The Universal Arrow of Time is a key for the solution of the basic physical paradoxes.

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Introduction.

The modern classical statistical physics, thermodynamics, quantum mechanics and gravity theory are developed and well-known theories. The described theories are developed and well studied for a long time. Nevertheless, it contains a number of paradoxes. It forces many scientists to doubt internal consistency of these theories. However the given paradoxes can be resolved within the framework of the existing physics, without introduction of new laws. Further in the paper the paradoxes underlying classical statistical physics, thermodynamics, quantum mechanics, non-quantum and quantum gravities are discussed. The approaches to solution of these paradoxes are suggested on basis universal arrow of time. The first one relies on the influence of the external observer (environment), which disrupts the correlations in the system and results in time arrows alignment. The second one is based on the limits of self-knowledge of the system in case of the observed system, the external observer and the environment are included in the considered system. The concepts of observable dynamics, ideal dynamics, and unpredictable dynamics are introduced. The phenomenon of complex (living) systems is contemplated from the point of view of these dynamics. Perspectives of practical use of Unpredictable systems for artificial intellect are considered.

Chapter 1. The Universal Arrow of Time: Classical mechanics.

0. Abstract: Solution of paradox for the entropy increase in reversible systems.

Statistical physics cannot explain why a thermodynamic arrow of time exists, unless one postulates very special and unnatural initial conditions. Yet, we argue that statistical physics can explain why the thermodynamic arrow of time is universal, i.e., why the arrow points in the same direction everywhere. Namely, if two subsystems have opposite arrow-directions initially, the interaction between them makes the configuration statistically unstable and causes decay towards a system with a universal direction of the arrow of time. We present general qualitative arguments for that claim and support them by a detailed analysis of a toy model based on the baker's map.

1. Introduction

The origin of the arrow of time is one of the greatest unsolved puzzles in physics [1-5]. It is well established that most arrows of time can be reduced to the thermodynamic arrow, but the origin of the thermodynamic arrow of time remains a mystery. Namely, the existence of the thermodynamic arrow of time means that the system is not in the state with the highest possible entropy.

But this means that the system is not in the highest-probable state, which lacks any statistical explanation. The fact that entropy increases with time means that the system was in an even less probable state in the past, which makes the problem even harder. Of course, the phenomenological fact that entropy increases with time can be described by assuming that the universe was in a state with very low entropy at the beginning, but one cannot explain why the universe started with such a very special and unnatural initial condition in the first place.

Recently, Maccone [6] argued that the problem of the origin of the arrow of time can be solved by quantum mechanics. He has shown that in quantum mechanics all phenomena which leave a trail behind (and hence can be studied by physics) are those entropy of which increases.

(The observer's memory erasing argument and the corresponding thought experiments discussed in [6], was also used previously for a resolution of entropy increase and the quantum wave-packet reduction paradoxes [7-9 From this he argued that the second law of thermodynamics is reduced to a mere tautology, suggesting that it solves the problem of the arrow of time in physics. However, several weaknesses on specific arguments used in [6], have been reported [10-12]. As a response to one of these objections, in a later publication [13] Maccone himself realized that his approach does not completely solve the origin of the arrow of time because the quantum mechanism he studied also requires highly improbable initial conditions which cannot be explained.

Yet, as Maccone argued in [13], we believe that some ideas presented in [6] and [13] do help to better understand the puzzle of the arrow of time. The purpose of this paper is to further develop, refine, clarify, and extend some of the ideas which were presented in [8, 9, 14, 15, 16, 30], and also in a somewhat different context in [6, 13], we argue that quantum mechanics is not essential at all. Indeed, in this paper we consider only classical statistical mechanics.

The idea is the following. Even though statistical physics cannot explain why a thermodynamic arrow of time exists, we argue that at least it can explain why the thermodynamic arrow of time is universal, i.e., why the arrow points in the same direction everywhere. Namely, if two subsystems have opposite arrow-directions initially, we argue that the interaction between them makes the configuration statistically unstable and causes decay towards a system with a universal direction of the arrow of time. This, of course, does not completely resolve the problem of the origin of the arrow of time. Yet, at least, we believe that this alleviates the problem.

The paper is organized as follows. In the next section we present our main ideas in an intuitive non-technical form. After that, in Sec. 3 the idea is the following. Even though statistical physics cannot explain why a thermodynamic arrow of time exists, we argue that at least it can explain why the thermodynamic arrow of time is universal, i.e., why the arrow points in the same direction everywhere. Namely, if two subsystems have opposite arrow-directions initially, we argue that the interaction between them makes the configuration statistically unstable and causes decay towards a system with a universal direction of the arrow of time. This, of course, does not completely resolve the problem of the origin of the arrow of time. Yet, at least, we believe that this alleviates the problem.

The paper is organized as follows. In the next section we present our main ideas in an intuitive non-technical form. After that, in Sec. 4 we study the effects of weak interactions between subsystems which, without interactions, evolve according to the baker's map. In particular, we explain how weak interactions destroy the opposite time arrows of the subsystems, by making them much more improbable than without interactions.
Finally, in Sec. 5 we present a qualitative discussion of our results, including the consistency with strongly-interacting systems in which the entropy of a subsystem may decrease with time.

2. Main ideas.

A priori, the probability of having a thermodynamic arrow of time is very low. However, our idea is to think in terms of *conditional* probabilities. Given that a thermodynamic arrow exists, what can we, by statistical arguments, infer from that?

To answer this question, let us start from the laws of an underlying microscopic theory. We assume that dynamics of microscopic degrees of freedom is described by a set of second-order differential equations (with derivatives with respect to time) which are invariant under the time inversion $t \rightarrow -t$. Thus, both directions of time have a priori equal roles. To specify a unique solution of the dynamical equations of motion, one also needs to choose some ``initial" time $t_0$, on which initial conditions are to be specified. (The ``initial" time does not necessarily need to be the earliest time at which the universe came into the existence. For any t_0 at which the initial conditions are specified, the dynamical equations of motion uniquely determine the state of the universe for both t> t_0 and t <t_0.) It is a purely conventional particular instant on time, which may be even in the ``future''. Indeed, in this paper we adopt the ``block-universe'' picture of the world (see, e.g., [4, 17, 18, 19] and references therein), according to which time does not ``flow''. Instead, the universe is a "static" object extended in 4 space-time dimensions.

Of course, the *a priori* probability of small entropy at t_0 is very low. But *given that* entropy at t_0 is small, what is the conditional probability that there is a thermodynamic arrow of time? It is, of course, very high. However, given that entropy at t_0 is low, the most probable option is that entropy increases in *both* directions with a minimum at t_0 On the other hand, in practice, at times at which we make measurements, the entropy is indeed low, but entropy does not increase in both directions. Instead, it increases in only one direction. This is because, on a typical t_0, not only the "initial" entropy is specified, but a particular direction of the entropy increase is specified as well. At the microscopic level, this is related to the fact that on t_0 one does not only need to specify the initial particle positions, but also their initial velocities.

Given that insight, next we ask the following question. Given that at t_0 the entropy is low and increases in the positive time direction, what can be statistically inferred from that? In this case, the most probable option is that entropy will continue to increase with t for t > t_0 , but also that it will in the negative time direction for t < t_0. . This is, indeed, what we observe in nature.

And now here comes the central question of this section. Given that at t_0 the entropy is low, why entropy at increases in the same (say, positive) direction everywhere? Isn't it more probable that the direction of entropy-increase varies from point to point at t_0? If so, then why don't we observe it? In other words, why the arrow of time is *universal*, having the same direction everywhere for a given t_0, having the same direction everywhere for a given t_0? We refer to this problem as the problem of *universality of the arrow of time.*

In this paper we argue that *this* problem can be solved by statistical physics. In short, our solution is as follows. If we ignore the interactions between different degrees of freedom, then, given that at t_0 the entropy is low, the most probable option is, indeed, that the direction of the arrow of time varies from point to point. On the other hand, if different degrees of freedom interact with each other, then it is no longer the most probable option. Instead, even if the direction of the arrow of time varies from point to point at t_0, the interaction provides a natural mechanism that aligns all time arrows to the same direction.

To illustrate the arrow-of-time dilemma, the thought experiments of Loschmidt (time reversal paradox) and Poincare (recurrence theorem) are also often used. The corresponding paradoxes in classical mechanics are resolved as follows. Classical mechanics allows, at least in principle, to exclude any effect of the observer on the observed system. However, most realistic systems are chaotic. , so a weak perturbation may lead to an exponential divergence of trajectories. In addition, there is also a non-negligible interaction. As a simple example, consider a gas expanding from a small region of space into a large volume. In this entropy-increasing process the time evolution of macroscopic parameters is stable against small external perturbations. On the other hand, if all the velocities are reversed, then the gas will end up in the initial small volume, but only in the absence of any perturbations. The latter entropy-decreasing process is clearly unstable and a small external perturbation would trigger a continuous entropy growth. Thus the entropy increasing processes are stable, but the decreasing ones are not. A natural consequence is that the time arrows (the directions of which are defined by the entropy growth) of both the observer and the observed system are aligned to the same direction, because of the inevitable non-negligible interaction between them. They can return back to the initial state only together (as a whole system) in both Loschmidt and Poincare paradoxes, so the observer's memory gets erased in the end. During this process the time arrow of the observer points in the backward direction, this has two consequences. First, an entropy growth is observed in the whole system as well as in its two parts, despite the fact that entropy decreases with coordinate time. Second, the memory of the observer is erased not only at the end but also close to that point, because the observer does not remember his ``past'' (defined with respect to the coordinate time), but remembers his ``future''.

Indeed, it may seem quite plausible that interaction will align all time arrows to the same direction. But the problem is - which direction? The forward direction or the backward one? How can any particular direction be preferred, when both directions are *a priori* equally probable? Is the common direction chosen in an effectively random manner, such that it cannot be efficiently predicted? Or if there are two subsystems with opposite directions of time at t_0, will the ``stronger'' subsystem (i.e., the one with a larger number of degrees of freedom) win, such that the joint system will take the direction of the ``stronger'' subsystem as their common direction?

The answer is as follows: It is all about conditional probabilities. One cannot question the facts which are already known, irrespective of whether these facts are in ``future'' or ``past''. The probabilistic reasoning is to be applied to only those facts which are not known yet. So, let us assume that the entropy is low at t_0 and that we have two subsystems with opposite time directions at t_0. Let us also assume that the subsystems do not come into a mutual interaction before t_1 (where $t_1>t_0$), after which they interact with each other. Given all that, we *know* that, for $t_0<t<t_1$, entropy increases with time for one subsystem and decreases with time for another subsystem. But what happens for $t>t_1$? Due to the interaction, the two subsystems will have the same direction of time for $t> t_1$. But which direction? The probabilistic answer is: The direction which is more probable, *given* that we know what we already know. But we already know the situation for $t< t_1$ (or more precisely, for $t_0<t<t_1$), so our probabilistic reasoning can only be applied to $t> t_1$.

It is this *asymmetry in knowledge* that makes two directions of time different. (Of course, the interaction is also asymmetric, in the sense that interaction exists for $t>t_1$, but not for $t_0<t<t_1$.) Thus, the probabilistic reasoning implies that entropy will increase in the *positive* time direction for $t>t_1$.

Alternatively, if there was no such asymmetry in knowledge, we could not efficiently predict the direction of the arrow of time, so the joint direction would be chosen in an effectively random manner.

Now we can understand why the arrow of time appears to be universal. If there is a subsystem which has an arrow of time opposite to the time-arrow that we are used to, then this subsystem is either observed or not observed by us. If it is not observed, then it does not violate the fact that the arrow of time appears universal to us. If it is observed then it interacts with us, which implies that it cannot have the opposite arrow of time for a long time. In each case, the effect is that *all what we observe must have the same direction of time*. This is similar to the reasoning in [6], with an important difference that our reasoning does not rest on quantum mechanics.

In the remaining sections we support these intuitive ideas by a more quantitative analysis

3. Statistical mechanics of the baker's map

The baker's map (for more details see Appendix) maps any point of the unit square to another point of the same square. We study a collection of
$N>> 1$ such points (called ``particles'') that move under the baker's map. This serves as a toy model for a ``gas'' that shares all typical properties of classical Hamiltonian reversible deterministic chaotic systems. Indeed, due to its simplicity, the baker's map is widely used for such purposes [20, 23, 24, 25].

3.1 Macroscopic entropy and ensemble entropy

To define a convenient set of macroscopic variables, we divide the unit square into 4 equal subsquares. Then the 4 variables N_1, N_2, N_3, N_4, denoting the number of ``particles" in the corresponding subsquares, are defined to be the macroscopic variables for our system. (There are, of course, many other convenient ways to define macroscopic variables, but general statistical conclusion are not expected to depend on this choice.) The
macroscopic entropy S_m of a given macrostate is defined by the number of different microstates corresponding to that macrostate, as

$$S_{\rm m} = -N \sum_{k=1}^{4} \frac{N_k}{N} \log\left(\frac{N_k}{N}\right) = -\sum_{k=1}^{4} N_k \log\left(\frac{N_k}{N}\right). \tag{1}$$

This entropy is maximal when the distribution of particles is uniform, in which case S_m is S_m^{max} = N log4. Similarly, the entropy is minimal when all particles are in the same subsquare, in which case $S_m = 0$.

Let *(x, y)* denote the coordinates of a point on the unit square. In physical language, it corresponds to the particle position in the 2-dimensional phase space. For N particles, we consider a statistical ensemble with a probability density $\rho(x_1, y_1;...; x_N, y_N; t)$ on the 2N dimensional phase space. Here *t* is the evolution parameter, which takes discrete values *t* = 0, 1, 2... for the baker's map. Then the *ensemble entropy* is defined as

$$S_{\rm e} = -\int \rho(x_1, y_1; \ldots; x_N, y_N; t) \ \log \rho(x_1, y_1; \ldots; x_N, y_N; t)\, dX, \tag{2}$$

where

$$dX \equiv dx_1\, dy_1 \ \cdots dx_N\, dy_N. \tag{3}$$

In general, ρ and S_e change during the evolution generated by the baker's map and depend on the initial ρ. However, if the initial probability-density function has a form

$$\rho(x_1, y_1; \ldots; x_N, y_N) = \rho(x_1, y_1) \cdots \rho(x_N, y_N), \tag{4}$$

which corresponds to an uncorrelated density function, then the probability-density function remains uncorrelated during the evolution.

As an example, consider $\rho(x_l, y_l)$ which is uniform within some subregion
Σ (with area A<1)) of the unit square, and vanishes outside of Σ. In other words, let

$$\rho(x_l, y_l, t) = \begin{cases} 1/A & \text{for } (x_l, y_l) \text{ inside } \Sigma, \\ 0 & \text{for } (x_l, y_l) \text{ outside } \Sigma. \end{cases} \tag{5}$$

In this case

$$S_{\rm e} = -\left(\frac{1}{A}\right)^N \log\left(\frac{1}{A}\right)^N A^N = N \log A. \tag{6}$$

Since A does not change during the baker's map evolution, we see that S_e is constant during the baker's map evolution. This example can be used to show that S_e is, in fact, constant for *arbitrary* initial probability function. To briefly sketch the proof, let us divide the unit 2N-dimensional box into a large number of small regions $\sum_a$, on each of which the probability is equal to ρ_a. During the evolution, each region $\sum_a$ changes the shape, but it's 2N-dimensional "area" A_a remains the same. Moreover, the probability ρ_a on the new $\sum_a$ also remains the same. Consequently, the ensemble entropy $S_e = -\sum_a A_a^N \rho_a \log \rho_a$ remains the same as well. This is the basic idea of a discrete version of the proof, but a continuous version can be done in a similar way.

3.2 Appropriate and inappropriate macroscopic variables

The macroscopic variables defined in the preceding subsection have the following properties:

1. For most initial microstates having the property $S_m < S_m^{max}$, S_m increases during the baker's map.
2. For most initial microstates having the property $S_m = S_m^{max}$, S_m remains constant during the baker's map.
3. The two properties above do not change when the baker's map is perturbed by a small noise.

We refer to macrovariables having these properties *as appropriate* macrovariables.

Naively, one might think that any seemingly reasonable choice of macrovariables is appropriate. Yet, this is not really the case. Let us demonstrate this by an example. Let us divide the unit square into 2^M equal vertical strips (M>>1). We define a new set of macrovariables as the numbers of particles inside each of these strips. Similarly to (1), the corresponding macroscopic entropy is

$$S_m = -\sum_{k=1}^{2^M} N_k \log\left(\frac{N_k}{N}\right), \tag{7}$$

where N_k is the number of particles in strip k. For the initial condition, assume that the gas is uniformly distributed inside odd vertical strips, while even strips are empty. Then $S_m < S_m^{max}$ initially. Yet, for a long time during the baker's evolution, S_m does not increase for any initial microstate corresponding to this macrostate. However, during this evolution the number of filled strips decreases and their thickness increases, until only one thick filled vertical strip remains. After that, S_m starts to increase. We also note that the evolution towards the single strip can be easily destroyed by a small perturbation.

Thus we see that vertical strips lead to inappropriate macrovariables. By contrast, horizontal strips lead to appropriate macrovariables. (Yet, the macrovariables in (1) are even more appropriate, because they lead to much faster growth of Sm.) This asymmetry between vertical and horizontal strips is a consequence of the intrinsic asymmetry of the baker's map with respect to vertical and horizontal coordinates. This asymmetry is analogous to the asymmetry between canonical coordinates and moments in many realistic Hamiltonian systems of classical mechanics. Namely, most realistic Hamiltonian systems contain only local interaction between particles, where locality refers to a separation in the coordinate (not momentum!) space.

Finally, we note that evolution of the macroscopic variables $N_k(t)$, k = 1, 2, 3, 4, is found by averaging over ensemble in the following way

$$N_k(t) = \int N_k(x_1, y_1; \ldots; x_N, y_N; t)\rho(x_1, y_1; \ldots; x_N, y_N; t)\, dX. \tag{8}$$

3.3 Coarsening

As we have already said, the ensemble entropy (unlike macroscopic entropy) is always constant during the baker's map evolution. One would like to have a modified definition of the ensemble

entropy that increases similarly to the macroscopic entropy. Such a modification is provided by *coarsening*, which can be defined by introducing a coarsened probability-density function
.

$$\rho^{\mathrm{coar}}(x_1,y_1;\ldots;x_N,y_N) = \int \Delta(x_1-x_1',y_1-y_1';\ldots;x_N-x_N',y_N-y_N') \times \rho(x_1',y_1';\ldots;x_N',y_N')\,dX', \tag{9}$$

where Δ is nonvanishing is some neighborhood of $X' = 0,0;\ldots;0,0.$ In this way, the coarsened ensemble entropy is

$$S_{\mathrm{e}}^{\mathrm{coar}} = -\int \rho^{\mathrm{coar}}(x_1,y_1;\ldots;x_N,y_N)\ \log \rho^{\mathrm{coar}}(x_1,y_1;\ldots;x_N,y_N)\,dX. \tag{10}$$

Of course, the function Δ can be chosen in many ways. In the following we discuss a few examples.

One example is the Boltzmann coarsening, defined by

$$\rho^{\mathrm{coar}}(x_1,y_1;\ldots;x_N,y_N) = \rho(x_1,y_1)\cdots\rho(x_N,y_N), \tag{11}$$

where

$$\rho(x_1,y_1) = \int \rho(x_1,y_1;\ldots;x_N,y_N)\,dx_2\,dy_2\,\cdots dx_N\,dy_N, \tag{12}$$

and similarly for other $\rho(x_l,y_l)$.

Another example is isotropic coarsening, having a form

$$\Delta(x_1-x_1',y_1-y_1';\ldots;x_N-x_N',y_N-y_N') = \Delta(x_1-x_1')\Delta(y_1-y_1')\cdots\Delta(x_N-x_N')\Delta(y_N-y_N'). \tag{13}$$

Yet another example is the Prigogine coarsening [20]

$$\Delta(x_1-x_1',y_1-y_1';\ldots;x_N-x_N',y_N-y_N') = \Delta(y_1-y_1')\cdots\Delta(y_N-y_N'), \tag{14}$$

which is an anisotropic coarsening over the shrinking direction.

Finally, let us mention the coarsening based on dividing the system into two smaller interacting subsystems. The coarsened ensemble entropy for the full system is defined as the sum of uncoarsened ensemble entropies of its subsystems. Such coarsened entropy ignores the correlations between the subsystems.

All these types of coarsening have the following property: If the initial microstate is such that macroscopic entropy increases, then the coarsened ensemble entropy also increases for that initial microstate. Yet, the Prigogine coarsening has the following advantages over Boltzmann and isotropic coarsenings:

First, if the initial microstate is such that the macroscopic entropy *decreases*, then the Prigogine coarsened ensemble entropy does *not* decrease, while the Boltzmann and isotropic coarsened ensemble entropies decrease.

Second, assume that the initial microstate is such that the macroscopic entropy increases, and consider some ``final" state with a large macroscopic entropy close to the maximal one. After this final state, consider it's ``inverted" state, (i.e., the state with exchanged x and y). Then the Prigogine coarsened ensemble entropy decreases in jump during such transform from the high-entropy final state to it's ``inverted" state, while the Boltzmann and isotropic coarsened ensemble entropies remain unchanged.

Thus, the Prigogine coarsening provides the most correct description of the ensemble-*entropy increase law* without any additional assumptions. For example, to get the same result with Boltzmann coarsening, one would need to introduce the additional ``molecular chaos hypothesis" to replace $\rho(x_1, y_1; x_2, y_2)$ with $\rho(x_1, y_1)\ \rho\ (x_2, y_2)$ in the equation of motion for $\rho(x, y, t)$.

4. The effects of weak interactions

4.1 Small external perturbations

The growth of the ensemble entropy can be achieved even without coarsening, by introducing a small external perturbation of the baker's map. The perturbation must be small enough not to destroy the growth of macroscopic entropy, but at the same time, it must be strong enough to destroy the reverse processes and Poincare returns. For most such perturbations, the qualitative features of the evolution do not depend much on details of the perturbation.

There are two ways how the external perturbation can be introduced. One way is to introduce a small external random noise. The macroscopic processes with the increase of macroscopic entropy are stable under such a noise. However, the area of a region is no longer invariant under the perturbed baker's map. In this way the ensemble entropy can increase.

The other way is to introduce a weak interaction with the environment (which can be thought of as an ``observer"). Again, the macroscopic processes with the increase of macroscopic entropy are stable, but the area of a region is no longer invariant under the perturbed baker's map. Consequently, the ensemble entropy can increase. However, such a system is no longer isolated. Instead, it is a part of a larger system divided into two subsystems. Hence, as we have already explained in Sec.3.3, the coarsened ensemble entropy for the full system can be defined as the sum of uncoarsened ensemble entropies of its subsystems. In the next subsection we study the weak interactions with the environment in more detail.

4.2 Weak interaction and the destruction of opposite time arrows

To proceed, one needs to choose some specific interaction between two gases. In the absence of interaction, each of them evolves according to the baker's map. We put the two unit squares one above another and specify the interaction with distance σ such that, between two steps of the baker's map, all closest pairs of particles (with distance smaller than σ between them) exchange their positions. (More precisely, we first find the pair of closest particles (with distance smaller than σ between them) and exchange their positions. After that, we find the second pair of closest particles (with distance smaller than σ between them and different from previously chosen particles) and exchange their positions too. We repeat this procedure until we exhaust all particles.) The interactions happen *only* between the particles in different subsystems. It has not sense to introduce such interaction inside of subsytems. Indeed, such interaction does not affect the motion of the particles, but gives rise to the mixing between the two subsystems when two particles of the pair belong to different subsystems. When they belong to the same system, we interpret them as trivial irrelevant exchanges, and consequently think of them as exchanges that have not happened at all.

Note also that such mixing by itself does not lead to the Gibbs paradox, as long as we consider the two unit squares as separate objects. The macroscopic entropy is defined as the sum of macroscopic entropies of the two subsystems.

Now let us consider the case in which the time arrows of the two subsystems have the same direction. The processes in which the macroscopic entropies of the two subsystems increase are stable under the interaction. Thus, most low-entropy initial conditions lead to a growth of macroscopic entropy of both subsystems, as well as of the full system.

Similarly, if we inverse a process above with increasing macroscopic entropy, we obtain a system in which macroscopic entropy of both subsystems, as well as of the full system - *decreases*. In this sense, the interaction does not ruin the symmetry between the two directions of time.

Now let us consider the most interesting case, in which entropy increases in the first subsystem and decreases in the second. The initial state of the first subsystem has low entropy (for example, all particles are in some small square near the point (0, 0) of the unit square). Likewise, the second system has low entropy (for example, all particles are in some small square near the point (1, 1) of the unit square) in the state

If there was no interaction, the final state of the first subsystem would be a high-entropy state corresponding to a nearly uniform distribution of particles. Likewise, the initial state of the second system would be a high-entropy state of the same form.

However, the solutions above with two opposite arrows of time are no longer solutions when the interaction is present. In most cases, the interaction mixes the particles between the subsystems. The number of solutions with interaction which have the initial-final conditions prescribed above is very small, in fact *much smaller than the number of such solutions in the absence of interaction.*

Let us make the last assertion more quantitative. After an odd number of (non-trivial) exchanges, the particle transits to the other subsystem. Likewise, after an even number of such exchanges, it remains in the same subsystem. The probabilities for these two events are equal to p = 1/2 and do not depend on other particles, at least approximately. Further, we can argue that the mixing between the two subsystems is negligible in the initial and final states, as the entropies of the two subsystems are very different. We want to calculate the probability of a small mixing in the final state, given that the mixing is small in the initial state. For definiteness, we shall say that the mixing is small if the number N_t, of transited particles is either $N_t < N/4$, or $N_t > 3N/4$. Thus, the probability is given by the cumulative binomial distribution $F(N_t; N, 1/2)$, given by

$$F(k;n,p) = \sum_{i=0}^{\lfloor k \rfloor} \binom{n}{i} p^i (1-p)^{n-i} \quad (15)$$

where [k] is the greatest integer less than or equal to k. The function F (k; n, p), satisfies the bound

$$F(k;n,p) \leq \exp\left(-2\frac{(np-k)^2}{n}\right). \quad (16)$$

Thus, since the opposite time arrows of subsystems are not destroyed when $N_t < N/4$ or $N_t > 3N/4$, we see that the probability of this is equal to

$$2F(N/4; N, 1/2) \leq 2e^{-N/8}. \quad (17)$$

Clearly, it decreases exponentially with N, which means that such a probability is negligibly small for large N. Hence, it is almost certain that processes with opposite time arrows will be destroyed

In the model above, we need a nearly equal number of particles in the two subsystems to destroy the opposite time arrows. This is because one particle can influence the motion of only one close particle. For more realistic interactions, one particle can influence the motion of a large number of particles in its neighborhood, which means that even a very small number of particles in one system can destroy the entropy decreasing processes of the other system.

4.3 Decorrelation in the interacting system

Hamiltonian systems are described not only by a macrostate, but also by complex nonlinear correlations between microstates. These correlations are responsible for reversibility. The interaction between two subsystems destroys these correlations inside the subsystems, but the full system remains reversible, i.e., the correlations appear in the full system. Thus, the decorrelation in the subsystems expands the correlations over the full system. (This process is a classical analogue of decoherence in quantum mechanics.)

Let us put these qualitative ideas into a more quantitative form. Linear (Pearson) correlations have a behavior very similar to the nonlinear correlations described above. The only difference is that these linear correlations decrease with time. The interaction we proposed can be approximated by a random noise with amplitude corresponding to a distance σ of the interaction between the particles.

Therefore, we expect that the interaction not only causes the alignment of the time arrows, but also decay of correlation which is even stronger than that without the interactions (Sec. A.5).). During this process the evolution of subsystems is irreversible, but the full system remains reversible.

We can quantify this decay of correlations by calculating the Pearson correlation for our subsystems, given by

$$r(m) = \frac{C(m)}{\sqrt{C(0)\langle C^m(0)\rangle}}, \tag{18}$$

where $\langle C^m(0)\rangle$ is the expected variance of the random variable x, calculated after m iterations of the map. The variance $C^m(0)$ can be calculated as

$$C^m(0) = \sum_{j=0}^{2^m-1} \int_{j2^{-m}}^{(j+1)2^{-m}} (2^m x - j - \langle x\rangle + S)^2\, dx, \tag{19}$$

where S is a random number defined as $S = \sum_{k=0}^{m-1} 2^k \zeta_k$. Here ζ_k is an i.i.d. random number with zero mean and variance σ^2, which models the influence of interactions on the evolution of the system. After a short calculation we get

$$\langle C^m(0)\rangle = C(0) + \langle S^2\rangle = C(0) + \sum_{k,k'=0}^{m-1} 2^{k+k'} \langle \zeta_k \zeta_{k'}\rangle. \tag{20}$$

Using the properties of i.i.d. variables $\langle \zeta_k \zeta_{k'}\rangle = \delta_{kk'}\sigma^2$, it follows that

$$\langle C^m(0)\rangle = C(0) + \frac{2^{2m}-1}{3}\sigma^2. \quad (21)$$

It is clear that the interactions will enhance the decay of correlations of at least linear dependencies, because

$$r(m) = \frac{2^{-m}}{\sqrt{1+4(2^{2m}-1)\sigma^2}}. \quad (22)$$

Yet, for the full system the Pearson correlation $r(m) = 2^{-m}$ remains the same. Since $\langle S^2\rangle^{1/2}$ must be much smaller than the system size (unit square), we can conclude that our assumptions resulting in (22) are correct only for $\langle S^2\rangle = [(2^{2m}-1)/3]\sigma^2 \ll 1$ and $\sigma^2/2^{-2m} \ll 1$.

4.4 Numerical simulation

So far, we have been using general abstract arguments. In this subsection we support these arguments by a concrete numerical simulation.

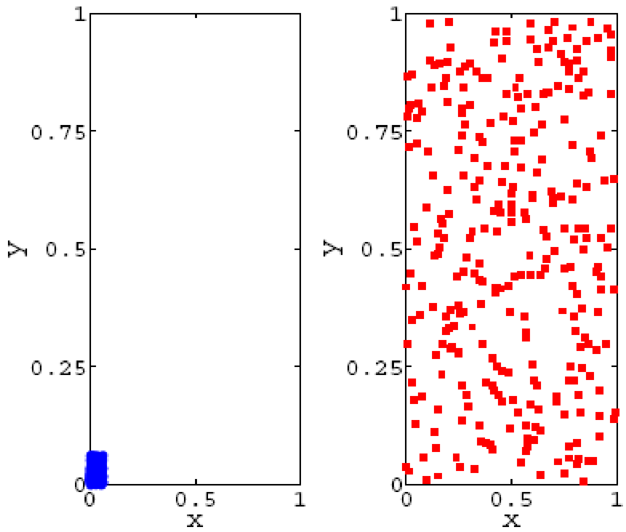

Рис. 1 The initial particle configuration at t = 1.

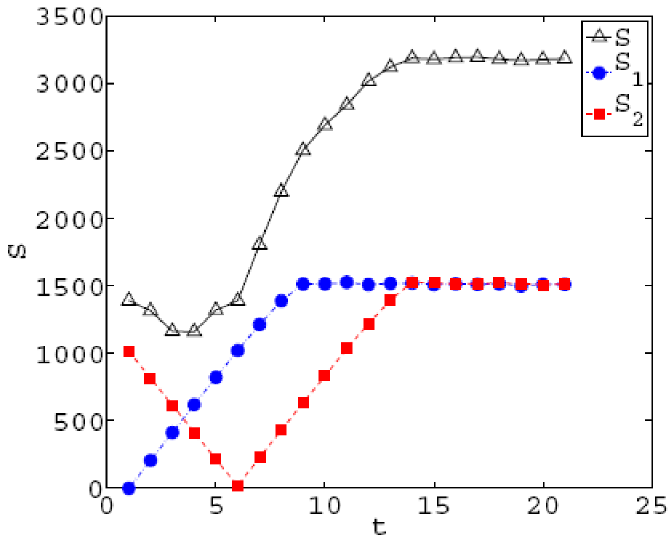

Рис. 2 Evolution of entropy without interaction.

We consider two subsystems (labeled as 1 and 2), each with N1 = N2 = 300 particles. The two subsystems occupy two unit squares. To define the coarsened entropy, each unit square is divided into 16x16=256 small squares. Thus, the entropy in the two subsystems is given by

$$S_i = -N_i \sum_{k=1}^{512} f_{k,i} \log f_{k,i}, \tag{23}$$

where $i = 1, 2,\ f_{k,i} = n_{k,i}/N_i$ and $n_{k,i}$ is the number of particles in the corresponding small square. Similarly, the total entropy is defined as

$$S = -(N_1 + N_2) \sum_{k=1}^{512} f_k \log f_k, \tag{24}$$

where $f_k = (n_{k,1} + n_{k,2})/(N_1 + N_2)$

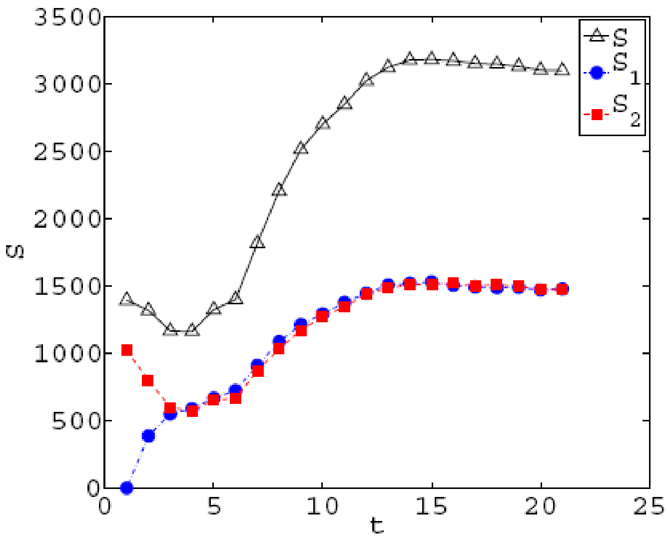

Рис. 3 Evolution of entropy with interaction.

For the system 1 we choose a zero-entropy initial state at t = 1 (see Fig. 1).). Similarly, for the system 2 we choose a zero-entropy "initial" state at t = 6. Such initial conditions provide that, in the absence of interactions, S1 increases with time, while S2 decreases with time for t <6.

To avoid numerical problems arising from the finite precision of computer representation of rational numbers, (27) is replaced by $x' = ax - \lfloor ax \rfloor,\ y' = (y + \lfloor ax \rfloor)/2$, with a= 1.999999. The results of a numerical simulation are presented in Fig. 1 and Fig. 2.

To include the effects of interaction, we define interaction in the following way. (For the sake of computational convenience, it is defined slightly differently than in Sec.4.2.) We take a small range of interaction $r_y = 0.01$ in the y-direction, which can be thought of as a parameter that measures the weakness of interaction. (Recall that y and x are analogous to a canonical coordinate and a canonical momentum, respectively, in a Hamiltonian phase space.) The interaction exchanges the closest pairs similarly as in Sec. 4.2, but now ``the closest'' refers to the distance in the y-direction, and there is no exchange if the closest distance is larger than r_y.
In addition, now interaction is defined such that only the x-coordinates of the particles are exchanged. By choosing the same initial conditions at t = 1 as in the non-interacting case (Fig. 1), the results of a numerical simulation with the interaction are presented in Fig. 3. We see that with interaction (Fig. 3) S_2 starts to increase at earlier times than without interaction (Fig. 2).

5 Discussion

In this paper, we have used the toy model based on the baker's map to demonstrate features which seem to be valid for general systems described by reversible Hamiltonian mechanics. Clearly, for such systems one can freely choose either final or initial conditions, but one cannot freely choose mixed initial-final conditions. Mixed initial-final conditions are conditions when canonical variables for the first part of particles are defined in initial state and canonical variables for the second part of particles are defined in final state. For most such mixed initial-final conditions, an appropriate solution (of the Hamiltonian equations of motion) does not exist. Similarly, our toy model suggests that for most Hamiltonians with weak interactions, the number of solutions with given coarse-grained initial-final conditions is much smaller then the number of solutions with only coarse-grained initial or only coarse-grained final conditions. This explains why, in practice, we never observe subsystems with opposite arrows of time, i.e., why the arrow of time is universal.

In a sense, this destruction of opposite arrows of time is similar to ergodicity. Both properties are valid for all practical purposes only, they are not exact laws. They are true for most real systems, but counterexamples can always be found [21, 22]. . Also, they both may seem intuitively evident, but to prove them rigorously is very difficult. For ergodicity the relevant rigorous result is the KAM (Kolmogorovв-Arnold-Moser) theorem, while for the destruction of the opposite time arrows a rigorous theorem is still lacking.

Our results also resolve the ``contradiction" between the Prigogine's ``New Dynamics" [20] (discussed in Sec. 3.3 of the present paper) and Bricmont's comments [26]. Dynamics of interacting systems we can be divided into two types of dynamics:

1. Reversible *ideal dynamics* is considered with respect to the coordinate time, in which case entropy can either decrease or increase.
2. Irreversible *observable dynamics* is considered with respect to the intrinsic time arrows of interacting systems, in which case entropy increases as we can see above.

In the framework of this terminology, the Prigogine's ``New Dynamics" [20] is one of the forms of the observable dynamics, while the Bricmont's paper [26] considers ideal dynamics. In particular, the observable dynamics does not include Poincare's returns and reversibility that are indeed unobservable by a real observer, which makes it simpler than ideal dynamics. Yet, in principle, both types of dynamics are correct.

It should also be noted that our results are not in contradiction with the existence of dissipative systems [27] (such as certain self-organizing biological systems) in which entropy of a subsystem can decrease with time, despite the fact that entropy of the environment increases. The full-system entropy (including the entropies of both the dissipative system and the environment) increases, which is consistent with the entropy-increase law. For such systems, it is typical that the interaction with the environment is *strong*, while results of our paper refer to *weak* interactions between the subsystems. For example, for existence of living organisms, a strong energy flow from the Sun is needed. The small flow from the stars is not sufficient for life, but is sufficient for the decorrelation and for the alignment of the time arrows. To quote from [6] : ``However, an observer is macroscopic by definition, and all remotely interacting macroscopic systems become correlated very rapidly (e.g. Borel famously calculated that moving a gram of material on the star Sirius by 1m can influence the trajectories of the particles in a gas on earth on a time scale of μs [28]).”

Appendix A. Basic properties of the baker's map

In this appendix we present some basic properties of the baker's map. More details can be found, e.g., in [29].

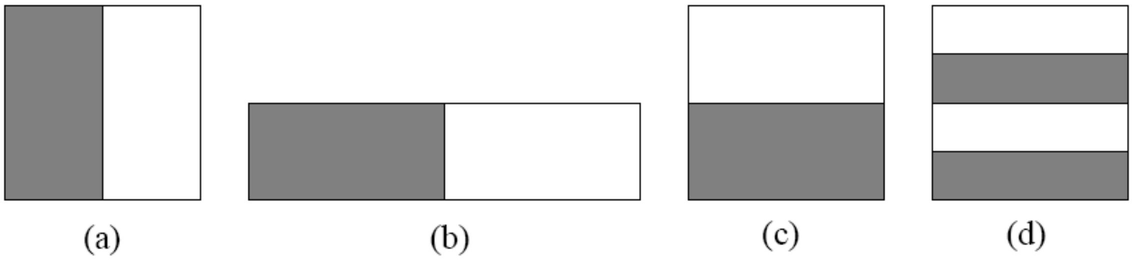

Fig. 4. Geometric interpretation of the baker's map. (a) Initial configuration. (b) Uniform squeezing in vertical direction and stretching in horizontal direction by a factor of 2. (c) The final

configuration after cutting the right half and putting it over the left one. (d) The final configuration after two iterations.

A.1 Definition of the baker's map

Consider a binary symbolic sequence.

$$\dots S_{-2}, S_{-1}, S_0; S_1, S_2, S_3 \dots \tag{25}$$

infinite on both sides. Such a sequence defines two real numbers

$$x = 0.S_1S_2S_3\dots, \qquad y = 0.S_0S_{-1}S_{-2}\dots. \tag{26}$$

The sequence can be moved reversibly with respect to the semicolon in both directions. After the left shift we get new real numbers

$$x' = 2x - \lfloor 2x \rfloor, \qquad y' = \frac{1}{2}(y + \lfloor 2x \rfloor), \tag{27}$$

where [x] is the greatest integer less than or equal to x. This map of unit square into itself is called the *baker's map*.

The baker's map has a simple geometrical interpretation presented in Fig.4. There (a) is the initial configuration and (c) is the final configuration after one baker's iteration, with an intermediate step presented in (b). The (d) part represents the final configuration after two iterations.

A.2 Unstable periodic orbits

The periodic symbolic sequences (0) and (1) correspond to fixed points (x, y) = (0, 0) and (x, y) = (1, 1, respectively. The periodic sequence (10) corresponds to the period-2 orbit {(1/3, 2/3), (2/3, 1/3)}. From periodic sequence ...001; 001... we get {(1/7, 4/7), (2/7, 2/7), (4/7, 1/7)}. Similarly, from ...011; 011... we get {(3/7, 6/7), (6/7, 3/7), (5/7, 5/7)}.

Any *x* and *y* can be approximated arbitrarily well by $0.X_0...X_n$ and $0.Y_0... Y_m$, , respectively, provided that *n* and *m*. are sufficiently large. Therefore the periodic sequence $(Y_m...Y_0X_0...X_n)$, can approach any point of the unit square arbitrarily close. Thus, the set of all periodic orbits makes a dense set on the unit square.

A.3 Ergodicity, mixing, and area conservation

Due to stretching in the horizontal direction, all close points diverge exponentially under the baker's iterations. In these iterations, a random symbolic sequence approaches any point of the square arbitrarily close. In general, such an ergodic property can be used to replace the ``time'' average <A> by the ``ensemble'' average

$$\langle A \rangle = \sum_n A(x_n, y_n) = \int A(x,y)\, d\mu(x,y) = \int A(x,y)\rho(x,y)\, dx\, dy, \tag{28}$$

where $d\mu(x,y)$ is the invariant measure and $\rho(x, y)$ is the invariant density for the map. For the baker's map, $\rho(x, y)= 1$.
Under the baker's iterations, any region maps into a set of narrow horizontal strips. Eventually, it fills uniformly the whole unit square, which corresponds to mixing. Similarly, reverse iterations map the region into narrow vertical strips, which also corresponds to mixing.
During these iterations, the area of the region does not change. This property is the area conservation law for the baker's map.

A.4 Показатели степени Ляпунова, сжимающиеся и растягивающиеся направления

If $x_0^{(1)}$ and $x_0^{(2)}$ have equal k first binary digits, then, for n<k,

$$x_n^{(2)} - x_n^{(1)} = 2^n (x_0^{(2)} - x_0^{(1)}) = (x_0^{(2)} - x_0^{(1)}) e^{n \log 2}, \tag{29}$$

where Λ= log 2 is the first positive Lyapunov exponent for the baker's map. Consequently, the distance between two close orbits increases exponentially with increasing n, and after k iterations becomes of the order of 1. This property is called sensitivity to initial conditions. Due to this property, all periodic orbits are unstable.
Since the area is conserved, the stretching in the horizontal direction discussed above implies that that some shrinking direction must also exist. Indeed, the evolution in the vertical y-direction is opposite to that of the horizontal x-direction. If $(x_0^{(1)}, y_0^{(1)})$ and $(x_0^{(2)}, y_0^{(2)})$ are two points with
$x_0^{(1)} = x_0^{(2)}$, then

$$y_n^{(2)} - y_n^{(1)} = 2^{-n} (y_0^{(2)} - y_0^{(1)}) = (y_0^{(2)} - y_0^{(1)}) e^{n(-\log 2)}. \tag{30}$$

Hence Λ= −log 2 is the second negative Lyapunov exponent for the baker's map.

A.5 Decay of correlations

Since x -direction is the unstable direction, the evolution in that direction exhibits a decay of correlations. The average correlation function C(m) for a sequence x_k is usually defined as

$$C(m) = \lim_{n\to\infty} \frac{1}{n} \sum_{k=1}^{n} (x_k - \langle x \rangle)(x_{k+m} - \langle x \rangle), \tag{31}$$

where $\langle x \rangle = \lim_{n\to\infty} \sum_{k=1}^{n} x_k / n$. Correlations can be more easily calculated if one knows the invariant measure μ(x), in which case

$$C(m) = \int (x - \langle x \rangle)(f^m(x) - \langle x \rangle) \, d\mu(x), \tag{32}$$

where $f^m(x) = x_m$ is the function that maps the variable x to its image after \$m\$ iterations of the map. For the baker's map $d\mu(x)=dx$, so we can write

$$C(m) = \sum_{j=0}^{2^m-1} \int_{j2^{-m}}^{(j+1)2^{-m}} (x - \langle x \rangle)\left(2^m x - j - \langle x \rangle\right) dx, \tag{33}$$

which yields

$$C(m) = \sum_{j=0}^{2^m-1} \left[2^m \frac{x^3}{3} - \left(2^m \langle x \rangle + \langle x \rangle\right) \frac{x^2}{2} + \langle x \rangle^2 x - j \left(\frac{x^2}{2} - \langle x \rangle x \right) \right]_{j2^{-m}}^{(j+1)2^{-m}} . \tag{34}$$

For the baker's map <x>=½, so the sum above can be calculated explicitly

$$C(m) = \frac{2^{-m}}{12}. \tag{35}$$

This shows that the correlations decay exponentially with m. The Pearson correlation for the system is given by

$$r(m) = C(m)/C(0) = 2^{-m}. \tag{36}$$

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Chapter 2. The Universal Arrow of Time: Quantum Mechanics

0. Abstract: Solution of Schrodinger's cat paradox, Wigner's friend paradox, paradox of a kettle which will never begin to boil

This paper is a natural continuation of our previous paper [1] and Chapter 1 of this essay. We illustrated earlier that in classical Hamilton mechanics, for overwhelming majority of real

chaotic macroscopic systems, alignment of their thermodynamic time arrows occurs because of their low interaction. This fact and impossibility to observe entropy decrease at introspection explain the second law of thermodynamics. The situation in quantum mechanics is even a little bit easier: all closed systems of finite volume are periodic or nearly periodic. The proof in quantum mechanics is in many respects similar to the proof in classical Hamilton mechanics – it also uses small interaction between subsystems and impossibility to observe entropy decrease at introspection. However, there are special cases which were not found in the classical mechanics. In these cases one microstate corresponds to a set of possible macrostates (more precisely, their quantum superposition). Consideration of this property with use of decoherence theory and taking into account thermodynamic time arrows will introduce new outcomes in quantum mechanics. It allows to resolve basic paradoxes of quantum mechanics: (a) to explain the paradox of wave packet reduction at measurements when an observer is included in the system (introspection) (paradox of the Schrodinger cat); (b) to explain unobservability of superposition of macroscopic states by an external observer in real experiments (paradox of Wigner's friend); (c) to prove full equivalence of multi-world and Copenhagen interpretations of quantum mechanics; (d) to explain deviations from the exponential law at decay of particles and pass from one energy level to another (paradox of a kettle which will never begin to boil).

1. Introduction

First of all, it is necessary to note that in our paper, unless other is stipulated, a full system is located in a closed finite volume, contains a finite number of particles and is isolated from environment. These are principal requirements of the entropy increasing law which we consider. The full system can be also described in terms of quantum mechanics laws.

In our previous paper [1] we considered alignment of thermodynamic time arrows in classical Hamilton mechanics leading to proof of the entropy increasing law. Here we intend to consider a quantum case. The reason of alignment of thermodynamic time arrows in quantum mechanics is the same as in the classical mechanics. It is *"entangling"* and *"decoherence*" [2-3, 17, 24-27], that is, low interaction between real chaotic macroscopic systems or a real chaotic macroscopic system in unstable state and a quantum microsystem (process of measurement in quantum mechanics).

Use of phenomenon of alignment of thermodynamic time arrows on quantum mechanics for analysis of widely known paradoxes of quantum mechanics allows their full and consistent resolution. All these paradoxes are caused by *experimental* unobservability for *real macroscopic* bodies of such purely quantum phenomena predicted by a quantum mechanics as (a) superposition of macrostates for the Copenhagen interpretation, or (b) presence of multiple worlds in case of multi-world interpretation.

Indeed, quantum mechanics has the principal difference from classical one: if in classical mechanics one microstate corresponds to just one macrostate, then in quantum mechanics one microstate (*a pure* state characterized by a wave function) can correspond to a set of macrostates. (In other words, this microsate is superposition of microstates corresponding to *various* macrostates). Such situation is not possible in classical mechanics! Moreover, such state can not be considered as a simple *mixed* state, i.e. a classical ensemble of these several macrostates (to be more exact, of macrostates corresponding to them which are included into the superposition) with corresponding probabilities. Evolution of these superpositions and mixed states is different. This difference is related to presence *of interference* terms for superposition (or *quantum correlations* of the worlds for multi-world interpretation). Although this difference is very small for macroscopic bodies, yet it exists. What would prevent to observe this difference experimentally? The same reasons that prevents to observe entropy decreasing because of alignment of thermodynamic time arrows!

Indeed, the more the detailed analysis below shows that experimental manifestations of interference (quantum correlations) are demonstrated in *considerable scale* only at entropy decrease. This process is not observable *in principle* if the observer *is included* into the observable system (*introspection*). Thus, entropy decrease is very difficultly observable if the observer is not included in the observed macrosystem, because of alignment of thermodynamic time arrows of the observable system and the observer/environment during decoherence. Almost full isolation of the macrosystem from environment / the observer is necessary between observations.

Also, small manifestations of the interference (quantum correlations) at entropy increase cannot be observed at introspection *in principle* (at introspection the full observation will be impossible – only macroparameters can be measured exactly, the full measuring is impossible). They are very difficultly observable for the external observer case because of decoherence with the observer/environment.

2. Qualitative consideration of the problem.

The reason of alignment of thermodynamic time arrows in quantum mechanics, as well as in classical mechanics, is low interaction between real chaotic macroscopic systems. It is a well studied phenomenon named “decoherence” [2-3, 17, 24-27]. It results is not only in widely known “entangling” states of systems but also in alignment of thermodynamic time arrows. (The direction of a thermodynamic time arrow is defined by the direction of the entropy increase). The reason of alignment of thermodynamic time arrows is absolutely the same as in classical Hamilton mechanics: instability of processes with opposite time arrows with respect to small perturbations. These perturbations exist between the observer/environment and the observed system (decoherence).

Similar arguments in the case of quantum mechanics were given in Maccone’s paper [4]. However, therein he formulated that the similar logic is applicable only in quantum mechanics. Incorrectness of this conclusion was shown in our previous papers [1, 5]. The other objection to his judgments was formulated in paper [6]. Therein small systems with strong fluctuations are considered. Alignment of thermodynamic time arrows does not exist for such small systems. It must be mentioned that both Maccone’s replay to this objection and the subsequent paper of the authors of the objection [7] do not explain the true reason of the disagreement described. The real solution is very simple. More specifically, the entropy increase law, the concept of thermodynamic time arrows and their alignment are applicable only to non-equilibrium *macroscopic* objects. Violation of these laws for microscopic systems with strong fluctuations is a widely known fact. Nevertheless, although the objection [6] is trivial physically, yet it is interesting from purely mathematical point of view. It gives good mathematical criterion for macroscopicity of chaotic quantum systems.

The situation in quantum mechanics is even simpler than in classical one: chaotic quantum systems are nearly periodic systems. Their chaotic character is defined by the fact that the energies (eigenvalues of a Hamiltonian determining “frequencies” of energy modes) are distributed over the random law [8].

One can often see a statement that behavior of quantum chaotic systems differs very strongly from that of classical ones. It is, however, a bad mistake related to deep misunderstanding of physics of these systems. Really, quantum chaotic systems are nearly periodic, whereas classical chaotic systems are characterized by the random law for Poincare’s returns times. Thermodynamic time arrows of the observer and the observable system have the same direction. Therefore, the observer is capable to carry out observation (or introspection) only on finite time intervals when its time arrow exists (i.e. its state is far from thermodynamic equilibrium), and it *does not change* its direction. On such *finite* times (that the observer is capable to carry out observation during this time) the behavior of chaotic quantum systems has the same character as that for classical quantum systems.

Decoherence results in transition of observed systems from a pure state to mixed one, i.e. results in entropy increase. (Actually, one macrostate transforms to the set of microstates). On the other hand, Poincare's returns yield the inverse result (i.e. "recoherence") and are related to the entropy decrease. Thus, decoherence and the correspondent alignment of thermodynamic time arrows of the observer and observable systems shall also lead to the syncs of moments when the systems pass from pure states to mixed states. Consequently, it makes impossible to observe experimentally the inverse process (i.e. "recoherence").

Summing up the above mentioned, consideration of alignment of thermodynamic time arrows in quantum mechanics is in many aspects similar to consideration in classical mechanics. However, consideration of this property for analysis of widely known paradoxes of quantum mechanics gives their full and consistent resolution. These are the following paradoxes: (a) explaining the paradox of wave packet reduction at measurements when an observer is included in system (introspection) (paradox of the Schrodinger cat); (b) explaining unobservability of superposition of macroscopic states by an external observer in real experiments (paradox of Wigner's friend); (c) proving the full equivalence of multi-world and Copenhagen interpretations of quantum mechanics; (d) explaining deviations from the exponential law at decay of particles and pass from one energy level on another (paradox of a kettle which will never begin to boil).

As it is described above, in quantum mechanics the solution of the problem of alignment of thermodynamic time arrows is similar to that in classical mechanics. But there is one important exception. In classical mechanics one microstate (a point in a phase space) corresponds to just one macrostate. In quantum mechanics one microstate (wave function) can correspond to the set of possible macrostates (quantum superposition of the wave functions corresponding to this macrostates). This situation appears in the well-known paradox of "Schrodinger cat".

Multi-world interpretation of quantum mechanics is very popular today. It states that these different macrostates correspond to different worlds. These parallel worlds exist simultaneously and interfere (summing to each other). It is suggested as a solution of "Schrödinger cat" paradox.

But then the following question appears: Why do we need to suppose simultaneous existence of these worlds? Instead we can say: "The system collapses in one of these macrostates with the probability defined by Bohr's rules. Why do we need these mysterious parallel worlds?" This point of view is named Copenhagen Interpretation.

The following objections are usually given:

1. We do not have any mechanisms describing the collapse in Copenhagen Interpretation.
2. We accept that wave functions are something which really exists.
3. These wave functions and their superposition satisfy to Schrodinger equations.
4. Multi-world interpretation follows automatically from 1 and 2.
5. Decoherence, which is also a consequence of Schrodinger equations, explains why we can see as a result only one of the worlds (with corresponding Bohr's probabilities).

But here it is possible to object to it: "Yes, we don't have any collapse mechanism. But we need not know it. We just postulate such collapse. Moreover, we do not want at all to know this mechanism. Really, we are capable to describe and calculate any physical situation without this knowledge".

But such approach encounters the following difficulties:

1. We cannot specify or calculate *the exact* instant when this collapse takes place. For macrobodies it is possible to specify just a very narrow, but still a finite interval of time in which this collapse happens.
2. For macrobodies there is a quite clear separation between the worlds (because of decoherence) but it will never be full. There is always some *small* "overlapping" between the worlds (the interference terms, quantum correlations of the worlds) even for macrobodies. Decoherence which is described above resolves the problem only partially. It "separates" macroworlds not completely but leaving this small "overlapping".

3. There are specific models of collapse (so-called GRW theory [16]). They can be verified experimentally. But until now, such experiments did not give any proof of existence of such collapse. They give only boundaries on parameters for such models (in the case when they are really true) defined by accuracy of the experiment.

But it is possible to object again:

1. Yes, there is a problem to define exact collapse times. But exactly the same problem does exist in multi-world interpretation as well: in what instant does the observer see, in what of the possible worlds he has occurred?
2. The problem of "overlapping" of the worlds also exists in the multi-world interpretation. Indeed, the observer sees only one world in some instant. He can tell nothing about existence or non-existence of other parallel worlds. So, he can conclude all predictions of the future (based on Bohr's rules) only on knowing of "his" world. But due to "overlapping" of the worlds (even just a small one) some effects appear which cannot be based on his predictions. It means that quantum mechanics cannot give even an exact *probabilistic* prediction.
3. It is possible to add one more uncertainty that exists in both interpretations. Suppose, for example that a superposition of two macrostates exists: "an alive cat" and "a dead cat". Why does the world split (or collapse) into these two states? What is wrong with the pair: ("an alive cat" – "a dead cat"), ("an alive cat" + "a dead cat")?

The three problems described above lead *to uncertainty* of predictions done by means of quantum mechanics. It cannot be inserted even within probabilistic frameworks based on Bohr's rules. This uncertainty is very small for macrobodies but it exists. It exists for *all* interpretations, yet masking and changing its form.

The majority of interpretations are developed with aim of overcoming these problems. Actually, different interpretations only "mask" the uncertainty problem yet not solving it.

4. All which is told above about GRW theories is true. There is no necessity to use it instead of quantum mechanics. However, it is not correct for Copenhagen Interpretation. The Copenhagen Interpretation resembles GRW very much but one important feature is very much *different* from GRW. The Copenhagen Interpretation postulates the collapse only for *one* final observer. It does not demand the collapse from the *remaining* macroobjects and observers. P
A physical experiment is described from a point of view of this final observer. The final "observer" is not some person possessing mysterious "consciousness". It is some standard macroscopic object. It is far from its state of thermodynamic equilibrium. The final observer is the last in the chain of observers and macrobodies. Direction of his thermodynamic time arrows is chosen as "positive" direction. It is similarly to our previous paper [1]. This constrain on collapse leads to serious consequence which does not appear in GRW. Namely, the existence of the collapse in GRW can be verified experimentally, but existence of the collapse in Copenhagen Interpretation cannot be proved or disproved even *in principle.* Let us demonstrate it. We will consider mental experiments which allow verifying existence of the collapse predicted in GRW. Further we will demonstrate that these experiments cannot be used for verification of the collapse in the Copenhagen Interpretation.

a. Quantum mechanics, as well as classical, predicts Poincare's returns. And, unlike classical chaotic systems, the returns happen periodically or almost periodically. But because of the collapse in GRW such returns are impossible and cannot be observed experimentally, i.e. this fact can be used for experimental verification.
b. Quantum mechanics is reversible. At a reversion of evolution the system must return to the initial state. However, the collapse results in irreversibility. This fact also can be verified experimentally.

c. We can observe experimentally the small effects related to the small quantum correlations which exist even after decoherence. In GRW this small effects disappear.

Suppose that we want to verify the collapse of the final observer in the Copenhagen Interpretation. Hence, we must include the observer into the observable system, i.e. there is *introspection* here. We will demonstrate that it is impossible to verify (or contravene) existence of the collapse in Copenhagen Interpretation by the methods described above:

a. Suppose that the observer waits for the return predicted by quantum mechanics. But the observer is included into the system; i.e., at Poincare's return, he will return to his initial state together with the entire system. Hence, his memory about his past will be erased. So, the observer will not be possible to compare the initial and finite state. It makes the verification of the existence (or non-existence) of the observer's collapse experimentally impossible.
b. The same reasons as those in item (a.) make impossible the experimental verification of the returns caused by the reversion of system evolution.
c. For observation of the small effects (quantum correlation macrostates), the measuring split-hair accuracy is necessary. But, as the observer is included into the observed system (introspection), it is not possible to make full measurement of such system. (Figuratively speaking, the observer uses some "ink" to describe the full system state. But the "ink" is also a part of the full system during intersection. So the "ink" must describe also itself!) Such system can be described by macroparameters only. It makes impossible experimental observation and calculation of the small effects of the quantum correlations.

As a matter of fact, the first two items (a., b.) are related to a following fact which took place also in classical mechanics [1]. Decoherence (decomposition on macrostates) leads to the entropy increase (one macrostate is replaced by a full set of possible macrostates). On the other hand, observation of the return (i.e. recoherence) is related to the entropy decrease. The observer is capable to carry out introspection experimentally only on finite time intervals when it has a time arrow (i.e. a state far from the thermodynamic equilibrium), and it *does not change* its direction. Thus, inability to experimentally distinguish the Copenhagen and Multi-world Interpretations is closely related to the entropy increase law and the thermodynamic arrow of time.

Everything from the abovementioned makes impossible to experimentally verify the difference between the Copenhagen and Multi-world Interpretation, so they can be regarded as equivalent. Such statements about indistinguishability of these interpretations meet in the literature. However, in cases when this fact is not just stated but attempts are made to prove it, it is usually referred to impossibility to make such verification only practically for macrobodies (FAPP - for all practical purposes). The understanding of its *principal* impossibility is lacking. This incorrect understanding is a basis for erroneous deduction about «exclusiveness» of Multi-world Interpretation. We will demonstrate the clearest example [9]:

"MWI proponents might argue that, in fact, the burden of experimental proving lies on MWI opponents, because it is they who claim that there is the new physics beyond the well tested Schrodinger equation."
"Despite the definition "interpretation", the MWI is a variant of quantum theory that is different from others. Experimentally, the difference is relative to collapse theories. It seems that there is no experiment distinguishing the MWI from other no-collapse theories such as Bohmian mechanics or other variants of MWI. The collapse leads to effects that are, in principle, observable; these effects do not exist if MWI is the correct theory. To observe the collapse, we would need a superb technology which would allow "undoing" a quantum experiment, including a reversal of the detection process by macroscopic devices. See Lockwood 1989 (p. 223), Vaidman 1998 (p. 257), and other proposals in Deutsch 1986. These proposals are all for mental

experiments that cannot be performed with current or any foreseen future technology. Indeed, interference of different worlds has to be observed in these experiments. Worlds are different when at least one macroscopic object is in macroscopically distinguishable states. Thus, what is needed is an interference experiment with a macroscopic body. Today there are interference experiments with larger and larger objects (e.g., fullerene molecules C_{60}), but these objects are still not large enough to be considered "macroscopic". Such experiments can only refine the constraints on the boundary where the collapse might take place. A decisive experiment should involve the interference of states which differ in a macroscopic number of degrees of freedom: an impossible task for today's technology".

The given proof of principal experimental unverifiability of collapse in Copenhagen Interpretation, as far as we know, can be found only in this and the previous papers [10-13]. It is possible to term it as the "Goedel" theorem of impossibility for quantum mechanics. Both its statement and its method of its proof really remind “the Goedel theorem of incompleteness”.

We concentrate on this problem so much here for the following reasons. Firstly, the impossibility to experimentally distinguish the Copenhagen and Multi-world Interpretations is closely related to the entropy increase law and the thermodynamic arrow of time. Secondly, it is too many people sincerely but erroneously believe that Multi-world Interpretation (or other less fashionable Interpretations) completely solves all problems of quantum mechanics. Uncertainty which was already described above is one of such problems of quantum mechanics. It means that quantum mechanics using Bohr’s rules is characterized with small uncertainty connected to small quantum correlation of the observer. How are they solved actually? These results can be concluded from the fact that the specified uncertainty exist in *ideal* dynamics over an abstract coordinate time. This uncertainty is absent in *observable* dynamics over the observer's time arrow and is not observed experimentally in principle.

1) Introspection. The same reasons already described above which do not allow verifying the collapse experimentally will not allow experimental discovery of the uncertainty specified in item 1 (the exact instant of the collapse) and item 2 (quantum correlations). So, it is senseless to discuss it.
2) External observation:

a. If this observation does not perturb the observable system then the collapse of the system and, hence, uncertainties [specified in item 1 (the exact instant of the collapse) and item 2 (quantum correlations)] do not arise. So, quantum mechanics can be verified experimentally in precise way. Such unpertrubative observation is possible for macrobodies only theoretically. The necessary condition is a known initial state (pure or mixed) (Appendix A).
b. The observed system is open. It means that there is a low interaction between the observable system and the observer/environment. This low interaction masks uncertainty (specified in points 1 and 2) and makes impossible its experimental observation.

Here it is necessary to return to the uncertainty described in item 3. The majority of real observations correspond to two cases: the introspection cases (when the full description is impossible in principle) or the open system (perturbed with uncontrollable small external noise from the observer/environment). How to describe such open or incomplete systems? It is made by input *of macroparameters* of the system. The real *observable* dynamics of such parameters is possible for a wide class of systems. It does not include “the parallel worlds” unobservable in realities, entropy reduction, quantum superposition of macrostates and other exotic, possible only in *ideal* dynamics. Observable dynamics is considered with respect to the thermodynamic time arrow of the real macroscopic non-equilibrium observer, weakly interacting with observable system and an environment (decoherence). Ideal dynamics is considered with respect to abstract, coordinate time. The problem of the pass from ideal to real dynamics is successfully solved in other papers [14-15, 17-18]. Selection of macrovariables is ambiguous, but also is not arbitrary. Macrovariables should be chosen so that at entropy increase random small external noise did not influence considerably their dynamics. Such macrovariables exist and are named pointer states [3, 17]. Presence of the selected states is a result of interaction locality in the real world. It means that close particles interact stronger than far particles. If the force of interaction were defined, for example, by closeness of momentums the principal states would be absolutely different. So, the property of a locality is untrue over distances comparable with wave length. So, radio waves have *field* pointer states, strongly differing from *particles* pointer states. The situation described here is completely equivalent to [1] where "appropriate" macrostates for classical mechanics were considered.

What can be an example of observable dynamics for quantum systems? These are the described above GRW theories. To understand it, we will return to the Copenhagen Interpretation. We can choose different non-equilibrium macrobodies as "the final observer" in the Copenhagen Interpretation. Theoretically, the collapse in this case will be seen differently for such different observers. This appearance is named “paradox of Wigner’s friend”. This appearance of ambiguity of the collapse in the Copenhagen Interpretation can be named “Quantum solipsism”. It is named by analogy to the similar philosophical doctrine. This problem can be resolved similarly to the paper [1]. The entropies of all weakly interacting macrobodies increase or decrease synchronously, because of alignment of thermodynamic time arrows. The collapse corresponds to entropy increase (one macrostate replaces on a set of possible macrostates). Hence, low interaction (decoherence) between macrobodies yields not only alignment of thermodynamic time arrows but also sync of all moments of “collapse” for different observers. It makes “Quantum solipsism” for macrobodies although theoretically possible but extremely difficult to be realized in practice. Thus, this resolution of “Quantum solipsism” by the collapses differs from Copenhagen Interpretation where the observer's collapse cannot be prevented even theoretically. Thus, the GRW theories described above are the description of the real *observable* dynamics of macrobodies (FAPP dynamics) for quantum mechanics. It throws out effects not observed in reality. It is, for example, non synchronism in the macrobodies collapses moments and entropy decrease that are predicted by *ideal* dynamics.

“The paradox of a kettle which will never begin to boil” can serve as a good illustration of the abovementioned connection of observed and ideal types of dynamics. In quantum mechanics, it is related to a deviation from the exponential law of particles decay (or a pass from one energy level on another). The exponential character of such law is very important – the relative rate of decay does not depend on an instant. It means that the decaying particle has no "age". In quantum mechanics, however, in small lengths of time the law *of ideal* dynamics of decay strongly differs from the exponential law. So, when the number of measurements of a decaying particle state for finite time interval increases the particle in limit of infinite number of measurements does not decays at all!

Let us observe a macrosystem consisting of large amount of decaying particles. Here it is necessary to note that decay of a particle happens under laws of ideal dynamics only between measurements. Measurements strongly influence dynamics of the system, as we described above. To transfer to *the observable* dynamics featured above, we should decrease perturbing influence of observation strongly. It is reached by increasing the interval between observations. It must be comparable with a mean lifetime of unperturbed particles. For such large intervals of time, we get real observable dynamics of decay. It is featured by an exponential curve, and the mean lifetime does not depend on a concrete interval between measurements. Thus, the exponential decay is a law of observable but not of ideal dynamics of particles. (The same reason explains absence of Poincare's returns for this system).

3. The quantitative consideration of the problem

3.1 Definition of the basic concepts

1) In classical mechanics a microstate is a point in a phase space. In quantum mechanics it corresponds to a wave function ψ (a pure state), and trajectories are evolution of a wave function in time. In classical mechanics a macrostate corresponds to a function of density distribution in a phase space. In quantum mechanics it corresponds to a density matrix ρ. The density matrix form depends on the chosen basis of orthonormal wave functions. If $\rho\rho\neq\rho$ then it is in mixed state.

2) The equation of motion for the density matrix ρ will have the following form:

$$i\frac{\partial \rho_N}{\partial t} = L\rho_N\,,$$

where L is the linear operator:

$L\rho = H\rho - \rho H = [H, \rho]$

and H is the energy operator of the system,

N is a number of particles

3) If A is the operator of a certain observable, then the average value of the observable can be found as follows:

$\langle A\rangle = tr\, A\, \rho$

4) If the observation is introspection the full observation is impossible. In case of external observation because of low interaction with the observer and instabilities of an observable chaotic system the full exposition also is senseless. Therefore, introducing some finite set M of *macrovariables* is necessary:

$A_{set} = \{A_1, A_2, \ldots, A_M\}$,

Where $M \ll N$

These macrovariables are known with finite small errors:

$\Delta A_i \ll A_i,\ 1\leq i\leq M$

This set of macrovariables corresponds to a macrostate with a density matrix ρ_{set}.

All microstates answering to requirements

$\{|\langle A_1\rangle - A_1| \leq \Delta A_1,\ |\langle A_2\rangle - A_2| \leq \Delta A_2,\ \ldots,\ |\langle A_M\rangle - A_M| \leq \Delta A_M\}$

are assumed to have equal probabilities.

Corresponding *to thermodynamic equilibrium* is a macrostate ρ_E. It corresponds to a set of microstates satisfying to the following requirement:

$|\langle E\rangle - E| \leq \Delta E$ ($\Delta E \ll E$),

where E is the full system energy.

All these microstates are assumed to have equal probabilities.

5) In quantum mechanics *ensemble entropy* is defined via density matrix **[15]**:

$S = -k\, tr\, (\rho \ln \rho)$,

where *tr* stands for matrix trace.

Entropy defined in such a way does not change in the course of reversible evolution:

$$\frac{\partial S}{\partial t} = 0$$

6) Macroscopic entropy is defined as follows:

a) For current ρ we find all corresponding sets of macrovariables

$$\begin{cases} A_{set}^{(1)} = \left\{A_1^{(1)}, A_2^{(1)} \ldots, A_M^{(1)}\right\} \Delta A_i^{(1)} \ll A_i^{(1)}, 1 \leq i \leq M \\ \vdots \\ A_{set}^{(L)} = \left\{A_1^{(L)}, A_2^{(L)} \ldots, A_M^{(L)}\right\} \Delta A_i^{(L)} \ll A_i^{(L)}, 1 \leq i \leq M \end{cases}$$

b) We find a matrix ρ_{set} for which all microstates corresponding to the specified set of macroparameters have equal probabilities

c) Macroscopic entropy $S = -k\, tr\, (\rho_{set} \ln \rho_{set})$

Unlike ensemble entropy, macroscopic entropy (macroentropy) is not constant and can both increase and decrease in time. For given energy $E \pm \Delta E$ it reaches its maximum for thermodynamic equilibrium. The direction of the macroentropy increase defines the direction of a *thermodynamic arrow of time* for the system.

7) Similarly to the classical case, the interaction locality results in the fact that not all macrostates are appropriate. They should be chosen so that small noise would not influence essentially evolution of the system for the entropy increase process. Such states are well investigated in quantum mechanics and named *pointer states* [3, 17]. Quantum superposition of such states is unstable with respect to small noise. So such superposition is not, accordingly, a pointer state. For macrosystems close to the equilibrium pointer states are usually corresponding to Hamiltonian eigenfunctions.

8) Coarsened value of ρ (ρ_{coar}) should be used to obtain changing entropy similarly to changing macroscopic entropy. We will enumerate ways to achieve it:

a) We define a set of pointer states and we project a density matrix ρ on this set. I.e. (a) we note a density matrix ρ in representation of these pointer states (b) we throw out non-diagonal terms of ρ and obtain ρ_{coar}. So entropy:

$S=-k\ tr\ (\rho_{coar} \ln \rho_{coar})$

b) We divide the system into some interacting subsystems (for example: the observer, the observable system and the environment). Then we define the full entropy as the sum of the entropies of these subsystems:

$S=S_{ob}+S_{ob\_sys}+S_{env}$

3.2 Effect of a weak coupling

3.2.1 Small external perturbation

We can put our macrosystem of finite volume inside of an infinite volume system ("environment", "reservoir") with some temperature. (This reservoir can be also a vacuum with zero temperature.) We will suppose that this reservoir is in thermodynamic equilibrium, has the same temperature as a temperature of the finite system in equilibrium and weakly interacts with our finite system. Then it is possible to use the quantum version of "new dynamics" developed by Prigogine [14] for such infinite systems. Dynamics of our finite system with a reservoir will be the same as its *observable dynamics* without a reservoir with respect to its thermodynamic time arrow. Such description has sense only during finite time. It is time when its thermodynamic time arrow exists (i.e. the system is not in equilibrium) and does not change its direction.

3.2.2 Alignment of thermodynamic time arrows at interaction of macrosystems (the observer and the observable system)

It ought to be noted that here our job is much easier than in the case of classical mechanics. This is due to the fact that the quantitative theory of small interaction between quantum systems (*decoherence*, *entangling*) is a well developed field [2-3, 17, 24-27]. We will not repeat these conclusions here but just give short results only:

(a) Suppose that we have two macrosystems for some instant. One or both of them are in their quantum superposition of pointer states. The theory of decoherence [2-3, 17, 24-27] states that small interaction between macrosystems (decoherence time is much less than relaxation time to equilibrium) transforms such system into the mixed state very fast in which the quantum superposition disappears. Such process of vanishing quantum superposition of pointer states corresponds to the entropy increase. It follows from Poincare's theorem that the system (in coordinate time) should return to its initial state. There should be an inverse process of recoherence. But it will happen in both systems synchronously. It means that any system can see only decoherence and entropy increase with respect to its thermodynamic time arrow. It means that both processes decoherence and time arrows will be synchronous in interacting subsystems. It is especially worthy of note that we consider here a case *of macroscopic* systems. For small systems where large fluctuations of parameters are possible, similar alignment of thermodynamic time arrows and the instances of "collapses" for subsystems is not observed [6-7].

(b) Now suppose that all macroscopic subsystems are in their pointer states. In the decoherence theory it is shown that in presence of small noise between its macroscopic subsystems the behavior of a quantum system is completely equivalent and is indistinguishable from behavior of the correspondent classical system [2-3, 17 , 24-27]. Thus, the analysis of alignment of thermodynamic time arrows is completely equivalent to the analysis made in paper [1].

(c) It is worth to specify what the meaning of "classical system" is in this case. It means that in the theory there do not exist specific mathematical features of quantum theory. They are, for example, such features as not commuting observables, quantum superposition of pointer states. At that, these "classical theories" can be very exotic, include Planck's constant and are not reduced to laws of the known mechanics of macrobodies or waves.

Superconductivity, superfluidity, radiation of absolute black body, and superposition of currents in Friedman's experiment [19] are often named "quantum effects". They are really quantum in the sense that their equations of motion include Planck's constant. But they are perfectly featured over macroscale by a mathematical apparatus of usual classical theories: either the theory of *classical* field (as pointer states), or the theory of *classical* particles (as pointer states). From this point of view, they are not quantum but classical. In quantum theory, featured objects both are particles and probability waves at the same time.

It is worth to note that in the classical limit, at room temperatures, quantum mechanics *of heavy-weighed* particles gives the theory *of classical* particles as pointer states (electron beams, for example). On the other hand, *light-weighted* particles give the *classical* field as pointer states (radiowaves). And these theories do not include Planck's constant.

However, at high temperatures when radiation achieves high frequencies, light quanta are featured by the theory *of classical* particles as pointer states. They give, for example, a spectrum of absolute black body on high frequencies. Though this spectrum includes Planck's constant its dynamics of pointer states (particles) will be classical. For deriving this spectrum the quantum mechanics formalism is not necessary (Planck derived this spectrum knowing nothing about the mathematical apparatus of quantum physics).

Vice versa, at low temperatures the particles start to be featured by *classical* fields as pointer states (superfluidity or superconductivity phenomena). For example, superconductivity is featured by *classical wave* of "order parameter". And though the equations which feature this field include Planck's constant, yet the equations correspond to mathematical apparatus of the *classical* field theory. These waves can be summed (superposed) with each other similarly to quantum waves. But the square of their amplitude does not define probability density. It defines density of Cooper pair. Such wave cannot collapse at measurement, as probability quantum waves can [20].

For quantum-mechanical states of bosons at low temperatures, pointer states are *classical* fields, and at high temperatures they are *classical* particles. The word "classical" is understood as a mathematical apparatus of the observable dynamics featuring their behavior, but not presence or absence of Planck's constant in their equations of motion.

What happens in the intermediate states between classical fields and classical particles? It is, for example, light in an optical wave guide ($L \gg \lambda \gg \lambda_{ultraviolet}$), L_{opt} - the characteristic size of the macrosystem (the optical wave guide) (Appendix B), λ - light-wave length, $\lambda_{ultraviolet}$- ultra-violet boundary of light). When using macroscales and macrovariables, and taking into account small noise from the observer, both descriptions ("classical waves" and "classical beam of particles") are identical. They are equivalent and can be used as pointer states. The equivalent situation arises for a case of superconductor where the roles of particles or waves play elemental "excitations" in gas of Cooper pairs.

Let's carry out a simple calculation to illustrate the said above.
Let E be energy of particle; k -Boltzmann constant, T-temperature, p - momentum, Δp - momentum uncertainty, λ - particle wave length, ω-frequency, Δx - a coordinate uncertainty; $\hbar$ - Planck constant. We will consider the "gas" of such particles which is in a cavity, filled with some material with distance between atoms a. a <<L, L - the characteristic size of the cavity. In vacuum $a \sim (L^3/N)^{1/3}$, N-number of particles in the cavity. c - speed of light (let suppose for simplicity that refraction index in the cavity is close to 1).

1) Firstly, let us consider light in weight particles which at room temperature have the speed close to speed of light c.
$E \sim pc$; $E \sim kT$; $p \sim \Delta p$; $\lambda \sim \Delta x$; $\Delta p \Delta x \sim \hbar$; $\omega = E/\hbar$
Hence,
$\hbar \sim \Delta p \Delta x \sim p\lambda \sim kT\lambda/c \Rightarrow \lambda \sim \hbar c/kT$
Condition *of classical* field approach with frequency $\omega \sim c/\lambda$:
$L < \lambda$ or $L \sim \lambda$. Hence $L < \hbar c/kT$ or $L \sim \hbar c/kT$
Condition of approach *of classical* relativistic particles with $E \sim \hbar c/\lambda$ and $p = E/c$:
$L \gg \lambda$. Hence, $L \gg \hbar c/kT$

2) Secondly, let us consider heavy particles *bosons* which at room temperature have the speed $v \ll c$
$p \sim (Em)^{1/2}$; $E \sim kT$; $p \sim \Delta p$; $\lambda \sim \Delta x$; $\Delta p \Delta x \sim \hbar$; $\omega = E/\hbar$
Hence,
$\hbar \sim \Delta p \Delta x \sim p\lambda \sim (kTm)^{1/2}\lambda \Rightarrow \lambda \sim \hbar/(kTm)^{1/2}$
Condition *of classical* field approach with frequency $\omega = p^2/(m\hbar)$:
$L < \lambda$ or $L \sim \lambda$. Hence $L < \hbar/(kTm)^{1/2}$ or $\sim \hbar/(kTm)^{1/2}$
Condition of approach *of classical* particles with energy $E = p^2/(2m)$ and momentum $p = mv$:
$L \gg \lambda$. Hence, $L \gg \hbar/(kTm)^{1/2}$

3) Let us consider now heavy particles *fermions* which at room temperature have the speed $v \ll c$
$p \sim (Em)^{1/2}$; $E \sim kT$; $p \sim \Delta p$; $\Delta p \Delta x \sim \hbar$
$\Delta x \leq \lambda$ and
$\lambda \leq a$ is a requirement of Pauli's principle for fermions. They cannot appear in the same state, so they are distributed in "boxes" with size a.
Hence,
$\hbar \sim \Delta p \Delta x \leq p\lambda \sim (kTm)^{1/2}\lambda \Rightarrow a \geq \lambda \geq \hbar/(kTm)^{1/2}$
$T \geq T_F = \hbar^2/(a^2 km)$ – Fermi's temperature when fermion gas transfers in the basic state and expression $E \sim kT$ becomes untrue.
At $T < T_F$: $E \sim E_F = kT_F$; $\lambda \sim \hbar/(E_F m)^{1/2} \sim a$
Requirement of *classical* field approach:
$L < \lambda$ or $L \sim \lambda$. It is impossible! $L \gg a \geq \lambda$
Requirement of approach of *classical* particles in quality pointer states with energy $E = p^2/(2m)$ and momentum $p = mv$ at $T \geq T_F$.
Requirement of approach of *classical* particles in quality pointer states, prisoners in «boxes» with size a, with energy $E \sim E_F$ and momentum $p \sim (E_F m)^{1/2}$ at $T \leq T_F$.
At $T \sim T_F$ we observe dynamics of "excitations" in the degenerated Fermi gas which is featured by particles or waves as pointer states for these "excitations".

To create the paradox of "Schrodinger cat" in experiment, the quantum superposition of the pointer states is necessary, instead of superposition of classical waves. Therefore, superposition of classical waves of "order parameter" or light waves is not related in any way to this paradox and does not illustrate it.

So, for example, experiments of Friedman [19] state a superposition of opposite currents. But the superposition is itself a pointer state for this case. This pointer state is classical, not *quantum* superposition of pointer states, as it is usually erroneously declared. Really, the state of bosons system (Cooper pairs) is featured at such low temperature *by a classical* wave as it was demonstrated above. These waves of "order parameter" are pointer states. They differ from pointer states of a high-temperature current of *classical particles* having a well-defined direction of motion. The superposition observed in Friedman's experiment is not capable to collapse to quantum-mechanical sense: its square features not probability but density of Cooper pairs [20]. It is not more surprising and not more "quantum" than usual superposition of electromagnetic modes in the closed resonator where spectrum of modes is discrete too. The only difference is that "order parameter" wave equations for pointer states include ħ. It is the only reason to use concept of "quantum" for this case.

3.3 Resolution of Loshmidt and Poincare paradoxes in framework of quantum mechanics

The state of a quantum chaotic system in a closed cavity with finite volume is featured by a set of energy modes $u_k(r_1, \ldots, r_N)$ with spectrum E_k distributed under *the random law* [8].
Let's write the expression for wave functions of a non-interacting pair of such systems:

$$\psi^{(1)}(\mathbf{r}_1,\ldots,\mathbf{r}_N,t)=\sum_k u_k(\mathbf{r}_1,\ldots,\mathbf{r}_N)e^{-\frac{iE_k^{(1)}}{\hbar}t}$$

$$\psi^{(2)}(\mathbf{r}_1,\ldots,\mathbf{r}_L,t)=\sum_l v_l(\mathbf{r}_1,\ldots,\mathbf{r}_L)e^{-\frac{iE_l^{(2)}}{\hbar}t}$$

The united equation is following:

$$\psi^{(1)}(\mathbf{r}_1,\ldots,\mathbf{r}_N,\mathbf{r}_1,\ldots,\mathbf{r}_L,t)=\psi^{(1)}(\mathbf{r}_1,\ldots,\mathbf{r}_N,t)\psi^{(2)}(\mathbf{r}_1,\ldots,\mathbf{r}_L,t)=$$

$$\sum_k\sum_l u_k(\mathbf{r}_1,\ldots,\mathbf{r}_N)v_l(\mathbf{r}_1,\ldots,\mathbf{r}_L)e^{-\frac{i(E_k^{(1)}+E_l^{(2)})}{\hbar}t}$$

At presence of small interactions between the systems

$$\psi^{(1)}(\mathbf{r}_1,\ldots,\mathbf{r}_N,\mathbf{r}_1,\ldots,\mathbf{r}_L,t)=$$

$$\sum_k\sum_l f_{kl}(\mathbf{r}_1,\ldots,\mathbf{r}_N,\mathbf{r}_1,\ldots,\mathbf{r}_L)e^{-\frac{iE_{kl}}{\hbar}t},$$

where $E_{kl}=E_k^{(1)}+E_l^{(2)}+\Omega_{kl}$, Ω_{kl}-generally a set of random variables, f_{kl}, u_k, v_l are eigenfunctions of corresponding Hamiltonians.

The obtained solutions are almost-periodic functions. The obtained period of return defines Poincare's period. The period of Poincare's return of full system is generally larger than periods of the both subsystems.

For resolution of Poincare and Loshmidt paradoxes (returns in these paradoxes contradict to entropy increase law) we will consider three cases now.

1) *Introspection*: At introspection the time the arrow is always directed over entropy growth, so the observer is capable to see only entropy growth with respect to this time arrow. Besides, return to the initial state erases the memory about the past. It does not allow the observer to detect entropy reduction. Thus, reduction of entropy and returns happen only with respect to coordinate time. But any experiment is possible with only with respect to time arrow of

the observer. With respect to coordinate time entropy reduction and returns cannot be experimentally observed [1, 10-13].

2) *External observation with small interaction* between macrosystems: Small interaction results in alignment of the thermodynamic time arrows of the observer and observed systems. Accordingly, all arguments that are relevant for introspection again become relevant for this case.

3) For a very hardly realizable *experiment with unperturbative observation* (Appendix A) macroentropy reduction can really be observed. However, it is worth to note that in the real world "entropy costs" on the experimental organization of such unperturbative observations will exceed considerably this entropy decrease. Indeed, the observable system needs to be isolated very strongly from environment noise.

In classical systems the period of Poincare's return is a random variable strongly depending on an initial state. In quantum chaotic systems the period is well defined and does not depend considerably on the initial state. However, this real difference in behavior of quantum and classical systems is not observed experimentally even in absence of any explicit constraint on experiment time. Indeed, any real physical experiment has a duration that is much smaller than Poincare's period of macrobodies. Physical experiments are possible only during the time while the thermodynamic time arrow exists (i.e. the system is not in a state of thermodynamic equilibrium) and does not change the direction.

3.4 Decoherence for process of measurement

3.4.1 Reduction of system at measurement [22-23].

Let's consider a situation when a measuring device was at the beginning in state $|\alpha_0\rangle$, and the object was in superposition of states $|\psi\rangle = \sum c_i|\psi_i\rangle$, where $|\psi_i\rangle$ - are experiment eigenstates. The initial statistical operator is given by expression

$\rho_0=|\psi\rangle|\alpha_0\rangle\langle\alpha_0|\langle\psi|$ (1)

The partial track of this operator which is equal to statistical operator of the system, including only the object, looks like

$tr_A(\rho_0)=\sum_n\langle\varphi_n|\rho_0|\varphi_n\rangle$

where $|\varphi_n\rangle$- any complete set of device eigenstates. Thus,

$tr_A(\rho_0)=\sum |\psi\rangle \langle\varphi_n|\alpha_0\rangle\langle\alpha_0|\varphi_n\rangle\langle\psi|=|\psi\rangle\langle\psi|,$ (2)

Where the relation $\sum |\varphi_n\rangle\langle\varphi_n| = 1$ and normalization condition for $|\alpha_0\rangle$ are used. We have statistical operator correspondent to object state $|\psi\rangle$. After measuring there is a correlation between device and object states, so the state of full system including device and object is featured by a state vector

$|\Psi\rangle=\sum c_i e^{i\theta i}|\psi_i\rangle|\alpha_0\rangle|.$ (3)

And the statistical operator is given by expression

$\rho_0=|\Psi\rangle\langle\Psi|=\sum c_i c_j^* e^{i(\theta i-\theta j)}|\psi_i\rangle|\alpha_i\rangle\langle\alpha_j|\psi_j\rangle.$

(4)

The partial track of this operator is equal to

$tr_A(\rho)=\sum_n\langle\varphi_n| \rho |\varphi_n\rangle |=$

$=\sum_{(ij)}c_i c_j^* e^{i(\theta i-\theta j)} |\psi_i\rangle\langle\varphi_n |\alpha_i\rangle\langle\alpha_j|\varphi_n\rangle\langle\psi_j|=$

$=\sum_{(ij)}c_i c_j^*\delta_{ij} |\psi_i\rangle\langle\psi_j|$ (5)

(Since various states $|\alpha_i\rangle$ of device are orthogonal each other); thus,

$tr_A(\rho)=\sum|c_i|^2|\psi_i\rangle\langle\psi_i|.$ (6)

We have obtained statistical operator including only the object, featuring probabilities $|c_i|^2$ for object states $|\psi_i\rangle$. So, we come to formulation of the following theorem.

Theorem 1 (about measuring). If two systems *S* and *A* interact in such a manner that to each state $|\psi_i\rangle$ systems *S* there corresponds a certain state $|\alpha_i\rangle$ of systems *A* the statistical operator tr_A

(ρ) over full systems *(S* and *A)* reproduces wave packet reduction for measuring, yielded over system *S*, which before measuring was in a state $|\psi\rangle = \sum_i c_i |\psi_i\rangle$.

Suppose that some subsystem is in mixed state but the full system including this subsystem is in pure state. Such mixed state is named *as improper mixed state*.

3.4.2 The theorem about decoherence at interaction with the macroscopic device. [18, 84]

Let's consider now that the device is a macroscopic system. It means that each distinguishable configuration of the device (for example, position of its arrow) is not a pure quantum state. It states nothing about a state of each separate arrow molecule. Thus, in the above-stated reasoning the initial state of the device $|\alpha_0\rangle$ should be described by some statistical distribution on microscopic quantum states $|\alpha_{0,s}\rangle$; the initial statistical operator is not given by expression (1), and is equal

$$\rho_0=\sum_s p_s|\psi\rangle|\alpha_{0,s}\rangle\langle\alpha_{0,s}|\langle\psi|. \quad (7)$$

Each state of the device $|\alpha_{0,s}\rangle$ will interact with each object eigenstate $|\psi_i\rangle$. So, it will be transformed to some other state $|\alpha_{i,s}\rangle$. It is one of the quantum states of set with macroscopic description correspondent to arrow in position i; more precisely we have the formula

$$e^{iH\tau/\hbar}(|\psi\rangle|\alpha_{0,s}\rangle)=e^{i\theta_{i,s}}|\psi\rangle|\alpha_{i,s}\rangle. \quad (8)$$

Let's pay attention at appearance of phase factor depending on index *s*. Differences of energies for quantum states $|\alpha_{0,s}\rangle$ should have such values that phases $\theta_{i,s}$(mod 2π) after time τ would be randomly distributed between 0 and 2π.

From formulas (7) and (8) follows that at $|\psi\rangle=\sum_i c_i|\psi_i\rangle$ the statistical operator after measuring will be given by following expression:

$$\rho=\sum_{(s,i,j)} p_s c_i c_j^* e^{i(\theta_{i,s}-\theta_{j,s})}|\psi_i\rangle|\alpha_{i,s}\rangle\langle\alpha_{j,s}|\langle\psi_j| \quad (9)$$

As from (9) the same result (6) can be concluding. So we see that the statistical operator (9) reproduces an operation of reduction applied to given object. It also practically reproduces an operation of reduction applied to device only ("practically" in the sense that it is a question about "macroscopic" observable variable). Such observable variable does not distinguish the different quantum states of the device corresponding to the same macroscopic description, i.e. matrix elements of this observable variable correspondent to states $|\psi_i\rangle|\alpha_{i,s}\rangle$ and $|\psi_j\rangle|\alpha_{j,s}\rangle$ do not depend on *r* and *s*. Average value of such macroscopic observable variable *A* is equal to

$$\mathrm{tr}(\rho A)=\sum_{(s,i,j)} p_s c_i c_j^* e^{i(\theta_{i,s}-\theta_{j,s})}\langle\alpha_{j,s}|\langle\psi_j|A|\psi_i\rangle|\alpha_{i,s}\rangle = =\sum_{(i,j)} c_i c_j^* a_{i,j}\sum_s p_s e^{i(\theta_{i,s}-\theta_{j,s})} \quad (10)$$

As phases $\theta_{i,s}$ are distributed randomly, the sum over s are zero at $i\neq j$; hence,

$$\mathrm{tr}(\rho A)=\sum|c_i|^2 a_{ii}=\mathrm{tr}(\rho' A). \quad (11)$$

where

$$\rho'=\sum|c_i|^2 p_s|\psi_i\rangle|\alpha_{i,s}\rangle\langle\alpha_{i,s}|\langle\psi_i| \quad (12)$$

We obtain statistical operator which reproduces operation of reduction on the device. If the device arrow is observed in position i, the device state for some s will be $|\alpha_{i,s}\rangle$. The probability to find state $|\alpha_{i,s}\rangle$ is equal to probability of that before measuring its state was $|\alpha_{i,s}\rangle$. Thus, we come to the following theorem.

Theorem 2. About decoherence of the macroscopic device. Suppose that the quantum system interacts with the macroscopic device in such a manner that there is a chaotic distribution of states phases of the device. Suppose that ρ is a statistical operator of the device after the measuring, calculated with the help of Schrodinger equations, and ρ' is the statistical operator obtained as a result of reduction application to operator ρ. Then it is impossible to yield such experiment with the macroscopic device which would register difference between ρ and ρ'.

It is the so-called Daneri-Loinger-Prosperi theorem **[21].**

For a wide class of devices it is proved that the chaotic character in distribution of phases formulated in the theorem 2 really takes place if the device is macroscopic and chaotic with unstable initial state. Indeed, randomness of phase appears from randomness of energies (eigenvalues of Hamiltonian) in quantum chaotic systems [8].

It is worth to note that though Eq. (12) is relevant with a split-hair accuracy it is only assumption with respect to (9). There from it is often concluded that the given above proof is FAPP. It means that it is only difficult to measure quantum correlations practically. Actually they continue to exist. Hence, *in principle* they can be measured. It is, however, absolutely untruly. Really, from Poincare's theorem about returns follows that the system will not remain in the mixed state (12), and should return to the initial state (7). It is the result of the very small corrections (quantum correlation) which are not included to (12). Nevertheless, the system featured here $|\alpha_{i,s}\rangle$ corresponds *to the introspection* case, and consequently, it is not capable to observe experimentally these returns *in principle (*as it was shown above in resolution of Poincare and Loshmidt paradoxes). Hence, effects of these small corrections exist only on paper in the coordinate time of ideal dynamics, but it cannot be observed *experimentally* with respect to thermodynamic time arrow of observable dynamics of the macroscopic device. So, we can conclude that Daneri-Loinger-Prosperi theorem actually results in a complete resolution (not only FAPP!) of the reduction paradox *in principle*. It proves impossibility to distinguish *experimentally* the complete and incomplete reduction.

The logic produced here strongly reminds Maccone's paper [4]. It is not surprising. Indeed, the pass from (7) to (12) corresponds to increasing of microstates number and entropy growth. And the pass from (12) in (7) corresponds to the entropy decrease. Accordingly, our statement about experimental unobservability to remainder quantum correlation is equivalent to the statement about unobservability of the entropy decrease. And it is proved by the similar methods, as in [4]. The objection [6] was made against this paper. Unfortunately, Maccone could not give the reasonable replay [28] to this objection. Here we will try to do it ourselves.

Let's define here necessary conditions.

Suppose A is our device, and C is the measured quantum system.

The first value, the mutual entropy *S (A: C)* is the coarsened entropy of ensemble (received by separation on two subsystems) excluding the ensemble entropy. As the second excluding term is constant, so *S (A: C)* describes well the behavior of macroentropy in time:

$S (A: C) = S (\rho_A) + S (\rho_C) - S (\rho_{AC})$,

Where $S = - tr (\rho \ln \rho)$,

The second value *I (A: C)* is the classical mutual information. It defines which maximum information about measured system (F_j) we can receive from indication of instrument (E_i). The more correlation exists between systems, the more information about measured system we can receive:

$I (A: C) = max_{E_i \otimes F_j} H (E_i : F_j)$, where

$H (E_i : F_j) = \Sigma_{ij} P_{ij} \log P_{ij} - \Sigma_i p_i \log p_i - \Sigma_j q_j \log q_j$

and $P_{ij} = Tr [E_i \otimes F_j \rho_{AC}]$, $p_i = \Sigma_j P_{ij}$ and $q_j = \Sigma_i P_{ij}$

given POVMs (Positive Operator Valued Measure) E_i and F_j for A and C respectively.

Maccone [4] proves an inequality

S (A: C) ≥ I (A: C) (13)

He concludes from it that entropy decrease results in reduction of the information (memory) about the system A+C and C.

But (13) contains an inequality. Correspondingly in [6] an example of the quantum system of three qubits is supplied. For this system the mutual entropy decrease is accompanied by mutual information increases. It does not contradict to (13) because mutual entropy is only up boundary for mutual information there.

Let's look what happens in our case of the macroscopic device and the measured quantum system

Before measurement (7)

$S\ (A: C) = -\sum_s p_s \log p_s + 0 + \sum_s p_s \log p_s = 0$

E_i-corresponds to the set $|\alpha_{0,s}\rangle$, F_j - $|\psi\rangle$
$I\ (A: C) = -\sum_s p_s \log p_s + 0 + \sum_s p_s \log p_s = 0 = S\ (A: C)$
In the end of measurement from (12)
$S\ (A: C) = -\sum_i |c_i|^2 \log |c_i|^2 - \sum_{s,i} |c_i|^2 p_s \log |c_i|^2 p_s + \sum_{s,i} |c_i|^2 p_s \log |c_i|^2 p_s = -\sum_i |c_i|^2 \log |c_i|^2$

E_i-corresponds to the set $|\alpha_{i,s}\rangle$, F_j - $|\psi_j\rangle$
$I\ (A: C) = -\sum_i |c_i|^2 \log |c_i|^2 - \sum_{s,i} |c_i|^2 p_s \log |c_i|^2 p_s + \sum_{s,i} |c_i|^2 p_s \log |c_i|^2 p_s =$
$-\sum_i |c_i|^2 \log |c_i|^2 = S\ (A: C)$
Thus, our case corresponds to
$I\ (A: C) = S\ (A: C)$ (14)
in (13). No problems exist for our case. It is not surprising – the equality case in (13) corresponds to macroscopic chaotic system. The system supplied by the objection [6] is not microscopic. It demonstrates the widely known fact that such *thermodynamic* concepts as the thermodynamic time arrows, the entropy increase and the measurement device concern to macroscopic chaotic systems. Both the paper [6] and the subsequent paper [7] describe not thermodynamic time arrows but, mainly, strongly fluctuating small systems. No thermodynamics is possible for such small systems as three cubits. The useful outcome of these papers is equality (14). It can be used as a *measure for macroscopicity* of chaotic quantum systems. On the other hand, the difference between mutual information and mutual entropy can be a criterion of fluctuations value.

4. Conclusion

In this paper the analysis of thermodynamic time arrow in quantum mechanics is presented. It is in many aspects similar to the classical case. The important difference of quantum systems from classical ones is that one microstate in quantum mechanics can correspond not to one macrostate but to a set of macrostates. It is referred to as quantum superposition of macrostates. For this case considering thermodynamic time arrow by means of the decohernce theory gives resolution of the quantum paradoxes. These paradoxes relate to a wave packet reduction (collapse).

Appendix A. Unpertrubative observation in quantum and classical mechanics

It is often possible to meet a statement that in classical mechanics, in principle, it is always possible to organize unpertrubative observation**.** On the other hand, in quantum mechanics interaction of the observer with the observable system at measurement is inevitable. We will show that both these statements are generally untrue.

Let us first define the nonperturbative observation [10-11, 30-31] in QM. Suppose we have some QM system in a known initial state. This initial state can be either a result of some preparation (for example, an atom comes to the ground electronic state in vacuum after long time) or a result of a measurement experiment (QM system after measurement can have a well defined state corresponding to the eigenfunction of the measured variable). We can predict further evolution of the initial wave function. So *in principle* we can make further measurements choosing measured variables in such a way that one of the eigenfunctions of the current measured variable is a current wave function of the observed system. Such measuring process can allow us the continuous observation without any perturbation of the observed quantum system. This nonperturbative observation can be easily generalized for the case of a known *mixed* initial state. Really, in this case the measured variable at each instant should correspond to such set of eigenfunctions that the density matrix in representation of this set at the same instant would be diagonal.

For example, let us consider some quantum computer. It has some well-defined initial state. An observer that known this initial state can *in principle* make the nonperturbative observation of any intermediate state of the quantum computer.

It is especially worth to note that such unpertrubative observation is possible only under condition of a known initial state. But an observer that doesn't know the initial state can not make such observation because he cannot predict the intermediate state of the quantum computer.

Let's consider now classical mechanics. Suppose that a grain of sand lies on a cone vertex. The grain of sand has *infinitesimally small* radius. The system is in the Earth field of gravity. Then attempt to observe system even with *infinitesimal perturbation* will lead to misbalance with the indefinite future through *a terminating* interval of time. Certainly, the reduced example is exotic – it corresponds to a singular potential and an infinitesimal object. Nevertheless, similar strongly labile systems are good classical analogues of quantum systems. Among them it is possible to search for analogies of quantum systems and quantum paradoxes. Having introduced a requirement that classical measuring renders very small but not zero perturbation on measured system, it is possible to lower requirements to a singularity of these systems.

Very often examples of "purely quantum paradoxes" can be met which do not ostensibly have analogy in classical mechanics. One of them is Elitzur-Vaidman paradox **[**29**]** with a bomb which can be found without its explosion:

Suppose that the wave function of one light quantum branches on two channels. In the end these channels of the waves again unite, and there is an interference of the two waves of probability. A bomb inserted into the one from the two channels will destroy the process of interference. Then it allows us to discover the bomb even for a case when the light quantum would not detonate it, having transited on other channel. (The light quantum is considered capable to detonate the bomb)

Classical analogy of this situation is the following experiment of classical mechanics:

In one of the channels where there is no bomb we throw in a macroscopic beam of many particles. In other channel where, maybe, there is the bomb, we will throw in simultaneously only one ***infinitesimally light*** *particle. Such particle is not capable to detonate the bomb but it may be thrown back out of it. If the bomb is not present the particle will transit the channel. On the exit of this channel for the bomb we will arrange the cone featured above with the grain of sand with* ***infinitesimal*** *radius on the cone vortex. If our infinitesimally light particle would throw down the grain of sand from the vertex it means that the bomb is not present. If the grain of sand would remains on the vertex after exit of particles beam from the second channel it means that the bomb is present.*

In the given example infinitesimally light particle is an analogue of an "imponderable" wave function of the light quantum. But the light quantum is sensitive to behavior of this "imponderable" wave function. Equally, the grain of sand with infinitesimal radius on the cone vertex is sensitive with respect to infinitesimally light particle.

Summing up, it is possible to say that the difference between quantum and classical systems is not as fundamental as it is usually considered.

Application B. Expansion on modes at arbitrary boundary conditions

Encountered quite often is a problem of description of radiation in a closed cavity filled by some substance. Usually it appears by decomposition of radiation on modes. These modes are a set of eigenfunctions of the wave equation for some cavity and for some boundary conditions. For example, it is a square cavity with periodical boundary conditions. Then the received radiation decomposition is substituted to the wave equation for radiation. There the modes of the series are differentiated termwise. Thus, such radiation feature as ω (k) is received. Here ω is frequency of a mode; **k** is a mode wave vector; |k | =2π/λ; λ is a mode wave length.

But here there is a purely mathematical problem. Suppose that the modes have been discovered for some shape of the cavity and for some boundary conditions. For termwise differentiability uniform convergence in all points of space is required. It is automatically true for any radiation with the same shape of a concavity and boundary conditions as modes. But for any other case it is not true. Modes are the full orthogonal set and any radiation may be presented as superposition of such modes. But generally the series converges nonuniformly (the series converges badly near cavity boundaries) and can not be termwise differentiable. The problem of possible necessity using different modes for different boundary conditions is discussed in Peierls's book **[32].** However, a case is considered there when some complete orthonormal set of modes exists for given boundary conditions. But the situation is possible that for such boundary condition no set of such modes is possible. Or the boundary conditions are not known, and only energy requirements on boundary are known. How can the problem be solved for such cases?

The point is that all perturbations in radiation are expanding with a velocity which is not exceeding the speed of light in cavity v=c. It means that any perturbation of initial conditions of radiation expands from a point x to a point x_1 only over finite time $(x-x_1)/c$. It means that perturbations from walls will reach the centre of the cavity in time t=L/c, where L is a characteristic size of the cavity. Non-uniform convergence appears only near the cavity walls. So inside the cavity far from walls the exact radiation field is almost precisely equal to the modes series during time L/c. Therefore, this field has uniform convergence and can be termwise differentiable during time L/c.

To estimate correctly frequency of a mode ω (**k**) it is necessary that its amplitude does not change essentially from walls perturbation over time t>>T. T=2π/ω(**k**) is time period of the mode. There from we receive the requirement of cavity macroscopicity:

$$2\pi/\omega << L/c$$

or

$$L >> 2\pi(c/\omega)$$

ω - correspondent to maximum of frequencies ω(**k**).

Let suppose that this condition is fulfilled.

It means that termwise differentiation of modes far from concavity walls can be made over timescales t<2π/ω=L/c.

On timescales t>L/c the outcome cannot be correct. Here the energy conservation law and the entropy increase law are usually used. By means of these laws slow evolution of amplitudes A (t, r) and phases φ(t, r) of modes can be received:

$$E(t, \mathbf{r}) = \Sigma_i A_i(t, \mathbf{r}) \sin(\omega(\mathbf{k}_i) t + \mathbf{k}_i\mathbf{r} + \varphi_i(t, \mathbf{r}))$$

For vacuum:

$$\omega(\mathbf{k}) = c|\mathbf{k}|$$
$$L >> \lambda$$

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Chapter 3.The Universal Arrow of Time: Nonquantum gravitation theory

0. Abstract: Solution of "informational paradox" for black holes and "paradox with the grandfather" for time travel "wormholes"

The paper is dealing with the analysis of general relativity theory (theory of gravitation) from the point of view of thermodynamic time arrow. Within this framework "informational paradox" for black holes and "paradox with the grandfather" for time travel "wormholes" are resolved.

1. Introduction.

In this paper we consider a thermodynamic time arrow [1-2] (defined by a direction of the entropy increase) within the limits of the non-quantum relativistic gravitation theory. In the classical Hamilton mechanics any initial and final states are possible. Besides, there is one-to-one correspondence between them. The situation is different with relativistic theory of gravitation. There are topological singularities of space which make possible a situation when for *finite* time different initial states give an identical final state. It is a collapse of black holes. On the other hand, having considered inverse process in time - white holes, we receive a situation when a single initial state can give a set of different final states for a *finite* time. There are also situations of other sort when non-arbitrary initial states are possible. It is a case of "wormholes" through which it is possible to travel in the past. Thus, there is necessity of self-consistency between the past and the future making impossible some initial states. Black Holes lead to informational paradox, and "wormholes" lead to "paradox with the grandfather". Analysis of these situations from a point of view of thermodynamical time arrow and resolution of the defined above paradoxes are a topic of this paper.

2. Black Hole

In modern cosmological models there are some phenomena additional to those featured in classical mechanics. In Einstein's relativity theory, as well as in classical mechanics, motion is reversible. But there is also an important difference from classical mechanics. It is *ambiguity* of a solution of an initial value problem: deriving a final state of a system from the complete set of initial and boundary conditions can give multiple solutions or no solution. In general relativity theory, unlike classical mechanics, two various states for *finite* time can give infinitesimally close states. It happens at formation of a black hole as a result of a collapse. Hence, formation of the black hole goes with its entropy increase.

Let's consider an inverse process featuring a white hole. In this process infinitesimally close initial states for *finite* time can give different terminating states. Time reversion leads to appearing of a white hole and results in entropy decrease. The white hole cannot exist in a reality because of the same reasons on which processes with entropy decrease are impossible in classical mechanics.

However, its instability is much stronger than instability in classical mechanics. It has finite value in respect to *infinitesimally small* perturbations. As a consequence, there are alignment of thermodynamic time arrows between the white hole and the observer/environment. The white hole transforms to a black hole for the observer. It means that the observer/environment even *infinitesimally weakly* interacting with the white hole can affect considerably its evolution for finite time. Thus the gravitational interaction of the observer/environment with the white hole is always different from zero.

There is a well-known informational paradox here **[**3**]**: the collapse leads to losses of the information in the Black Hole. It, in turn, results in incompleteness of our knowledge of a state of system and, hence, to unpredictability of dynamics of system, including Black Hole. The information which in classical mechanics always conserves in a black hole disappears for ever. Is it really so? Or, probably, it is stored in some form inside of a black hole? Usually only two answers to this problem are considered: either the information really vanishes completely; or the information is stored inside and can be extracted by some way. But, most likely, the third answer is true. Because of inevitable influence of the observer/environment it is impossible to distinguish these two situations experimentally in principle! And if it is impossible to verify something experimentally, it cannot be a topic for the science.

Actually, suppose that the information is stored in a black hole. Is it possible to resolve informational paradox and to extract this information from it? Perhaps, we can reverse a collapsed black hole, to convert it into a white hole and to extract the disappeared information? It would seem impossible. But recently an interesting paper appeared which seems allowing to make it, although indirectly [4]. It is proved that a black hole is completely equivalent to an entry to a channel coupling two Universes, and an entry of this channel is similar to the black hole, while an exit is similar to the white hole. This white hole can be considered, in some sense, as a reversed black hole. But to verify that the information does not disappear we should come into the second Universe. To do it, we need to suppose that there is some "wormhole" which connects these two Universes. Let assume that the observer can pass it and observe the white hole. But even if it happens, we know that the white hole is extremely unstable with respect to any observation. Attempts to observe it will result in its transformation into a black hole. It will close any possibility to verify that the information is stored. Hence, both solutions of informational paradox are really equivalent and observationally are not distinguishable.

This property of nonreversible information losses results in the fact that the entropy increase law turns to be an exact law of the nature within framework of the gravitational theory. Really, here appears such a new fundamental value as entropy of a black hole. It distinguishes gravitational theory from classical mechanics where the law entropy increase law has only approximate character (FAPP, for all practical purposes).

The accelerated expansion of the Universe results in the same effect of nonreversible information losses: there are unobservable fields, whence we are not reached even by light. Hence, these fields are unobservable, and the information stored in them is lost. Once again, it results in unpredictability of relativistic dynamics.

3. Time wormhole

Let us consider from the point of view of the entropy such a paradoxical object of general relativity theory as time "wormhole" **[5]**. At first we will consider the most popular variant offered by Morris and Thorne **[6].** Suppose we have a space wormhole with the extremities lying nearby. By a very simple procedure (we will place one of the extremities on a spaceship and move it with a speed close to the speed of light, and then we will return this extremity on the former place) this space wormhole can be conversed into a time wormhole (wormhole traversing space into one traversing time). It can be used as a time machine. Such wormhole demands the special exotic matter necessary for conserving its equilibrium. However, there were models of a time machine which allow dispensing absolutely without the exotic substance [7, 9]. Or, using an electromagnetic field, allow dispensing by its small amount [8]. Use of such a time machine can lead to the well-known "paradox of the grandfather" when the grandson, being returned in the past, kills his grandfather. How can this paradox be resolved?

From the physical point of view, the paradox of the grandfather means that not all initial states which exist before time machine formation are realizable. Introducing the additional feedback between the future and the past, a time wormhole makes them impossible. Hence, we either should explain non-reliability of such initial states, or suppose that time "wormhole" is unstable, like a white hole, and easily changes.

Curiously enough, but the both explanations are true. However, for macroscopic wormholes the first explanation has priority. Really, it would be desirable very much to have a macroscopic topology of the space to be stable. Constrains on initial states appears from entropy increase law and the corresponding alignment of thermodynamic time arrows related to instability of states with opposite directions of these time arrows [1-2]. But macroscopic laws of thermodynamics are probabilistic. For a very small number of cases they are not correct (large-scale fluctuations). Both for these situations and for microscopic wormholes where the concept of a thermodynamic time arrows and thermodynamics laws are not applicable, the second explanation will have priority. It is related to extreme instability of the topology which is defined by the time machine [9]. We discussed above such type of extreme instability for white holes. For macroscopic wormholes the solution can be discovered by means of the entropy increase law. It is ensured by instability of processes with the entropy decrease with respect to the Universe. This instability results in alignment of thermodynamic time arrows.

Indeed, a space wormhole does not lead to a paradox. The objects immersed by its one extremity will go out of the other extremity during later time. Thus, the objects from a more normalized low-entropy past occur in a less normalized high-entropy future. During the motion through the wormhole, the entropy of the travelling objects also increases: they transfer from a more normalized state into a less normalized one. Thus, the time arrows of the object travelling inside of the wormhole, and the time arrow of the world around the wormhole would have the same directions. It is also true for travelling through the time wormhole from the past to the future.

However, for travelling from the future to the past of the time arrow directions of the traveler into the wormhole and the world around the wormhole will already be opposite [10, 11-13]. Really, the object travels from the less normalized future to the more normalized past but its entropy increases, instead of decreasing! Hence, thermodynamic time arrows of the Universe and of the traveler will have opposite directions. Such process at which entropies of the traveler decreases concerning the Universe are unstable [1-2]. Hence, "memory about the past" of the traveler will be destroyed (and, may be, he will be destroyed completely), what will not allow him "to kill the grandfather".

Which mechanism at travelling in the wormhole ensures alignment of thermodynamic time arrows of the traveler and the Universe? Both extremities of a "wormhole" are large bodies having some finite temperature. Both extremities under the second thermodynamics laws inevitably should radiate light which partially penetrates into the wormhole. Already at the moment of formation of a "time machine" (transformation of the space wormhole into the time one), a closed light ray appears between its extremities. Every time when the ray spins a circle it gets more and more biased to a violet part of the spectrum. Passing a circle after circle, rays are lost their focal point; therefore energy does not get amplified and does not become infinite. The violet bias means that the history of a particle of light is finite and defined by its coordinate time, despite the infinite number of circles [14]. This and other rays of light in the wormhole fluctuate. They also have a direction of its thermodynamic time arrow coinciding with a thermodynamic time arrow of the Universe. Thanks to the inevitable interaction with this radiation, a very unstable state of the traveler is destroyed. The state of the traveler is unstable because his thermodynamic time arrow is opposite to the Universe thermodynamic time arrows. The resulting destruction is enough to prevent the paradox of the grandfather.

"Free will" would allow us to initiate freely only irreversible processes with the entropy increase, but not with its decrease. Thus, we cannot send an object from the future to the past. Process of alignment of thermodynamic time arrows and the correspondent entropy increase law forbids *the initial conditions* necessary for travelling of the macroscopic object to the past and resulting in the "paradox of the grandfather".

In paper **[**10**]** it is strictly mathematically proved that the thermodynamic time arrow cannot have identical orientation with the coordinate time arrow during all travel over a closed timelike curve. Process of alignment of thermodynamic time arrows (related to instability of processes with entropy decrease) is this very *physical mechanism* which actually ensures performance of the entropy increase law.

Macroscopic laws of thermodynamics are probabilistic. For a very small number of cases they do not work (large-scale fluctuations). Both for these situations and for microscopic systems where thermodynamics laws are not applicable, the other explanation of the grandfather paradox will have priority. In this case the time wormhole, like a white hole, appears unstable even with respect to infinitesimally weak perturbations from gravitation of travelling object. It can result in its fracture and prevention of the paradoxes, as is proved strictly in **[**9**]**. What are outcomes of reorganization of the space-time topology after fracture of the time wormhole? The author of [9] writes:

"As we argue … non-uniqueness does not let the time travel paradoxes into general relativity — whatever happens in a causal region, a space-time always can evolve so that to avoid any paradoxes (at the sacrifice of the time machine at a pinch). The resulting space-times sometimes … curiously remind one of the many-world pictures".

Let's formulate the final conclusion: *for macroscopic processes* instability of processes with the entropy decrease and correspondent alignment of thermodynamic time arrows makes existence of initial conditions that allow travel to the past to be almost impossible. Thereby it prevents both wormholes fracture and traveling of macroscopic bodies in the past leading to the "paradox of the grandfather".

For very improbable situations of macroscopic wormholes and for microscopic wormholes the wormhole fracture must occur. This fracture is a result of a remarkable property of general relativity theory – extreme instability: infinitesimal external action (for example, gravitation from traveler) can produce wormhole fracture for finite time!

4. Conclusions

Let's summarize the said above. A process of observation should be inevitably taken into account when examining any physical process. We must transform from ideal dynamics over coordinate time arrow to observable dynamics with respect to thermodynamic time arrow of observer. It allows us to exclude all unobservable in the reality phenomena leading to paradoxes. Thus it is necessary to consider the following things. The observer inevitably is a non-equilibrium macroscopic chaotic body with the thermodynamic time arrow defined by his entropy increase direction. He yields all measurements with respect to this thermodynamic time arrow. Dynamics of bodies with respect to this thermodynamic time arrow is referred to as observable dynamics. It differs from ideal dynamics, with respect to the coordinate time arrow. All bodies are featured in observable dynamics in macroparameters, unlike in the ideal dynamics where microparameters are used. The coordinate does not exist at thermodynamic equilibrium. It can change the direction and does not coincide with the coordinate time arrow of the ideal dynamics. There is always a small interaction between the observer and observable system. It leads to alignment of thermodynamic time arrows of the observer and the observable systems.

We can see a mysterious situation. The same reasons which have allowed us to resolve paradoxes of wave packet reduction in quantum mechanics, paradoxes of Loshmidt and Poincare in classical mechanics allow to resolve the informational paradox of black holes and the paradox of the grandfather for time wormholes. Such remarkable universality!

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Chapter 4. The Universal Arrow of Time: Quantum gravitation theory

0. Abstract: Solution of "informational paradox" for black holes, "paradox with the grandfather" for time travel "wormholes", black stars paradox, Penrose's project of new quantum gravitation theory paradoxes, anthropic principle paradox.

The paper is dealing with the analysis of quantum gravitation theory from the point of view of thermodynamic time arrow. Within this framework "informational paradox" for black holes and

"paradox with the grandfather" for time travel "wormholes", black stars, Penrose's project of new quantum gravitation theory, anthropic principle are considered.

1. Introduction

The paper includes the analysis of quantum gravitation theory from the point of view of the thermodynamic time arrow [1-3]. Within this framework "informational paradox" for black holes and "paradox of the grandfather" for time "wormholes", black stars [4] and anthropic principle [5] are considered. It is shown that wishes of Penrose [6-7] for the future theory of quantum gravitation need not creation of a new theory but can be realized within framework of already existing theories by means of the thermodynamic approach.

2. Black holes

In general relativity theory, unlike in classical mechanics, two different states for *finite* time can give infinitesimally close states. It happens during formation of a black hole as a result of its collapse. It results in the well-known informational paradox **[**8**]**: the collapse leads to losses of the information in the black hole. It results in incompleteness of our knowledge of the system state. Hence, it can leads to unpredictability of the system dynamics. The information which in classical and quantum mechanics is always conserved disappears in a black hole. Is it really so? Usually only two answers to this problem are considered: either the information really vanishes completely, or the information is conserved inside the black hole and can be extracted. We will see that in quantum gravitation we have the same answer, as in general relativity theory – both answers are possible and true because the difference is not observed experimentally.

For the semi-classical theory of gravitation where gravitation is featured by relativistic relativity theory and fields are featured by quantum field theory, resolution of the paradox is made with the help of Hawking radiation.

In quantum field theory the physical vacuum is filled by permanently appearing and disappearing "virtual particles". Close to the event horizon (but nevertheless outside it) of a black hole, pairs of particle-antiparticle can be born directly from vacuum. A situation is possible when an antiparticle total energy appears to be subzero, and a particle total energy appears to be positive. Falling to the black hole, the antiparticle reduces its total energy and mass while the particle is capable to fly away to infinity. For a remote observer it looks like Hawking radiation of the black hole.

Since this radiation is incoherent, all information accumulated inside of it disappears after evaporation of the black hole. It is an answer of the semi-classical theory. It would seem that this result contradicts to reversibility and unitarily of quantum mechanics where the information can not be lost. We would expect the same result from quantum gravitation theory. But is it really so?

We don't have now a finished theory of quantum gravitation. However, for a special case of the 5-dimentional anti-de-Sitter space this paradox is considered by many scientists to be resolved. The information is supposed to be conserved, because a hypothesis about AdS/CFT dualities, i.e. hypotheses that quantum gravitation in the 5-dimensional anti-de-Sitter space (that is with the negative cosmological term) is equivalent mathematically to a conformal field theory on a 4-surface of this world [9]. It was checked in some special cases but not proved yet in a general case.

Suppose that if this hypothesis is really true, it automatically solves the problem of information. The matter is that the conformal field theory is structurally unitary. If it is really dual to quantum gravitation then the corresponding quantum gravitation theory is unitary too. So, the information in this case is not lost.

Let's note that it not so. Taking into account the influence of the observer makes information losses inevitable. The process of black hole formation and its subsequent evaporation happens on the whole surface of the anti-de-Sitter world (described by the conformal quantum theory) which includes the observer as well. The observer inevitably gravitationally interacts with the black hole and its radiation. Unlike to the conventional quantum mechanics, all-pervading gravitational interaction exists in quantum gravitation. So, influence of the observer already cannot be made negligibly small under any requirements. Interaction with the observer makes the system not unitary, similarly to the semi-classical case.

It would seem that we can solve the problem by including the observer in the description of the system. But the observer cannot precisely know the initial state and analyze the system when he is its part! So, he cannot experimentally verify the difference between unitary and not unitary evolution. It is necessary to have complete knowledge of the system state for such verification. But it is impossible at introspection.

In the anti-de-Sitter world Universe expansion is inevitably replaced by a collapse. But the same effect information losses are available also for the accelerated expansion of the Universe - there appear unobservable parts of Universe, whence we are not reached even by light. Hence, these parts are unobservable, and the information containing in them is lost. It again results in unpredictability.

Thus, the experimental verification of the informational paradox becomes impossible *in principle* again! In case of quantum gravitation information, conservation happens only on paper in the ideal dynamics. In the real observable dynamics the difference is not observed experimentally in principle. It is possible to consider both answers to the problem to be correct. The two cases of conservation or non-conservation of information are not distinguishable experimentally.

Principal difference between the conventional quantum theory and quantum gravitation theory occurs because of inevitable gravitational interaction. In usual quantum theory interaction between an observer and an observed system can be made zero in principle at known initial conditions of the observed system. In quantum gravitational systems the small gravitational interaction with the observer is irremovable in principle: it creates principally inherent decoherence and converts evolution of any observable system into non-unitary. Only the non-observable ideal evolution on paper can be made formally unitary. But it is also possible not to make it unitary – here we have freedom to choose. If we wish to feature real observable dynamics we can put the dynamics to be non-unitary. For macrobodies such observable dynamics is quasi-classical theory. It is experimentally indistinguishable for the real macroscopic observer from unitary quantum gravitation dynamics of large black holes.

3. Time wormhole

Let us consider from the point of view of the entropy such a paradoxical object of general relativity theory as time "wormhole" **[5]**. At first we will consider the most popular variant offered by Morris and Thorne **[6].** Suppose we have a space wormhole with the extremities lying nearby. By a very simple procedure (we will place one of the extremities on a spaceship and move it with a speed close to the speed of light, and then we will return this extremity on the former place) this space wormhole can be conversed into a time wormhole (wormhole traversing space into one traversing time). It can be used as a time machine. Such wormhole demands the special exotic matter necessary for conserving its equilibrium. However, there were models of a time machine which allow dispensing absolutely without the exotic substance [7, 9]. Or, using an electromagnetic field, allow dispensing by its small amount [8]. Use of such a time machine can lead to the well-known "paradox of the grandfather" when the grandson, being returned in the past, kills his grandfather. How can this paradox be resolved?

Let's consider that the answer to this problem is given by the semi-classical theory of gravitation. Suppose that the macroscopic topology of the space related to the time machine is unchanged. At the moment of the time machine formation (transformation of the space wormhole into time one) between its extremities there is a closed light ray. Its energy does not reach infinity, despite the infinite number of passes, because of a defocusing of the light [16]. Another situation, however, arises in the semi-classical theory with a radiation field of "vacuum fluctuations" [14]. Passing the infinite number of times through the wormhole and being summed with each other, these fluctuations reach the infinite energy which will destroy any traveller.

However, the situation in quantum gravitation is different. Quantum fluctuations contain large energies when they arise on short distances. So it is possible to find so small distance on which energy of fluctuation will be large enough for formation of a tiny black hole, and the horizon of this tiny black hole will have the same size as this small distance. The space - time is not capable to remain homogeneous on such short distances. This mechanism ensures natural "blocking" of singular fluctuations formation, restricting them in their sizes: "maximum energy in minimal sizes" [16].

Detailed calculations of quantum gravitation show [15] that this "blocking" to formation of singular fluctuations provides a very small but not a zero probability of unobstructed transiting through a time "wormhole" for macroscopic object. How can the "paradox of the grandfather" be prevented in this situation? Here it is convenient for us to use the language of the multi-world interpretation of quantum mechanics. To prevent this paradox, the traveller should penetrate into the parallel world where it can easily "kill the grandfather" without breaking a causality principle. Such a parallel world will interfere quantum-mechanically with the worlds of the "not killed grandfather" where the observer was unsuccessful to transit the time wormhole. However, the probability amplitude of such the world will be extremely small. Can the observer in the world where "the grandfather is not killed" discover the alternative world at least in principle, using quantum correlations between the worlds? Similarly to "paradox of the Schrodinger cat, he cannot do it because of the same reasons as in the conventional quantum mechanics [2]. Observation of large effects of quantum correlations is impossible because of "observer's memory erasing" [1-2]. Penetration to the parallel world of quantum mechanics is experimentally indistinguishable from the time wormhole fracture and penetration to the parallel world of general relativity theory [3, 17]. It means that from the point of view of the external real macroscopic observer a situation when the traveler has perished in the wormhole or has penetrated in "another world" is observationally indistinguishable. It is equivalent to a situation when the traveller falls into a black hole. We do not know whether he is crushed in the singularity or penetrated into "the other world" through the white hole [18]. (Although this difference is observed and essential for the traveller. But he will carry away all these observations with himself into "the other world".) We see that as well as in a case of "informational paradox", the difference between quantum and semi-classical theories for macroscopic objects experimentally is not observed for the macroscopic observer which is not travelling in the time wormhole.

4. Black stars

Recently an interesting theory of "black stars" appeared [4]. Usually a collapse of a black hole is considered as a fast process. However, we don't know well states of the matter under high pressures. We know that intermediate stages such as white dwarfs or neutron stars are possible before a black hole collapse. These intermediate stages make a collapse not avalanche-like but gradual. Probably, additional intermediate stages will appear on the way to a collapse, for example, quark stars. These intermediate stages make this process to be gradual without a fast collapse at all. For classical gravitation it is incidental. The star becomes a black hole for gradual process too. But for semi-classical gravitation it is important. It can be shown that for such case at slow squeezing quantum fluctuations at a surface will prevent a star material to collapse to a singularity and to become a black hole. Outside, this object would be similar to a black hole but inside it would be different, conserving all information without singularity. It will allow for a traveller to penetrate through its surface and to come back. It is worth to note that there is a considerable objection against such picture.

How stable is such construction of a star with respect to the external perturbation imported by the traveller? Also how stable is the traveller during such travel? The traveller is a macroscopic body. After penetration to a black star, he will increase its mass stepwise at finite value. It can results in its collapse to a black hole. Suppose that the process again goes "gradually" without collapse. Then the traveller "would be dissolved" into the star and cannot come back as well. Thus, it seems that the difference between a black star and a black hole can not be observed experimentally. So, it means that the difference between these objects exists only on paper, i.e. in ideal dynamics.

5. Penrose's project of new quantum gravity theory

In his remarkable books [6-7] Penrose gives a remarkable prediction of the future theory of quantum gravitation. In this theory:

1) Unlike to usual quantum mechanics, wave packet reduction is a fundamental property of the theory.
2) This reduction is inseparably linked with the phenomenon of gravitation.
3) The reduction leads not only to probabilistic laws but can lead to some more complex uncertain behavior that can not be predicted even by a probability law.
4) Unlike to remarkable coherent quantum systems, classical chaotic non-equilibrium systems are exposed to criticism. They are supposed to be not relevant for modelling of real complex systems. The unpredictable systems described above must be only pure quantum system.

It is worth to note that we need not a new theory for receiving all these properties. Let's take into account an inevitable gravitational interaction of the macroscopic real observer and his thermodynamic time arrow. It results in all described above outcomes within framework of already existing theories of quantum gravitation. Besides, classical chaotic non-equilibrium systems possess all properties of quantum ones. For any "purely quantum effect" it is always possible to discover such classical analogue (Appendix A [2]). Namely:

1) We saw above that an inevitable gravitational interaction of a macroscopic real observer with an unstable observable system inevitably makes evolution of the observable system non-unitary. The difference between the unitary and non-unitary theory exists only on paper and is not observed experimentally in quantum gravitation theory.
2) Because of the reasons stated above the gravitation interaction results in the inevitable reduction and correspondent non-unitarity in framework of the current quantum gravitation theory. Moreover, for macroscopic objects the semiclassical theory is already possessing desirable fundamental property of non-unitary. It is experimentally equivalent to the quantum gravitation theory.
3) Behavior of many macroscopic bodies, in spite of non-unitarity, can be described completely by a set of macroparameters and laws of their evolution. There are, however, *unpredictable* systems whose behavior cannot be described completely even by probability laws.

For example, let us consider quantum computers. Suppose that some person started such a quantum computer and knows its initial state. Its behavior is completely predicted by such person. However, for the second person who is not present at start, its behavior is *uncertain* and *unpredictable*. Moreover, an attempt of the second person to observe some intermediate state of the quantum computer would result in destroying its normal operation.

In case of quantum gravitation even the person who started quantum computer cannot predict its behavior. Indeed, the inevitable gravitational interaction between the person and the quantum

computer will make such prediction impossible. Thus, "the unpredictability which is distinct from a probability law" becomes a fundamental property of any quantum gravitation theory.
4) Unstable classical systems in many aspects remind on the properties of the quantum system (Appendix A [2]). Moreover, mathematical models of classical analogues of quantum computers exist [19]. Some paradoxical properties of the life objects reminding quantum computers can be modelled by classical unstable systems [20].

Summing up, we can see that all wishes of Penrose are realizable within the framework of the existing paradigm and there is no need in any new fundamental theory. Moreover, all properties of macroobjects are usually described by macroparameters to exclude influence of the macroscopic observer. That inevitably results in unobservability of too small intervals of time and space. So it is possible to construct their observable dynamics on basis of "discrete model of space-time". But such dynamics would not be a new theory. For any macroscopic observer the dynamics would be experimentally indistinguishable from the current quantum theory of gravitation.

6. Anthropic principle in quantum gravity theory

The number of possible vacuum states in quantum gravitation theory is equal to a very large value. For a selection of suitable vacuums anthropic principle is usually used [5]. It means that evolution of the system should result in appearing an observer which is capable to observe the Universe. But such formulation is of too philosophical nature. It is difficult to use it in practice. We can formulate here more accurate physical principles which are equivalent to the anthropic principle:

The initial state of the Universe should result in formation of its substance in the form of a set of many macroscopic non-equilibrium objects weakly interacting with each other. These objects should have entropy and temperature. They should have thermodynamic time arrows. Small local interaction between objects should result in alignment of thermodynamic time arrows. Though these objects consist of many particles and are described by a huge set of microparameters, evolution of these objects can be described by a set of macroparameters, except for rare instable state.

However, these unstable states play an important role, forming a basis for origin of an observer in the Universe. There should be unstable global correlations between parts of the Universe and non-equilibrium macrosystems with local interior correlations which are the origin of the observer.

We can conclude here: to get the situation described above, the initial state of the Universe should be highly ordered and possees the low entropy.

I.e., in short, evolution should result in the world that can be described in the thermodynamic form [1-3, 21-23]. Only such the world can be the origin of an observer who is capable to study this world.

7. Conclusions

We see that the informational paradox and the paradox of the grandfather are resolved in the quantum gravitational theory very similarly to those in the non-quantum general relativity theory. It is realized by consideration of weak interaction of systems with the real non-equilibrium macroscopic observer. Moreover, this approach (similarly to usual quantum theory) allows resolving the wave packet reduction problem. But this reduction in quantum gravitation becomes a fundamental property of the theory, unlike in the case of conventional quantum mechanics. Such approach allows considering other complicated questions of quantum gravitation – anthropic principle, black stars.

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Chapter 5. The Universal Arrow of Time: Unpredictable dynamics

0. Abstract: Solution of the paradox about contradiction between reductionism and principal (not defined by complexity) emergence on basis Gödel-like theorem; Solution of the paradox about the existence of the systems with entropy decrease.

We see that exact equations of quantum and classical mechanics describe ideal dynamics which is reversible and leads to Poincare's returns. Real equations of physics describing observable dynamics, for example, master equations of statistical mechanics, hydrodynamic equations of viscous fluid, Boltzmann equation in thermodynamics, and the entropy increase law in the isolated systems are irreversible and exclude Poincare's returns to the initial state. Besides, these equations describe systems in terms of macroparameters or phase distribution functions of microparameters. There are two reasons of such differences between ideal and observable dynamics. Firstly, there is uncontrollable noise from the external observer. Secondly, when the observer is included into described system (introspection) the complete self-description of a state of such full system is impossible. Besides, introspection is possible during finite time when the thermodynamic time arrow of the observer exists and does not change the direction. Not in all cases ideal dynamics broken by external noise (or being incomplete at introspection) can be changed to predictable observable dynamics. For many systems introduction of macroparameters that allow exhaustive describing of dynamics of the system is impossible. Their dynamics becomes unpredictable in principle, sometimes even unpredictable by the probabilistic way. We will refer to dynamics describing such system as *unpredictable dynamics*. As follows from the definition of such systems, it is impossible to introduce a complete set of macroparameters for *unpredictable dynamics*. (Such set of macroparameters for observable dynamics allowed predicting their behavior by a complete way.) Dynamics of unpredictable systems is not described and not predicted *by scientific* methods. Thus, **the science itself puts boundaries for its applicability.** But such systems can *intuitively* "understand itself" and "predict" the behavior "of its own" or even "communicate with each other" at *intuitive* level.

1. Introduction

Let's give definitions of *observed and ideal dynamics* [1-4], and also explain necessity of introduction of observable dynamics. We will refer to exact laws of quantum or classical mechanics as to ideal dynamics. Why have we named them ideal? Because for the most of real systems the entropy increase law or wave packet reduction in the quantum case are observed. These properties contradict with laws of ideal dynamics. Ideal dynamics is reversible and includes Poincare's returns. It is not observed in irreversible observable dynamics. Where does this inconsistency between these kinds of dynamics come from?

The real observer is always a macroscopic system far from thermodynamic equilibrium. It possesses a thermodynamic time arrow of its own which exists for a finite time (until the equilibrium is reached) and can change its direction. Besides, there is a small interaction of the observer with the observable system which results in alignment of thermodynamic time arrows and, in case of quantum mechanics, in wave packet reduction.

The observer describes the observable system in terms of macroparameters and corresponding thermodynamic time arrow. It also results in the difference of observable dynamics and ideal dynamics. The ideal dynamics is formulated with respect to the abstract coordinate time in terms of microparameters.

Violations of ideal dynamics are related to either openness of measured systems (i.e. it can be explained by influence of environment/observer) or impossibility of self-measuring at introspection (for the full closed physical systems including both the environment and the observer). What is it possible to do for such cases? The real system is either open or incomplete, i.e. we cannot use physics for prediction of the system evolution? Not at all!

Lots of such systems can be described by equations of exact or probabilistic dynamics, despite openness or incompleteness of description. We name it observable dynamics. The most of equations in physics – master equations of statistical mechanics, hydrodynamic equation of viscous fluid, Boltzmann equation in thermodynamics, and the entropy increase law – are equations of observable dynamics.

To possess the property specified above observable dynamics should meet certain requirements. It cannot operate with the full set of microvariables. In observable dynamics we use much smaller number of macrovariables which are some functions of microvariables. It makes the dynamics much more stable with respect to errors of initial conditions and external noise. Really, a microstate change does not result inevitably in a macrostate change, as one macrostate is correspondent to a huge set of microstates. For example, in case of gas such macrovariables are density, pressure, temperature and entropy. Microvariables are velocities and coordinates of all its molecules.

How can we get observable dynamics from ideal dynamics? It can be got either by insertion to equations of the ideal equations of small external noise, or insertion of errors to an initial state. Errors/noise should be large enough to break effects unobservable in reality. It is reversibility of motion or Poincare's returns. On the other hand, they should be small enough not to influence observable processes with entropy increase.

For the complete physical system including the observer, observable system and a surrounding medium, Observable Dynamics is not falsifiable in Popper's sense [36] (under condition of fidelity of Ideal Dynamics). I.e. the difference between Ideal and Observable Dynamics in this case cannot be observed in experiment.

However, there are cases when it is not possible to find any observable dynamics. The system are unpredictable, because of either openness or description incompleteness. It is a case of *unpredictable dynamics* [21, 29-33] considered here.

2. Unpredictable dynamics

Let's introduce the concept of *synergetic models* [10]. We will name so simple physical or mathematical systems. Such systems illustrate in a simple form some real or supposed properties of unpredictable and complex (living) systems.

Unpredictable systems, as a result of its unpredictability, are extremely unstable with respect to external observation or thermal noise. To prevent their chaotization, they should have some protection from external influence.

Therefore, we are mainly interested in synergetic models of systems that are capable to protect itself from external noise (from decoherence in quantum mechanics). They conserve internal correlations (quantum or classical), resulting in reversibility or Poincare's returns. They also can conserve correlations with the surrounding world.

There are three methods for such protection:

1) The passive method - creation of some "walls" or shells impenetrable for noise. It is also possible to keep such systems at very low temperatures. Many models of quantum computers may serve as an example.

2) The active method, inverse to passive - complex dissipative or living systems, they conserve disequilibrium by the help of active interaction and interchanging of energy and substance with environment (metabolism). It is thought that the future models of quantum computers should correspond to this field.

3) When correlations cover the whole Universe. The external source of noise is absent here. Origin of correlations over Universe is that Universe was in low entropy initial states. Universe appeared from Big Bang. We will name these correlations as global correlations. Sometimes it is figuratively named "holographic model of Universe".

The following facts ought to be noted:

1) Many complex systems during evolution pass dynamic bifurcation points when there are several alternative ways of future evolution. The selection of one of them depends on the slightest fluctuations of the system state in the bifurcation point [5-6]. In these points even weak correlations can have huge influence on future. These correlations define one from alternative ways of future evolution specified above. Presence of such correlations restricts predictive force of the Science, but it does not restrict at all our personal intuition. Since we are an integral part of our Universe we are capable at some subjective level to "feel" these correlations inaccessible for scientific observation. No contradiction with current physics exists here.
2) In the described unobservable systems the entropy decrease is often observed or they are supported at a very low-entropy state. It does not contradict to the second thermodynamics law of the entropy decrease. Really, for creation of both passive and the active protection huge negoentropy from environment is necessary. Therefore the total entropy of system and an environment only increase. The entropy increase law remains correct for a full system (observable system + an environment + the observer) though it is untrue for the observable system. Entropy decrease in the full system can happen, for example Poincare's returns. But they are unobservable [1-4]. Therefore, we can skip them.
3) Existence of many unpredictable systems is accompanied by the entropy decrease (It does not contradict to the entropy increase according to the second law of thermodynamics as it is explained above in the third item). Thus, existence of such systems corresponds to the generalized principle of Le-Shatelie - Brown: the system hinders with any modification of the state caused both by external action, and internal processes, or, otherwise, any modification of a state of the system caused both by external and internal reasons, generates in the system the processes guided on reducing this modification. In this case the entropy growth generates appearance of systems cause the entropy decrease.
4) Often maximum entropy production principle (MaxEPP) demonstrates correct results [38]. According to this principle, the non-equilibrium system to aspire to a state at which entropy growth in system would be maximal. Despite the apparent inconsistency, MaxEPP does not contradict to Prigogine's minimum entropy production principle (MinEPP) for linear non-equilibrium systems [38]. These are absolutely different variation principles. Though for both cases the extreme of the same function (the entropy production) is looked for, but various restrictions and various parameters of a variation are thus used. It is not necessary to oppose these principles, as they are applicable to various stages of evolution of non-equilibrium system. MaxEPP means that dissipative unpredictable systems (including living systems), being in the closed system with finite volume, accelerate appearance of thermodynamic equilibrium for this system. It means that they also reduce Poincare's return time, i.e. promote faster return to the low-entropy state. It again corresponds to the generalized principle of Le-Shatelie - Brown: the entropy growth generates appearance of systems cause the entropy decrease. From all the above-stated it is possible to give a very interesting conclusion: *global "purpose" of dissipative systems (including living systems) is (a) minimization of their own entropy (b) stimulation of the global full system to faster Poincare's return to the initial low-entropy state.*
5) Global correlations generally "spread" over a closed system with the finite volume and result only in Poincare's unobservable return [1-4]. However, in the presence of objects conserving local correlations, global correlations can become apparent in correlation between such objects with each other and around the world. Thus, presence of conserved local correlations allows making global correlations to be observable, preventing their full "spreading" over the system.

6) The correct definition of thermodynamic macroscopic entropy is a very difficult problem for complex physical systems without local equilibrium [39].
7) Very important facts ought to be noted. Unstable correlations exist not only in quantum but also in classical mechanics. Hence, such models should not have only quantum character. They can be also classical! Very often it is wrongly stated that only the quantum mechanics have such properties **[11-12].** However**,** it is not so **[7-9].** Introduction of small, but finite interaction by "hands" during classical measurement and small errors of an initial state erases the difference between properties of quantum and classical mechanics (in the presence of unstable correlations of microstates).

3. Synergetic models of local correlations

Let's consider examples of synergetic models of unpredictable systems using the passive or active methods for protection from noise.

1) There are exceptional cases for which there is no alignment of thermodynamic time arrows [12-13].

2) Phase transition or bifurcation points. In such points (some instance for evolution or some value for external parameter) a macroscopic system described by observable dynamics can be transformed not to single but to several macroscopic states. That is, observable dynamics loses the unambiguity in these points. There are huge macroscopic fluctuations in these points, and used macroparameters does not result in predictability of the system. Evolution becomes unpredictable, i.e. there is unpredictable dynamics.

3) Let's take a quantum microscopic or mesoscopic system described by ideal dynamics and isolated from decohernece. Its dynamics depends on uncontrollable microscopic *quantum correlations*. These correlations are very unstable and can disappear as a result of decoherence (entangling with environment/observer). For example, let us consider a quantum system. Suppose that some person knows its initial and final states only. Its behavior is completely predicted by such person. In the time interval between the start and finish the system is isolated from the environment/observer. In that case these microscopic correlations do not disappear and influence dynamics. However, for the second person who is not present at start, its behavior is *uncertain* and *unpredictable*. Moreover, an attempt of the second person to observe some intermediate state of the quantum computer would result in destroying its normal operation. I.e. from the point of view of such observer, this is unpredictable dynamics. Well-known examples of such systems are *quantum computers* and *quantum cryptographic transmitting systems* **[14-15].**

Quantum computers are unpredictable for any observer who does not know its state in the beginning of calculations. Any attempt of such observer to measure the intermediate state of a quantum computer during calculation destroys calculation process in unpredictable way. Its other important property is high parallelism of calculation. It is a consequence of QM laws of linearity. Initial state can be chosen as the sum of many possible initial states of "quantum bits of the information". Because of QM laws of linearity all components of this sum can evolve in independent way. This parallelism allows solving very quickly many important problems which usual computers cannot solve in real time. It gives rise to large hopefulness about future practical use of quantum computers.

Quantum cryptographic transmitting systems use property of the unpredictability and unobservability of "messages" that cannot be read during transmitting by any external observer. Really, these "messages" are usual quantum systems featured by quantum laws and quantum correlations. An external observer which has no information about its initial states and tries make measuring (reading) of a "message" in course of transmission inevitably destroy this transmission. Thus, message interception appears *principally* impossible under laws of physics.

4) It should be emphasized that, contrary to the widespread opinion, both quantum computers and quantum cryptography **[14-15]** have classical analogues. Really, in classical systems, unlike in quantum systems, measuring can be made precisely in principle without any distortion of the measured state. However, in classical chaotic systems too there are uncontrollable and unstable microscopic additional correlations resulting in reversibility and Poincare's returns. Introducing some small finite perturbation or initial state errors "by hands" destroys these correlations and erases this principal difference between classical and quantum system behavior. Such small external noise from environment always exists in any real system. By isolation of chaotic classical systems from this external noise we obtain classical analogues of isolated quantum devices with quantum correlations.

There exist synergetic models of the classical computers which ensure, like quantum computers, huge parallelism of calculations **[7].**

Analogues of quantum computers are molecular computers **[9]**. The huge number of molecules ensures parallelism of evaluations. The unstable microscopic additional correlations (resulting in reversibility and returns) ensure dynamics of intermediate states to be unpredictable for the external observer which is not informed about the computer initial state. He would destroy computer calculation during attempt to measure some intermediate state. .

Similar arguments can be used for classical cryptographic transmitting systems using these classical unstable microscopic additional correlations for information transition. "Message" is some classical system that is chaotic in intermediate states. So any attempt to intercept it inevitably destroys it similarly to QM case.

5) Conservation of unstable microscopic correlations can be ensured not only by passive isolation from an environment and the observer but also by active dynamic mechanism of perturbations cancelling. It happens in so-called physical **stationary systems** in which steady state is supported by continuous **stream of energy or substance through system**. An example is a micromaser **[16]** - a small and well conducting cavity with electromagnetic radiation inside. The size of a cavity is so small that radiation is necessary to consider with the help of QM. Radiation damps because of interaction with conducting cavity walls. This system is well featured by density matrix in base energy eigenfunction. Such a set is the best choose for observable dynamics. Microscopic correlations correspond to non-diagonal elements of the density matrix. Non-diagonal elements converge to zero much faster than diagonal ones during radiation damping. In other words, decoherence time is much less than relaxation time. However, a beam of excited particles, passing through a micromaser, leads to the strong damping deceleration of density matrix non-diagonal elements (microcorrelations). It also leads to non-zero radiation in steady state.

Also, in the theory of quantum computers methods of the active protection are developed. These methods protect quantum correlations from decoherence. They are capable to conserve correlations as long as desired, by iterating cycles of active quantum error correction. Repetition code in quantum information is not possible due to the no-cloning theorem. Peter Shor was first to discover the method of formulating a quantum error correcting code by storing the information of one qubit onto a highly-entangled state of nine qubits [17].

6) In physics a macrostate is usually considered as some passive function of a microstate. However, it is possible to consider a case when the system observes (measures) both its macrostate and an environment macrostate. The result of the observation (measurement) is recorded into the microscopic "memory". By such a way the feedback appears between macrostates and microstates.

An example of very complex stationary systems is living systems. Their states are very far from thermodynamic equilibrium and extremely complex. These systems are highly ordered but their order is strongly different from order of a lifeless periodical crystal. Low entropy disequilibrium of live beings is supported by entropy growth in environment[1]. It is metabolism -

[1] *Entropy of the Sun grows in such a way, for example. It is an energy source for life on the Earth.*

the continuous stream of substance and energy through a live organism. On the other hand, not only metabolism supports disequilibrium, this disequilibrium is itself a catalytic agent of metabolic process, i.e. creates and supports it at a necessary level. As the state of live systems is strongly non-equilibrium, it can support existing unstable microcorrelations, preventing to decoherence. These correlations can be both between parts of a live system and between different live systems (or live systems with lifeless systems). If it happens dynamics of the live system can be referred to as unpredictable dynamics. Huge successes of the molecular biology allow describing very well dynamics of live systems. But there is no proof that we are capable to feature completely all very complex processes in the live system.

It is difficult enough to analyze real living systems within framework of concepts of ideal, observed and unpredictable dynamics because of their huge complexity. But it is possible to construct simple mathematical models. It is, for example, non-equilibrium stationary systems with metabolism. It would allow us to understand a possible role of all of three types of dynamics for such systems. These models can be both quantum [11-12, 18-20, 35] and classical [7-9].

7) The cases described above do not characterize all multiplicity of unpredictable types of dynamics. Exact conditions at which ideal dynamics transfers in observable and unpredictable dynamics present a problem which is not solved completely for mathematics and physics yet. The role of these three types of dynamics for complex stationary systems is an unsolved problem too (being related to the previous problem). The solution of these problems will allow understanding physical principles of life more deeply.

4. Synergetic models of global correlations expanded over the whole Universe

With the help of synergetic “toy” models it is possible to understand synchronicity[2] (simultaneity) of processes causally not connected [37], and also to illustrate a phenomenon of global correlations.

Global correlations of the Universe and the definition of life as the totality of systems maintaining correlation in contrast to the external noise is a reasonable explanation of the mysterious silence of Cosmos, i.e. the absence of signals from other intelligent worlds. All parts of the universe having the unique center of origin (Big Bang) are correlated, and life maintains these correlations which are at the base of its existence. Therefore, the emergence of life in different parts of the Universe is correlated, so that all the civilizations have roughly the same level of development, and there aren’t just any supercivilizations capable of somehow reaching the Earth.

Blow up systems

[2] The study was conducted by Russian specialists under guidance of Valeri Isakov, a mathematician who specializes in paranormal phenomena. They were not able to obtain data from domestic flights, so the researchers used Western statistics. As it turned out over the past 20 years, flights which ended in disaster were refused by passengers by 18% more in number than in case of normally ended flights. "We are just mathematics who revealed a clear statistical anomaly. But mystically-minded people may well associate it with the existence of some higher power"- quoted Isakov, "Komsomolskaya Pravda".
http://mysouth.su/2011/06/scientists-have-proved-the-existence-of-guardian-angels/;
http://kp.ru/daily/25707/908213/
“That was Staunton’s theory, and the computer bore him out. In cases where planes or trains crash, the vehicles are running at 61 percent capacity, as regards passenger loads. In cases where they don’t, the vehicles are running at 76 per cent capacity. That’s a difference of 15 percent over a large computer run, and that sort of across-the-board deviation is significant. Staunton points out that, statistically speaking, a 3 percent deviation would be food for thought, and he’s right. It’s an anomaly the size of Texas. Staunton’s deduction was that people know which planes and trains are going to crash… that they are unconsciously predicting the future."
Stephen King, "The Stand" (1990)

Examples are non-stationary systems with "blow up" **[6, 22-25]** considered by Kurdumov's school. In these processes a function on plane is defined. Its dynamics is described by the non-linear equation, similar to the equation of burning:

$$\partial\rho / \partial t = f(\rho) + \partial / \partial r\,(H(\rho)\,\partial\rho / \partial r), \qquad \text{(I)}$$

where ρ - density, $N = \int \rho\, dr$, r - space coordinate, t - time coordinate, $f(\rho)$, $H(\rho)$ - non-linear connections:

$f(\rho) \to \rho^{\beta}, H(\rho) \to \rho^{\sigma}$,

These equations have a set of dynamic solutions named solutions with "blow up". It was proved localization of processes in the form of structures (at $\beta > \sigma + 1$) with discrete spectrum. The structures can be simple (with individual maximums of different intensity). They also can be complex (united simple structures) with different space forms and several maximums of different intensity. It is shown that the non-linear dissipative medium potentially contains a spectrum of such various structures-attractors. Let (r, φ) be polar coordinates.

$$\rho(r,\varphi,t) = g(t)\Theta_i(\xi,\varphi), \quad \xi = \frac{r}{\psi(t)}, \quad 1 < i < N$$

$$g(t) = \left(1 - \frac{t}{\tau}\right)^{-\frac{1}{\beta-1}}, \quad \psi(t) = \left(1 - \frac{t}{\tau}\right)^{\frac{\beta-\sigma-1}{\beta-1}}$$

Number of eigenfunctions:

$$N = \frac{\beta - 1}{\beta - \sigma - 1}$$

For these solutions a value of function can converge to infinity for *finite* time τ. It is interesting that the function reaches infinity in all maximums in the same instant, i.e. is synchronous. In process of converging to time τ the solution "shrinks", the maximums "blow up" and moves to a common centre. Approximately at the moment of 0.9τ the system becomes unstable, and fluctuations of the initial condition can destroy the solution. For high correlated initial condition it is possible to reduce these fluctuations to as small values as desired.

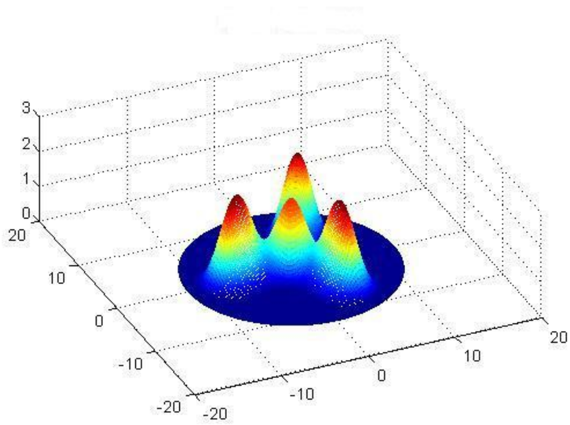

Fig. 1. From [35]. It is one of structures-attractors of the equation of burning (I) in the form of the solution with "blow up".

By means of such models we can illustrate the population growth (or level of engineering development of civilizations) in megacities of our planet **[25].** Points of maximum of function ρ are megacities, and population density is a value of the function ρ.

It is possible to spread this model to the whole Universe. Then the points of maximum are civilizations, and population density of civilizations (or level of engineering development of civilizations) is a value of the function ρ. For this purpose we will make the model more complicated. Suppose that at the moment when process starts to go out on a growing asymptotic solution there is very fast expansion ("inflation") of the plane in which process with "blow up" runs. Nevertheless, processes of converging to infinity remain synchronous and are featured by the equation of the same type (only with the changed scale), in spite of the fact that maximums are distant at large intervals.

This complicated model is capable to explain the qualitative synchronism of processes in very far parts of our Universe as a result of “inflation” after Big Bang. The high degree of global correlations reduces the fluctuations leading to destruction of the solution structure. These global correlations are modelling coherence of parts of our Universe.

Processes with "blow up" appear with necessary completeness and complexity only for some narrow set of coefficients of the equation (I). ($N >> 1$, $\beta > \sigma + 1$, $\beta \approx \sigma + 1$ is a necessary condition for appearance of a structure with large number of maximums and their slow coming to the common center). It allows drawing an analogy with “anthropic principle” **[26].** The anthropic principle states that the fundamental constants of the Universe have such values that a result of Universe’s evolution is our Universe with anthropic “beings” capable to observe the Universe.

One more fact is worth mentioning: if we want that the ordered state in the model would not be destroyed at $t=0.9\tau$, and would continue to exist as long as possible then exact adjustment is required *not only for model parameters, but also for an initial state*. It is necessary that fluctuations arising from the initial state would not destroy orderliness as long as possible. And the presence of this rare exclusive state can be also explained by the anthropic principle.

“Cellular” model of Universe

It is also interesting to illustrate the complex processes by means of "cellular" model. Discrete Hopfield’s model [27-28] can be used as a good basis. This model can be interpreted as a neural network with a feedback or as a spin lattice (a spin glass) with unequal interactions between spins. Such systems are used for recognition of a pattern.

This system can be featured as a square two-dimensional lattice of meshes *NxN* which can be either black or white ($S_i=\pm 1$). Coefficients of linear interaction between meshes J_{ji} are unequal for different pairs of meshes. They can be chosen so that in the process of discrete evolution the overwhelming majority of initial states would transfer in one of possible final states. This set of final states (attractors) can be chosen and defined “by hands”.

$$S_i(t+1) = sign\left[\sum_{j=1}^{N} J_{ij} S_j(t)\right],\ 1 \le i \le N$$

$$J_{ij} = J_{ji},\ J_{kk} = 0\ \ 1 \le i, j, k \le N$$

Attractors correspond to energy *E* minimum:

$$E = -\frac{1}{2}\sum_{i=1}^{N}\sum_{j=1}^{N} J_{ij} S_i S_j$$

Let choose lattice attractors to be letters A or B.

There are such two initial unstable states which differ by one mesh only (*a critical element*). Thus, one of them has a state as A attractor, and another as B attractor. Such unstable initial states clearly illustrate a property of the *global instability* of a complex system. This instability is inherent in a system as a whole, not in its some part. Only some external observer can change the value of the critical element and vary the system evolution. Internal dynamics of the system cannot do it. *Global correlation* between meshes of an unstable initial state defines completely a final attractor (A or B) of the lattice.

It is possible to complicate the model. Let suppose that each mesh in the lattice featured above is such a sub-lattice. We will define evolution of such composite lattice going to two stages.

At the first stage large meshes do not interact. Interaction exists only in sub-lattices. This interaction is the same as for the one-stage model featured above. Coefficients of the linear interaction between meshes are chosen so that attractors, as well as its was observed before, are letters A or B. Initial states of all sub-lattices can be chosen as unstable and containing the critical element. We will perceive the final state A of sub-lattices as a black mesh for a large lattice, and the state B of sub-lattices – as a white mesh.

The second stage of evolution is defined as evolution of this large lattice over the same way as in the one-stage model featured above. The initial state of the large lattice is defined by the first stage. This initial state, appearing at the first stage, is also unstable and contains the critical element. For final state of the large lattice to each black mesh, we will appropriate state A of the sub-lattices, and for each white mesh we will appropriate state B of the sub-lattices.

The initial state of the composite lattice can be chosen always so that an attractor of the two-stage process will be A. For every mesh included to A, the sub-lattice state also corresponds to A. Let's name this state of the composite lattice as "A-A". Then this very final attractor can be explained by:

a) global correlations of the unstable initial state

b) specific selection of all coefficients of interaction between meshes.

Let's make the model even more complicated. Similarly to the aforesaid, we will make this lattice not two-level but three-level, and the process will be three-stage instead of two-stage. A final state will be "A-A-A".

Let's suppose that prior beginning of the aforementioned three-stage process our composite lattice was occupying a very small field of physical space. But as a result of expansion ("inflation") it was dilated to a huge size. Then the aforementioned three-stage process was begun. Thus, it is possible to explain presence of the unstable correlation of the initial state of the composite lattice leading to a total state "A-A-A". Indeed, before "inflation" all meshes were closed by each other. So the unstable initial correlation can be easily formed under such conditions.

This three-level composite lattice can be compared to our Universe. Its smallest sub-lattices "A" can be compared to "intelligent organisms". Lack of their interaction with the environment at the first stage (before formation of the final state "A") is equivalent to the active or passive protection of internal correlations from external noise. Lattices of the second level in state "A-A" correspond to "civilizations" organized by "intelligent organisms" ("A") at the second stage. At the third stage, "supercivilization" ("A-A-A") is formed by "civilizations" ("A-A").

Then global correlations of the unstable initial state of the composite lattice can serve as analogues of the possible global correlations of the unstable initial state of our Universe existed before its inflation. Coefficients of interaction of the meshes correspond to the fundamental constants of our Universe. The initial process of the lattice expansion (before its three-stage evolutions) corresponds to Big Bang. The specific selection of interaction coefficients between the meshes leading to the asymptotic state "A-A-A", and the initial correlations can be explained by "anthropic principle". Here we remind that the anthropic principle states that the fundamental constants of the Universe have such values that the result of Universe's evolution is our Universe with anthropic "beings" capable to observe the Universe.

5. Conclusions

The phenomenon existence of unpredictable complex (including living) systems is considered in the paper.

It is shown, that though existence of such systems, apparently, contradicts to the entropy increasing law, and actually does not lead to the real contradiction with it. Indeed, for existence of such systems in the real world the very specific boundary conditions are necessary. The entropy increase for making of such requirements in real external world much more exceeds the entropy decrease observed inside such systems.

The possibility of the proof of the Gödel-like theorem for such systems is shown. It means that reductionism (reducibility of the complex system's behavior to fundamental physics laws) does not contradict to existence of the principal emergency. The principal emergency is the existence of principal unpredictability of complex system's behavior on the basis of fundamental physics laws. This emergency is not result of a system complexity only.

It is shown, that this unpredictability is closely connected to existence of the complex correlations both inside these composite systems, and with around world. Simple mathematical models, illustrating the principal possibility of such correlations are constructed.

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Chapter 6. The Universal Arrow of Time: Future of artificial intelligence – Art, not Science or Practical Application of Unpredictable Systems

0. Abstract: Solution of Unpredictability paradox – Unpredictable does not mean Uncontrolled

Perspective of the future of artificial intellect (AI) is considered. It is shown that AI development in the future will be closer rather to art than to science. Complex dissipative systems whose

behavior cannot be understood completely in principle will be the basis of AI. Nevertheless, it will not be a barrier for their practical use.

1. Introduction

Nowadays technologies relating to design of systems of artificial intellect (AI) are actively developed in the world. In this paper we would like to consider not tactical but strategic problems of this process. Interesting papers on this topic are few now, but they exist [1]. It is due to the fact that most of serious experts are occupied with solving tactical problems and often does not think about farther prospects. However, the situation at the beginning of cybernetics origin was not like that. In those days these problems were actively considered. Therefore, we will construct our paper as a review of problems of cybernetics as they were seen to participants of the symposium in 1961 [2]. We will try to give the review of these prospects from the point of view of the up-to-date physical and cybernetic science and its latest achievements.

2. Analysis of problems

The principal strategic direction in 1961 has been set by lecture of Stafford Beer "On the way to a cybernetic factory". He sees a control system as some black box with a large quantity of internal states. Depending on internal states of the black box, different functions are carried out linking its input and output. Among all these functions some optimal function exists. This function realizes its operation by optimal way according to some measure of optimality. The feedback will be organized between an output of the factory and internal state of the black box ensuring optimality of search of the internal state.

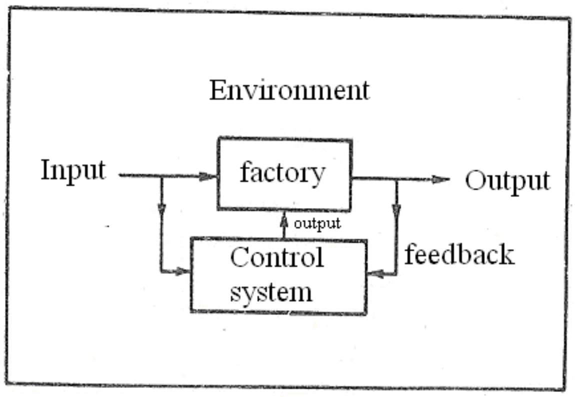

Figure 1. Diagram of control of a factory.

Here the following three difficulties arise:

1) It is clear that the number of internal states of such black box should be huge to ensure realization of all possible functions. For this purpose the author suggests to use some block of the substance, possessing huge number of internal states at atomic level. It is something, for example, like the colloid system of Gordon Pask. This system realizes reversion of matrixes of the astronomical order.
2) Space of search of such box is huge and the search over all possible internal states is not real for reasonable time. Therefore, the strategy which would allow discovering not the most optimum solutions but at least just "good" is necessary. At present such strategy is named as "genetic algorithm" [3] supplied *with the random generator*. Also the method of heuristics is

widely used. [4] It is a set of empirical recipes for the search of optimum between the internal states. They are either found from the previous experience or defined by the external expert.
3) Criteria of optimality cannot be formulated accurately for all cases. Therefore, we may take for the "purpose" of such box its physical "survival". Then it will search for such criteria itself, or its operations would be estimated by some external expert.

In the specified solutions of problems there is one very basic difficulty. Let our black box has n binary inputs and one binary output. Then number of all possible internal states of box is 2^{2^n}. How large is this number? The answer is given by D.G. Willis in "Set of realized functions for the complex systems". The physical calculation made here shows that all molecules of the Earth is enough only for creation of the black box with maximum n=155. It does not make sense to reproduce his calculation here. The modern physics gives an exact method of calculation for the upper bound of memory through entropy of a black hole of corresponding mass [25]. (But it is problematic to extract this information because of informational paradox.) The estimation for memory, however, will not be more optimistic. It is clear that such number of the inputs is not sufficient for controlling over the complex systems. Consequently, the number of possible functions realized by box should be regarded as some subset of all possible functions. How can we choose this subset?

Now the methods based on neural networks [26] or fuzzy logic [27] are actively developed. They allow easy realizing many "intuitive" algorithms which are used by people. Besides, there are well developed methods of training or self-training for them. However, it is shown for both methods that any possible function is realized by these methods. On the one hand it is good, as proves their universality. On the other hand it is bad, as this redundancy do not allow us to lower space of search of the black box when using these methods.

In his lecture Willis offers a solution which is actual even now. He suggests using a subset of all functions of n variables. This subset can be realized by a combination of p functions with k variables where

$$p \ll 2^n \quad (1)$$
$$k \ll n \quad (2)$$

This class is small enough, so it can be realized.

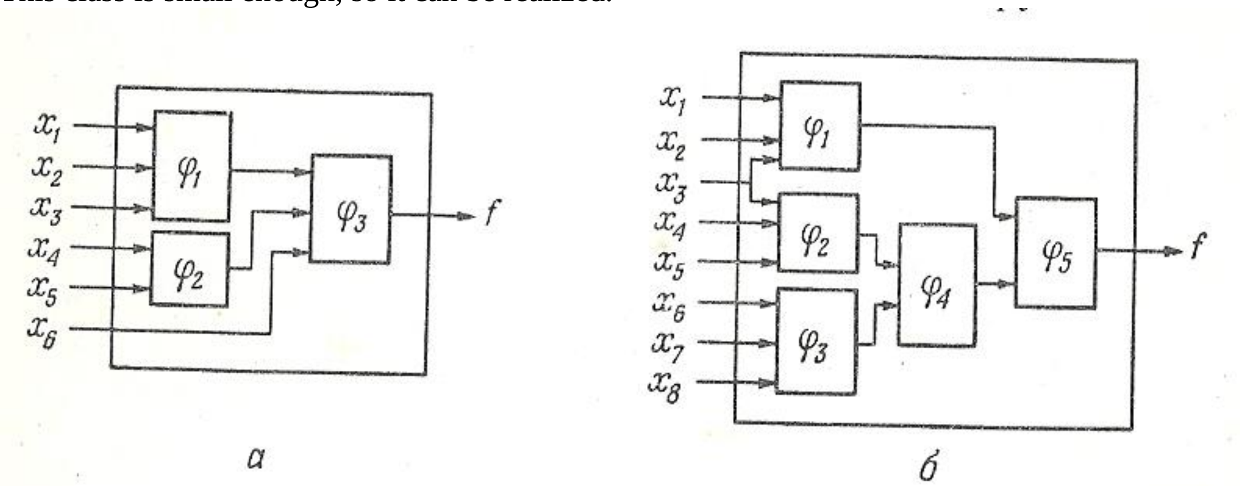

Figure 2. Exact expansion of switching functions on functions with a smaller number of variables.
a) n=6, p=3, k=3 б) n=8, p=5, k=3

This solution is acceptable for a wide class of problems. For example, the neural network was used for recognition of the handwritten digit highlighted on the screen [28]. The screen was divided into meshes (pixels). The mesh could be black or white. Thus meshes were divided into groups of neighboring meshes (k cells). Each group arrived on input of the network with one output. These outputs were grouped also in k the nearest groups which moved on inputs of the network etc. As a result there were only 10 exits which yielded outcome of classification. The specified network uses restrictions relating to “locality” of our world.

But it is possible to introduce other similar criterions restricting space of search by less hard way. For example, we can use only the requirement (1) and not use the requirement (2). Instead of (2) we restrict type of used functions, i.e. we create some “library” of the useful functions.

For example, for existing field of the pattern recognition such set of functions already exists. It is software packages of functions for images processing. Example of such package is Matlab [29]. By combining these functions it is possible to create a large number of the useful features for recognition. To select useful superposition of functions, it is possible to use a random search of the genetic algorithm. But it can be made also by using human intuition: a person can combine these functions so that they would reproduce some intuitively felt feature of an object. The person himself cannot mathematically specify this feature without such search. These are human-machine systems of search.

It is worth to note that both creation of such “libraries” and human-machine search are not algorithmizable processes. They are based on human intuition. For this reason we think that the artificial intellect is closer to Art than to Science.

Let’s consider problems which arise when this approach is used:

1) Those restrictions (“libraries”) which we set on internal states of the black box are human formed. It makes this process labor-consuming and restricted by human intuition.

2) Human-machine search is more effective than the genetic algorithm but suffers from the two above-mentioned problems.

Let’s consider the following lecture which is, apparently, the most prophetical and gives a trajectory to a solution of these problems: George W. Zopf “Relation and context”.

His main thought is that for construction of an effective model for artificial intellect we should not use some mathematical scientific abstraction like a black box. To construct such model we need to use properties of similar systems in the surrounding world. These are living adaptive systems. What their properties allow them to overcome restrictions and problems specified above?

Their most important property is that such systems are not, like a black box, some external objects in relation to the surrounding world. They are inseparably linked within it. (For example, Zopf pays attention to the fact that the features used for recognition of the object, or even the “code” of neurons of a brain (consciousness) are context-dependent. It means that they depend not only on internal state of the object or the brain, but also on their external environment.) It explains efficiency of restrictions on realized internal states of adaptive systems. They do not need to invent some “library” of search functions - it is already given to them in many aspects from their birth. These systems have happened from the surrounding world and are relating to it already at their birth by a set of hidden connections. So, their “library” of search functions is quite effective and optimal. The same is true for algorithms of adaptation – unlike “genetic algorithms”, they are already optimally arranged with respect to the surrounding world. It allows preventing search and verification of large number of unsuccessful variants. Moreover, “purposes” of adaptive systems are not set by somebody from the outside. In many aspects they are already arranged with respect to their search algorithms and surrounding world restrictions.

We often perceive events in the world surrounding us as a set of independent, casual appearances. Actually, this world reminds a very complicated mechanism penetrated by a set of very complex connections. (“Accidents don’t happen accidentally”.) We cannot observe all completeness of these connections.

At first, as we are only a small part of this world, our internal states are not sufficient for mapping all its complexity. Secondly, we inevitably interact with the surrounding world and we influence it during observation. The modern physics states that this interaction cannot be made to naught in principle [6-12]. So to model and to consider this influence exactly, we need to observe not only the external world but we need to observe ourselves too! Such introspection cannot be made *completely in principle* at any our degree of internal complexity. Introduction of physical macrovariables only reduces acuteness of the problems but does not resolve it.

Nevertheless, as it was already mentioned above, we are a part of the surrounding world and are related to it by the set of connections. So we are capable on such effective behavior. It creates illusion that we are capable effectively to foresee and to calculate everything. This property of adaptive living systems may possibly be referred to as superintuition[3] [13]. It considerably exceeds adaptive properties of any black box developed by purely scientific methods.

Hence, we should build our future systems of AI also on the basis of some similar “physical” adaptive systems possessing superintuition. We will give here the list of properties of such systems [9-10, 17-18].

1) The random generator of such systems (making selection of internal state) should not generate just random numbers. Such numbers should be in the strong connection (correlation) both with the surrounding world and with internal state of AI system, ensuring superintuition.

2) The internal state of the system should be complex. It should be not equilibrium but stationary; i.e. it should correspond to the dynamic balance. It is like a water wall in a waterfall. The internal state should be either for classical mechanics systems correlated, unstable (or even chaotic) or for quantum mechanics systems quantum coherent. Such systems are capable to conserve the complex correlations either inside of themselves or between themselves and the surround world.

3) The internal state of the system should be closed from external observation. It is achieved, at first, by high internal complexity of the system. Secondly, the system should change strongly the internal state and behavior at an attempt of external observation. This property is intrinsic for both unstable classical systems (close to chaos), and quantum coherent systems.

4) The system should be strongly protected from an external thermal noise (decoherence).

5) The system should support the classical unstable or quantum coherent state and be protected from the external thermal noise not so much passively as actively. I.e. it should not be some hard armour or low temperatures. Rather it should be some active metabolic process. The system should be in a stationary dynamic balance, instead of thermodynamic equilibrium. So the vertical wall of water in a waterfall is supported by its constant inflow from the outside.

6) The main purpose of such system should be its “survival”.

To use similar systems, we need not to know in details their internal states and algorithms of operation which they will establish at interaction with the surrounding world. Moreover, trying to make it we will strongly risk breaking their normal operation. The only thing we should be concerned in is that the purposes which they pursue for “survival” are coinciding with the solution of problems which are necessary for us.

We see that physics becomes necessary for creation of such cybernetic AI systems. Are there prototypes of such systems nowadays? Many features of the abovementioned systems are inherent to quantum computers [19-20, 24] or to their classical analogues, namely classical

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[3] The study was conducted by Russian specialists under guidance of Valeri Isakov, a mathematician who specializes in paranormal phenomena. They were not able to obtain data from domestic flights, so the researchers used Western statistics. As it turned out over the past 20 years, flights which ended in disaster were refused by passengers by 18% more in number than in case of normally ended flights. "We are just mathematics who revealed a clear statistical anomaly. But mystically-minded people may well associate it with the existence of some higher power"- quoted Isakov, "Komsomolskaya Pravda".
http://mysouth.su/2011/06/scientists-have-proved-the-existence-of-guardian-angels/;
http://kp.ru/daily/25707/908213/
“That was Staunton’s theory, and the computer bore him out. In cases where planes or trains crash, the vehicles are running at 61 percent capacity, as regards passenger loads. In cases where they don’t, the vehicles are running at 76 per cent capacity. That’s a difference of 15 percent over a large computer run, and that sort of across-the-board deviation is significant. Staunton points out that, statistically speaking, a 3 percent deviation would be food for thought, and he’s right. It’s an anomaly the size of Texas. Staunton’s deduction was that people know which planes and trains are going to crash… that they are unconsciously predicting the future."
Stephen King, "The Stand" (1990)

unstable computers [14] and molecular computers [16]. Besides, there is a lot of literature where synergetic systems modeling specified above property of living systems are constructed "on paper". In quantum field it is [21-23, 30-32], and for classical unstable systems [15].

Here two problems arise:

1) Which of the above-mentioned objects will be appropriate in the best way for creation of AI systems?
2) What purposes necessary for "survival" of these systems do we need to put? Indeed, these purposes must be coinciding with solution of our problems.

The solution of these two problems is not an algorithmizable creative process. It makes again artificial intellect to be closer to Art than to Science. Really, usually we cannot even know how such systems are arranged inside. We can define their restrictions only. It is necessary to direct these systems to solve problems useful for us. We often are not capable even to understand and to accurately formulate our own purposes and problems. Without all this knowledge the Science is powerless. So creation of such systems more likely will be related to writing music or drawing pictures. Only "brushes" and "canvas" will be given to us by the Science.

Are AI systems capable to solve the two abovementioned problems instead of us? For the first problem such chances exist, but the second one cannot be solved without us in principle. Indeed, nobody can know better than us that we want. But both these problems are interconnected. Therefore, people always will have to do intellectual job. It is true also for the case that our "intelligent assistants" will be very powerful.

3. Conclusion

Perspective of the future of artificial intellect (AI) is considered here. It is shown that AI development in the future will be closer rather to art than to science. Complex dissipative systems whose behavior cannot be understood completely in principle will be a basis of AI. Nevertheless, it will not be a barrier for their practical use. But a human person inevitably will conserve his important role. It is impossible to completely to exclude him from the process.

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