply get extinct like many other species in Earth’s history.

– What you are speaking about is known for a long time as Gaia hypothesis, – intervened the Patriarch. – The Gaia hypothesis was proposed by James Lovelock [125, 126, 127]. Gaia is Earth goddess in Greek mythology. According to Lovelock, “the entire range of living matter on Earth from whales to viruses and from oaks to algae could be regarded as constituting a single living entity capable of maintaining the Earth’s atmosphere to suit its overall needs and endowed with faculties and powers far beyond those of its constituent parts” [127]. In fact Lovelock suggests a quite sound and testable idea that life on Earth participates in and even is the main constituent of the global feedback mechanisms which ensures stability of environmental conditions on Earth comfortable for life. For example, the surface temperature of Earth remained remarkably constant for eons despite the fact that the energy provided by the Sun has increased by about 30%. The atmospheric composition is also surprisingly constant instead being unstable as expected from the oxygen’s high chemical reactivity. The same is true for the ocean salinity which is important for most cells. Undoubtedly living organisms has played a crucial role in maintenance of this dynamical equilibrium through “active feedback processes operated automatically and unconsciously by the biota” [128]. However, Lovelock’s allegory of living Earth was perceived by some scientists too literally and was fiercely attacked, especially by neo-Darwinians who thought it was impossible for natural selection to produce global feedback mechanisms in physical, chemical and biological processes on Earth implied by the Gaia hypothesis.

Gaia hypothesis assumes that natural selection can produce biologically mediated feedbacks that contribute to environmental homeostasis on the global scale. “In the real world, by contrast, natural selection favors any trait that gives its carriers a reproductive advantage over its non-carriers, whether it improves or degrades the environment (and thereby benefits or hinders its carriers and non-carriers alike). Thus Gaian and anti-Gaian feedbacks are both

likely to evolve” [129].

– I also share neo-Darwinians’ concerns about incapability of natural selection to produce highly integrated dynamical system on Earth’s scale, – remarked Wu-k’ung ironically. – I’m afraid neo-Darwinians in their “Quest for the Secret of Beauty” resemble beast-like creatures from the 1942 drawing of famous Georgian painter Lado Gudiashvili.



– However, – continued Wu-k’ung, – I think there is only one possibility for the whole Darwin’s theory to be proved finally true. This is only possible if we live in a computer simulation and if creators of this computer game have somewhat weird sense of humor.

– In a computer simulation? – The Patriarch was startled. – I heard Karl Svozil had some unusual ideas in this direction [130]. What do you mean?

– Yes, I know about Svozil’s contribution, but the real proponent of this weird idea is Nick Bostrom, – answered Wu-k’ung. – In fact he states that “at least one of the following propositions is true: (1) the human species is very likely to go extinct before reaching a ‘posthuman’ stage; (2) any posthuman civilization is extremely unlikely to run a significant number of simulations of their evolutionary history (or variations thereof); (3) we are almost certainly living in a computer simulation” [131].

The argument is simple and alike to what I used when argued that the intelligent design is a vastly more probably origin of humans, – continued Wu-k’ung. – Extrapolating the progress in the present-day computer science and practice, it is not unbelievably unrealistic that enormous amounts of computing power will be available in the future. “One thing that later generations might do with their super-powerful computers is run detailed simulations

of their forebears or of people like their forebears. Because their computers would be so powerful, they could run a great many such simulations. Suppose that these simulated people are conscious (as they would be if the simulations were sufficiently fine-grained and if a certain quite widely accepted position in the philosophy of mind is correct). Then it could be the case that the vast majority of minds like ours do not belong to the original race but rather to people simulated by the advanced descendants of an original race. It is then possible to argue that, if this were the case, we would be rational to think that we are likely among the simulated minds rather than among the original biological ones. Therefore, if we don't think that we are currently living in a computer simulation, we are not entitled to believe that we will have descendants who will run lots of such simulations of their forebears. That is the basic idea" [131].

– But what relation all this has to Darwin's theory? – asked the Patriarch.

– Suppose the computer game the participants of which we allegedly are is not a simple game but self-adaptive, – answered Wu-k'ung. – I mean that the rules of this game (which we call natural laws) are not fixed forever but can change depending the participants' scientific output. If a clever and original new scientific theory emerges which does not contradict the already formed architecture of the game, this new perspective immediately becomes a part of the game's make-up. So to say, quarks have not existed before Murray Gell-Mann and George Zweig proposed the quark model in 1964.

– And now, – continued Wu-k'ung smiling, – if somebody elaborates the Darwinian evolution in every detail, so that it becomes absolutely clear how, by what concrete mechanisms the complexity emerges and increases during the evolution, then such a theory will be undoubtedly extremely cute and, therefore, it immediately materializes as part of the computer game.

– The biggest irony, – added Wu-k'ung sadly, – the biggest irony is that under such circumstances, which require extreme intelligence from the side of game's designers, we will be absolutely assured that the Intelligent Design is a hoax and Darwin's ideas proved to be true, while, on the contrary, just the opposite is true.

– This is too much! – The Patriarch was enraged. Darwinian evolution was his pet theory. – I'm afraid you have to leave this place forever!

– Just last question, my Master, – uttered Wu-k'ung in confusion. – I'm curious since you taught me three pillars of modern physics but was embarrassed to ask. There were four elephants supporting the earth in the illustration you showed me. What is the fourth elephant for?

– The fourth elephant is the most important, – answered the Patriarch frowned. – It is for "utter scientific integrity" [132], utter honesty what the scientist should be adhered to. "The first principle is that you must not fool yourself – and you are the easiest person to fool. So you have to be very careful about that. After you've not fooled yourself, it's easy not to fool other scientists. You just have to be honest in a conventional way after that" [132].

– Without this fourth elephant it is impossible to create and sustain a wealthy and sound science, – continued the Patriarch. – Some thinks an ambition is a driving force of science. Well, scientists are human and thus subject to all human weakness. But without utter scientific integrity ambitions only produce "turtles all the way down" approach and there's a story "Yertle the Turtle" [133] by Dr. Seuss which gives the final word how this approach ultimately ends:

On the far-away island of Sala-ma-Sond,
Yertle the Turtle was king of the pond.
A nice little pond. It was clean. It was neat.
The water was warm. There was plenty to eat.
The turtles had everything turtles might need.
And they were all happy. Quite happy indeed.

They were... until Yertle, the king of them all,
Decided the kingdom he ruled was too small.
“I’m ruler”, said Yertle, “of all that I see.
But I don’t see enough. That’s the trouble with me.
With this stone for a throne, I look down on my pond
But I cannot look down on the places beyond.
This throne that I sit on is too, too low down.
It ought to be higher!” he said with a frown.
“If I could sit high, how much greater I’d be!
What a king! I’d be ruler of all that I see!”

So Yertle the Turtle King, lifted his hand
And Yertle, the Turtle King, gave a command.
He ordered nine turtles to swim to his stone
And, using these turtles, he built a new throne.
He made each turtle stand on another one’s back
And he piled them all up in a nine-turtle stack.
And then Yertle climbed up. He sat down on the pile.
What a wonderful view! He could see ’most a mile!

“All mine!” Yertle cried. “Oh, the things I now rule!
I’m the king of a cow! And I’m the king of a mule!
I’m the king of a house! And, what’s more, beyond that
I’m the king of a blueberry bush and a cat!
I’m Yertle the Turtle! Oh, marvelous me!
For I am the ruler of all that I see!”

And all through the morning, he sat up there high
Saying over and over, “A great king am I!”
Until ’long about noon. Then he heard a faint sigh.
“What’s that?” snapped the king, and he looked down the stack.
And he saw, at the bottom, a turtle named Mack.
Just a part of his throne. And this plain little turtle
Looked up and he said, “Beg your pardon, King Yertle.
I’ve pains in my back and my shoulders and knees.
How long must we stand here, Your Majesty, please?”

“SILENCE!” the King of the Turtles barked back.
“I’m king, and you’re only a turtle named Mack.”

‘‘You stay in your place while I sit here and rule.
I’m the king of a cow! And I’m the king of a mule!
I’m the king of a house! And a bush! And a cat!
But that isn’t all. I’ll do better than that!
My throne shall be higher!’’ his royal voice thundered,
‘‘So pile up more turtles! I want ’bout two hundred!’’

‘‘Turtles! More turtles!’’ he bellowed and brayed.
And the turtles ’way down in the pond were afraid.
They trembled. They shook. But they came. They obeyed.
From all over the pond, they came swimming by dozens.
Whole families of turtles, with uncles and cousins.
And all of them stepped on the head of poor Mack.
One after another, they climbed up the stack.

Then Yertle the Turtle was perched up so high,
He could see forty miles from his throne in the sky!
‘‘Hooray!’’ shouted Yertle. ‘‘I’m the king of the trees!
I’m king of the birds! And I’m king of the bees!
I’m king of the butterflies! King of the air!
Ah, me! What a throne! What a wonderful chair!
I’m Yertle the Turtle! Oh, marvelous me!
For I am the ruler of all that I see!’’

Then again, from below, in the great heavy stack,
Came a groan from that plain little turtle named Mack.
‘‘Your Majesty, please... I don’t like to complain,
But down here below, we are feeling great pain.
I know, up on top you are seeing great sights,
But down here at the bottom we, too, should have rights.
We turtles can’t stand it. Our shells will all crack!
Besides, we need food. We are starving!’’ groaned Mack.

‘‘You hush up your mouth!’’ howled the mighty King Yertle.
‘‘You’ve no right to talk to the worlds highest turtle.
I rule from the clouds! Over land! Over sea!
There’s nothing, no, NOTHING, that’s higher than me!’’

But, while he was shouting, he saw with surprise
That the moon of the evening was starting to rise
Up over his head in the darkening skies.
‘‘What’s THAT?’’ snorted Yertle. ‘‘Say, what IS that thing
That dares to be higher than Yertle the King?
I shall not allow it! I’ll go higher still!
I’ll build my throne higher! I can and I will!’’

I'll call some more turtles. I'll stack 'em to heaven!
I need 'bout five thousand, six hundred and seven!''

But, as Yertle, the Turtle King, lifted his hand
And started to order and give the command,
That plain little turtle below in the stack,
That plain little turtle whose name was just Mack,
Decided he'd taken enough. And he had.
And that plain little lad got a bit mad.
And that plain little Mack did a plain little thing.
He burped!
And his burp shook the throne of the king!

And Yertle the Turtle, the king of the trees,
The king of the air and the birds and the bees,
The king of a house and a cow and a mule...
Well, that was the end of the Turtle King's rule!
For Yertle, the King of all Sala-ma-Sond,
Fell off his high throne and fell Plunk! in the pond!

And today the great Yertle, that Marvelous he,
Is King of the Mud. That is all he can see.
And the turtles, of course... all the turtles are free
As turtles and, maybe, all creatures should be.

by Dr. Seuss

6 Final remark

Seeing that there was no other alternative, Wu-k'ung had to bow to the Patriarch and take leave of the congregation, "Once you leave," the Patriarch said, "you're bound to end up evildoing, I don't care what kind of villainy and violence you engage in, but I forbid you ever to mention that you are my disciple. For if you but utter half the word, I'll know about it; you can be assured, wretched monkey, that you'll be skinned alive, I will break all your bones and banish your soul to the Place of Ninefold Darkness, from which you will not be released even after ten thousand afflictions!" "I will never dare mention my master," said Wu-k'ung. "I'll say that I've learned this all by myself" [134].



Maybe in some remote future offsprings of nanotechnology of our civilization forget their

Masters and will frantically argue that they originated from the primordial Chaos and learned all the glory of science all by themselves assisted only by the blind watchmaker Evolution.

Acknowledgments

The author thanks George Svetlichny for his question about the role of the fourth elephant and for indicating to the author that Dr. Seuss' story "Yertle the Turtle" gives the final word on the "turtles all the way down" subject.

April 1, 2009, Novosibirsk.

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