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GENERATING FLOWS AND A SUBSTITUTIONAL MODEL OF SPACE-TIME

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A number of contradictions existing in the modern picture of the World urges one to develop an explicit construction of time and, simultaneously, to a re-comprehension of many basic notions of science.
A model of a clock is suggested, parametrizing changes in natural systems by the number of replacements (substitutions) of their elements. A hypothesis is formulated that the substitutions originate from generating flows; all natural systems are assumed to be open with respect to those flows. The approaches suggested make it possible to describe the formation phenomenon and to formulate extremal principles for system motions. Properties of substitutional time, substitutional motion and world symmetries are studied. Approaches to the construction of charges, interactions, space and equations of motion are outlined.

1. The generating flows hypothesis

The scientific description of the World contains a longstanding conflict between the evident time reversibility in the fundamental laws of natural science and the formation phenomenon, i.e., a clear distinction between the past and the future in the world of real processes [1].

There is one more contradiction, not always clearly understood, between the second law of thermodynamics, acting in a closed Universe, and the lack of manifestations of degradation and an inevitable trend to equilibrium in the World [2, 3].

We suggest a research program aimed at directing some possible ways to resolving the above contradictions. It should be noted that in a realization of such a program, many basic notions of science must be recomprehended, so that the investigation cannot be confined only to time construction and has to encompass other notions, such as space, particles, interaction and others.

The treatment to be suggested rests on some axiomatic constructions, whose basis consists of the notions undefined in the present approach, namely, those of sets theory and system theory: an element, an object, variability, a hierarchy level of a specified depth and so forth [4, 5, 6]. In what follows some starting principles are described.

The hierarchy principle: all natural systems are hierarchic, i.e., any object is an element of a higher rank system and any element is a system consisting of elements.

The variability principle: any change of a system consists in a change of the set of elements at levels of certain depths in the hierarchy containing the system. The term "element replacement" will be used as a synonym of the term "substitution". The element replacement process will be called "substitutional motion" (it is assumed that the replaced elements may belong to any hierarchy levels and the replacements may occur with increasing, decreasing or conserved number of elements).

The generating flows existence hypothesis: all natural systems are open with respect to flows of elements of some levels of the hierarchic structure. In particular, our Universe is open with respect to generating flows.

2. Elements of a picture of the World

Having at our disposal the generating flows, let us begin to construct the elements of a picture of the World [7].

We will call particles sources or sinks of generating flows in our Universe. Some particles are sources (sinks) of a flow of a single hierarchy level, others are those for several levels. The dynamic characteristics of flows create particle charges. Flows of different hierarchy levels create different particle charges: gravitational, electric, baryonic, etc. The sources and sinks of flows of the same level may correspond to charges of different signs. The particle modelling by "entries" and "exits" of generating flows allows one to suggest the Lesage mechanism for the description of interactions. The elements of generating flows and the particles acquire a different status of existence. The particles possess charges and masses and take part in interactions, i.e., form what is identified as matter, or substrates. The flow elements have no charge (although create those of the particles), are interaction carriers and can perhaps be identified with fields. It is suggested to call the whole set of generating flows the substance.

The generating flows create the formation: the difference between the past and the future consists in different numbers of substance elements of the corresponding hierarchy levels in a certain system. (I would like to note that the substitutional approach assumes the finiteness principle: natural systems include a finite number of elements of any hierarchy level. The number of particles in the Universe is finite as well.) The recognition of generating flows removes the conflict between the second law of thermodynamics and the development phenomena, since the second law applies solely to closed systems and becomes unapplicable to an open part of the Universe where the generating flows create the course of time.

We will call one of depth hierarchy levels in the structure of a system under study the time-forming level. Any element substitution at an arbitrary level higher than the time-forming one will be called an event. The number of generating flow elements (which is finite in the substitutional approach) of the time-forming level, replaced between two events in the system under study, will be called a substitutional time interval. I would like to stress that the choice of a time-forming level is arbitrary and is determined by the researcher's will and goal. Thus the substitutional time scales, determined by different choices, may turn out to be non-uniform with respect to each other. More precisely, time intervals, equal by a certain scale, may turn out to be unequal by another scale. (We assume the imperativity principle to be valid: the substitutional time intervals between replacements of a single element of a time-forming level are equal to each other and equal to unity.) Thus substitutional time as a phenomenon of variability of objects of the World is created by a selected generating flow and is parametrized by the number of elements of this flow. Substitutional time lacks universality: it is, strictly speaking, discrete; the uniformity of its course is relative.

Events on the time-forming level and deeper ones are out of time. (Recall that even in quantum mechanics some "timeless", instantaneous events are present: photon absorption and emission by atoms, wave packet reduction, and a change of quantum numbers of one of the parts of a system when another, arbitrarily remote part, is subject to measurement, i.e., the Einstein-Podolsky-Rosen paradox.)

An explanation of the term "flow" seems to be needed. One often calls a flow of a certain quantity the amount of this quantity changed in a system per physical time unit. In the model under consideration, a flow is parametrized directly, by a change in the absolute number of elements of the generating substance in a system.

The whole set of substances of generating flows on the levels higher than the time-forming one creates space, where particles exist and interact. The space turns out to be a substantial (but not substrate) medium. A clear image of the spatial structure of particles will include sources ("springs", "fountains", or "jets") in a water reservoir rather than eddies or mountains. A sequence of elements "emitted" by a particle forms a set of its neighbourhoods, i.e., creates the notion of proximity in space and consequently topology and metric in it. It is suggested to parametrize spatial measurements, just as those of time intervals, by numbers of elements of the corresponding hierarchy levels. Along with the arbitrariness in choosing the time-forming level, a researcher thus preserves the arbitrariness in choosing the space-creating levels (the conventionality principle).

The substitutional motion principle: any motion of a system consists in replacing its constituent elements at a certain hierarchy level, i.e., is a sort of system change, or substitutional motion. Note that the substitutional motion occurs in space not in the form of "moving apart" the substance elements, but rather by "penetration" of these elements inside the objects and substitution of previously existing elements, i.e., there is no "ether wind" or "ether friction" and the substance of generating flows is thus different from the "ether" of the 19th century. A good visible image of substitutional motion is a "running advertisement" where objects (characters) move due to "entering" and "leaving" lamps — "points" of the functioning medium. It is to be emphasized that the substitutional motion principle is of utmost importance for the model suggested: it allows one to avoid many difficulties inherent to unempty space models.

The generating flow propagation (more precisely, variation of the amount of generating substance in a system) can have two "signs" with respect to source particles: emission and absorption. The distinguished flow direction creates, in addition to the course of time, an asymmetry between left-handed and right-handed coordinate frames, as well as different charge signs. A mental flow "reversal" should lead to three connected effects: time reversal ("time parity" violation), mutual replacement of left-handed and right-handed coordinate frames ("space parity" violation) and particle charge sign reversal ("charge parity" violation; as adopted in quantum electrodynamics, an antiparticle turns out to be a particle moving "against time"). The generating flow reversal (and the corresponding agreed changes of charge, space and time parities) does not change the state of the World.

The generating flow hypothesis also admits radical suggestions on the specific features of life: just as particles—charges are sources of generating flows creating physical interactions, living organisms are sources of specific flows of pre-elements belonging to some hierarchy levels of matter structure. The distinction between the living and the lifeless thus turns out to be connected with a specific nature and number of cellular generating flows. An experienced reader may discover in the hypothetic substantial flows of the substitutional approach a rehabilitation of vitalism ("vital forces"). However, the statements of the substitutional conception are much closer to prose: the case in point is in some quite material structure levels of natural systems, just so far undetected by modern research instruments. The hypothetic pre-element flows on those levels are needed not especially to introduce a kind of vital forces, but just conform with the logic of deriving a whole circle of natural-scientific constructions in the frames of the substitutional approach.

3. Equation of substitutional motion

I would like to present an illustration of a possible way of developing a dynamic theory on the basis of the substitutional approach [5, 7]. Consider a two-level hierarchic object, whose variability is described by element replacements on its structure levels. The upper level will be interpreted as the spatial dimension of the model system and the lower one as a substantial manifestation of its coordinate time. The numbers of spatial-level elements entering and leaving the system will be denoted, respectively, Δn^+ and Δn^-. Accordingly, Δm^+ and Δm^- denote the replaced time-forming elements. The number of upper-level elements will be interpreted as the system energy characteristic, the Lagrange function, whose variation, ΔL, is $\Delta n^+ - \Delta n^-$. The number of lower-level elements will be interpreted as the system momentum whose variation is $\Delta p = \Delta m^+ - \Delta m^-$. The displacement in space is $\Delta x = \Delta n^+ + \Delta n^-$, while the time interval is $\Delta t = \Delta m^+ + \Delta m^-$.

The above definitions make it possible to formulate the theorem of dynamics for a substitutional object:

$$(1+a+b)\frac{\Delta p}{\Delta t} = \frac{\Delta L}{\Delta x} + a - b$$

where

$$a = \frac{\overline{\Delta m^+}}{\overline{m}}\frac{n+\Delta n^+}{\Delta n^+ + \Delta n^-}, \quad b = \frac{\overline{\Delta m^-}}{\overline{m}}\frac{n+\Delta n^-}{\Delta n^+ + \Delta n^-}$$

and an overbar denotes averaging of the number of lower-level elements over upper-level elements. The theorem connects the momentum variation rate $\Delta p/\Delta t$ with the "force" applied to the system $\Delta L/\Delta x$.

The velocity of the object $v = \Delta x/\Delta t$ turns out to be equal to $v = 1/[\overline{m}(1+a+b)]$; if the object moves in such a way that its element system (space-level points) change, but its pre-elements (time-forming level elements) in the elements are unchanged (formally: Δn^+ and (or) $\Delta n^- \neq 0$ but $\overline{\Delta m^+} = \overline{\Delta m^-} = 0$, then $v = 1/\overline{m}$, where $\overline{m}$ is the mean number of pre-elements in the elements $\left(\text{in the sense } \overline{m} = \frac{1}{\Delta n}\sum_{x=n}^{n+\Delta n} m(x)\right)$.

The motion of a substitutional object has the following properties:

- Since $\overline{m} \neq \infty$, $v \neq 0$, i.e., a substitutional object is "nonlocal". Each level numbered i has its own characteristic velocity $v_{i\text{mean}} = 1/\overline{m}_i \equiv N_i/N_{i+1}$ where N_i is the amount of elements at the level numbered i.

- There is a maximum possible velocity of substitutional motion in the medium of each level. This is the velocity possessed by objects consisting of elements with a single pre-element each ($\overline{m} = 1$).

- In the linear approximation the velocity addition theorem is valid. Namely, let the elements of a medium, containing at average $\overline{m}_{\text{av}}$ pre-elements, change their "filling" by $\Delta\overline{m}^+$ pre-elements, i.e., the object loses its velocity with respect to the medium. The velocity of the object is $v_{\text{obj}} \approx \dfrac{1}{\overline{m}_{\text{av}}(1+a)}$. For

$$a = \frac{\overline{\Delta m^+}}{\overline{m}}\frac{n+\Delta n^+}{\Delta n^+ + \Delta n^-} \ll 1$$

one has

$$v_{\text{obj}} = \frac{1}{\overline{m}_{\text{av}}}(1-a) = v_{\text{av}} - u$$

where $u = av_{\text{av}}$, or $u = v_{\text{av}} - v_{\text{obj}}$, i.e., the relative velocity may be represented as an algebraic sum of velocities.

- A motion with $\Delta n^+ = \Delta n^-$ and $\Delta m^+ = \Delta m^-$ will be called equilibrium (such that neither elements, nor pre-elements are stored or depleted in the object). In an equilibrium motion the force applied to the object, $\dfrac{\Delta L}{\Delta x} = \dfrac{\Delta n^+ - \Delta n^-}{\Delta n^+ + \Delta n^-}$ vanishes and the momentum is constant (the theorem of inertia).

- An equilibrium motion can be discovered by measuring the quantities ΔL and Δp, which vanish at any equilibrium motions (the equilibrium motion relativity theorem).

- At actions with $\Delta n^+ = \Delta n^- = 0$ the Lagrange function of the system does not change, the velocity is zero, but the object momentum can change due to changing pre-elements in its elements:

$$\frac{\Delta p}{\Delta t} = \frac{\overline{\Delta m^+} - \overline{\Delta m^-}}{\overline{\Delta m^+} + \overline{\Delta m^-}}.$$

- Let us define the reversal of substitutional motion by the following transformations:

$$\Delta n^+ \leftrightarrow \Delta n^- \qquad \Delta m^+ \leftrightarrow \Delta m^-.$$

The equation of substitutional motion is invariant under the motion reversal (the motion reversal theorem). Noteworthy, the "time reversal" ($\Delta m^+ \to -\Delta m^+$, $\Delta m^- \to -\Delta m^-$ and consequently $\Delta t \to -\Delta t$ does not leave invariant the dynamic equation but preserves the Newton equation (see the next property).

- For "single-level motion" (Δn^+ and/or $\Delta n^- \neq 0$ but $\overline{m^+} = \overline{m^-} = 0$) the substitutional motion dynamic equation

$$(1 + a + b)\frac{\Delta p}{\Delta t} = \frac{\Delta L}{\Delta x} + a - b$$

passes over to Newton's dynamic equation

$$\frac{\Delta p}{\Delta t} = \frac{\Delta L}{\Delta x}.$$

- In the case of non-intensive pre-element replacements in elements, more precisely, if $a,\ b \ll 1$, the dynamic equation in the linear approximation takes the form

$$\frac{\Delta p}{\Delta t} = \frac{\Delta L}{\Delta x} - \frac{\Delta L}{\Delta x}(a + b) + a - b. \qquad (1)$$

Since $a,\ b \sim 1/m \sim v$, it turns out that at some substitutional motion velocities some new forces appear in addition to Newtonian ones. These forces are proportional to these velocities and the Newtonian forces: for instance, when $\Delta m^+ = \Delta m^- \equiv \Delta m$, it turns out that

$$\frac{\Delta p}{\Delta t} = \frac{\Delta L}{\Delta x} - \frac{\Delta L}{\Delta x}\frac{\overline{\Delta m}}{\overline{m}}\frac{2n}{\Delta n^+ + \Delta n^-}.$$

In this case the equation of motion is not invariant under time reversal.

- Suppose there is, in addition to elements and pre-elements, a pre-particle level preceding to them. Define for the pre-particles (l) the "coordinate" variations $\Delta\tau = \Delta l^+ + \Delta l^-$ and the "function" variations $\Delta G = \Delta l^+ - \Delta l^-$. The dynamic equation is easily generalized to the case of motion with pre-particle replacement:

$$\frac{\Delta G}{\Delta\tau}(1 + c + d) = \frac{\Delta p}{\Delta t} + c - d;$$
$$\frac{\Delta G}{\Delta\tau}(1 + a + b + e + f + \ldots) = \frac{\Delta L}{\Delta x} + a - b + e - f + \ldots$$

where the corrections $a,\ b,\ c,\ d$ and others estimate the intensities of "internal" motions in elements as compared with the intensity of the object motion on the level of elements.

4. Entropy parametrization of substitutional time

Space and time interval measurement implies in the substitutional approach the procedure of counting the number of elements. Such counting in structured mathematical objects, explicating the natural-scientific objects in their formal descriptions, requires that the notion of a quantity be generalized. One of the ways of such generalization is provided by the functor method of comparing mathematical structures [6]. An analogue of the number of elements of a structureless set is, for objects with a specified mathematical structure, the invariant of that structure, namely, the number of structure morphisms (it is finite, as well as the numbers of elements of systems). The invariants of the majority of mathematical structures are expressed in terms of structure invariants of sets with a partition associated with an arbitrary specified structure. The logarithms of structure invariants of partitioned sets have a typical entropy-like form. For example, if the morphisms preserving the structure of partitioned sets, are mappings, then the logarithm of the specific invariant is $-n\sum_{i=1}^{w}\frac{n_i}{n}\log\frac{n_i}{n}$ where n_i are the numbers of elements in the partition classes, $n = \sum_{i=1}^{w} n_i$, w is the number of the partition classes (compare with the Boltzmann formula for the entropy of a perfect gas). It is proposed to use the entropy invariants for a parametrization of substitutional motions of complex objects of natural science. True, such a usage requires additional assumptions on the laws creating the motion description.

5. Extremal principle of substitutional motion

We suggest an extremal principle for selecting the real motion from the spectrum of all motions potentially admitted by the system structure: a transition is conducted from a given state of the system to a state whose system structure invariant is maximum within the substantial restrictions, imposed by the generating flows that create the system variability.

According to the extremal principle, the logarithm of the system invariant does not decrease along real trajectories and can thus play the role of the system's parametric time; this is the reason for calling it "entropy time".

Consider an example of a multi-level substitutional object, with the set of elements of the top level partitioned into classes, and the generating flows of lower-order pre-elements. Let us fix the time-forming level of our system at depth τ. According to the extremal principle, the motion of the object under consideration is described by the following variation problem:

$$\begin{cases} H = -n \sum_{i=1}^{w} \frac{n_i}{n} \log \frac{n_i}{n} \to \max \\ \sum_{i=1}^{w} \overline{m}_i^k \Delta n_i \le \Delta M^k, \quad k = \overline{1,\tau} \\ \sum_{i=1}^{w} n_i = n \\ n_i \ge 0, \quad i = \overline{1,w}. \end{cases} \tag{2}$$

Here n_i is the number of elements in the partition class i, $\overline{m}_i^k$ is the average number of pre-elements of the level k in the elements of the class i; ΔM^k is the amount of substance of the level-k generating flow that passed through the system in the substitutional time period ΔM^τ.

If $\Delta M^k = 0$, then the system is closed, the extremal principle leads to an equilibrium state and is equivalent to the second law of thermodynamics.The existence of generating flows leads to structure formation and system self-organization.

It can be shown [8] that the following relation is valid for the entropy time H:

$$H = \sum_{k=1}^{\tau} \lambda^k \Delta M^k \tag{3}$$

where λ^k are the Lagrange multipliers in the variation problem (2), and that $\partial H / \partial \Delta M^k \ge 0$ ($k = \overline{1,\tau}$), i.e., the entropy time H and the substitutional time ΔM^k of the system are monotone, thus confirming what was asserted on the possibility of entropy parametrization of substitutional time. I would like to note that by (3) the entropy time turns out to be an "averager" of different substitutional times. This formula also demonstrates a connection between the entropy time and the ordinary thermodynamic entropy: if one of the flows ΔM^k is the heat flow ΔQ, then the corresponding Lagrange multiplier is conventionally denoted by $1/T$ where T is the absolute temperature of the system, and the corresponding term in the sum takes the form of thermodynamic entropy $\Delta Q/T$.

For the problem (2) the stratification theorem [8] is valid: the space of the system $\prod_{k=1}^{\tau} \Delta M^k$ splits into $2^\tau - 1$ domains, so that in each of them the solution to the problem (2) depends on the generating flows of one of the non-empty subsets of the total set of levels $k = \overline{1,\tau}$. For the flows from this subset, with its corresponding space domain, some of the inequalities of the problem (2) become equalities, while for levels which do not belong to this subset, they remain strict inequalities. In other words, in each space domain of the system, its motion is determined by some of the generating flows and is not determined by the others. If the generating flows from different hierarchy levels of the system structure create different types of particle interactions, then these interactions manifest themselves in different domains of the system space.

The extremal principle may be interpreted as the principle of maximum structuring of the system, its maximum complexity, or maximum entropy. One more interpretation of the extremal principle is possible, the substantial one. Namely, for the variation problem (2), an analogue of the Gibbs theorem is valid, that the maximum entropy problem with the generating flows bounded above is equivalent to the minimum problem for any of the generating flows with the structure invariant of the system bounded below. Thus the extremal principle gains the meaning of minimum "consumption" of the generating substance, or minimum substitution time.

6. Concluding remarks

The model suggested essentially includes the view of a substantial nature of space.

The model to a certain extent removes the conflict between the relational and substantial approaches with respect to time. The point is that the traditional relational time models (see e.g. [9]) postulate particles of matter and their motion, while time is a construction of the theory. The approach described here lays the responsibility for the time phenomenon upon the substance of one of the levels of the system hierarchy structure (again matter, if you please, but in a peculiar form), while motion is postulated by the variability principle and substitutional clocks, as well as the formation phenomenon, become constructions of the theory. Thus the relational and substantial approaches become similar in their structures, just the former deals with material objects in their known form, while the latter assumes matter so far undetected by modern research technologies.

The idea of generating flows is not new, both in philosophy and in natural science. For example, in physics a "time flow", carrying energy (but no momentum) and possessing "active" properties, was studied by N.A. Kozyrev [10]. I would like to note in connection with Eq. (1) that N.A. Kozyrev measured experimentally in a large series of works some forces additional to Newtonian ones, proportional to bodies' speeds and weights. The methodologies of Kozyrev's works are described in the review [11].

The Lesage mechanism of modelling particle interactions, such that particles are sources and sinks of generating flows, may be illustrated by a quote referring to Newton's gravity law: "The modern proof of Newton's theorem rests on hydrodynamic arguments, tracing back to Laplace: the point is that the only spherically symmetric motion of an incompressible fluid is radial motion at a speed inversely proportional to squared distance from the centre... Thus the force field of attraction by a point mass mathematically coincides with the velocity field of an incompressible fluid" [12].

Models with matter creation in the Universe are actively discussed in astrophysics for more than half-century. These models have gained a new impetus from modern observational data [13].

In a thermodynamically closed Universe, in roughly 10^{14} years the last stars would die out, the matter of the cooled stars, dilute gas and evaporated black holes would slowly decay, and in the whole Universe would remain only rare electrons and positrons at enormous distances from each other [14]. The dying-out perspective for the World may be called the Chronos principle, after the god who devoured his children. The adoption of generating flows changes the picture of our World evolution, depriving it of the bugaboo of thermal death, non-existence and decay and creating self-organization and complication. The alternative to the Chronos principle is worth calling the Kozyrev principle, implying that the deepest properties of matter, space and time bear the possibility of struggle against thermal death by opposing processes which may be called the processes of life [3].

The generating flow hypothesis is to a large extent radical. It may be suggested that a reader with a restrained position consider the generating flow hypothesis as just a convenient way of description and modelling of the formation, time and development phenomena, or, if one pleases, move the flow conception from the field of ontology to the methods of epistemology.

At any rate, a constructive statement of the problem is apparently not the existence of a generating flow, but a way to operationally produce it. i.e., to measure in a reproducible way its certain characteristics, different from its main manifestation, the course of our time.

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