Noosphere as Optimal Control.
Part 1. Control Theory, Geosphere and Biosphere[1]

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The conceptual system developed in optimal control theory for technical purposes is used as a philosophical instrument applied to cyclic information processes, which are expected to be the basis of noosphere. Noosphere was perceived by the founding fathers of this concept, Vladimir Vernadsky, Pierre Teilhard de Chardin, e.a. as an outgrowth of the evolutionary process, which begins with cosmogenesis and proceeds through geosphere and biosphere. We attempt to apply the optimal control concepts to all three levels — geospheric, biospheric, and noospheric — due to their having a common structure of information processes (or entropic processes considered as proto-information). These processes include homeostasis, accumulation and expenditure of information, formation of hierarchical information structures, evolution involving the breaks of homeostasis etc. In noosphere, controlled system may have the same informational capabilities as controlling system, so that the term "dialog" is more adequate; in this case, we extend optimal control description to game theory. The cyclic, feedback logic of optimal control seems better adapted to noospheric processes than usual cause-effect logic.

The first part of the paper considers the geospheric and biospheric level. We introduce the basic notions characterizing optimal control cycle: duality of observation and control, hierarchy of models, active sounding, balance of information inflow and outflow, optimized criterion, networked (distributed) control, etc. Then, natural homeostases at the geospheric level are considered as a form of self-regulation having specific optimized criteria. The constitutive feature of this level is the absence of information processing in the strict sense: its place is taken by entropic processes. Therefore, no goal can exist at this level, and we consider it as a part of cosmogenesis, which is allegedly goalless/meaningless. We discuss the anthropic principle as a means to overcome this limitation and its possible impact on understanding of geosphere. Next, we consider the biospheric level as one with genetic information accumulation but without reflection. Interaction between genetic and phenetic structures is described in optimal control terms. Phylogenesis is described as restructuring of genetic "models", and the problem of origin of life is considered as a specific case of information paradox called "loan from the future". We consider also the Gaia concept of biosphere regulating the geosphere and express it in optimal control language.

Keywords: optimal control, homeostasis, evolution, biosphere, geosphere, information cycles.

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Introduction

Optimal control as a language for noosphere. Nikolai Fedorov, the forefather of noospheric thinking, understood as "regulation" (in modern terms, optimal control, *OC*) [Fedorov, 1990] what later obtained the name of noosphere. His modern follower, Nikita Moiseev [Moiseev, 1999: 167], was a professional mathematician working in OC domain. This paper continues their line by translating the rigorous mathematics of OC into philosophical language — of course, metaphoric — for noosphere, applicable as well to geosphere and biosphere. This unified approach to geo-, bio- and noosphere (called *GBN* below) is the major advantage of OC; it extends toward hard science the purely philosophical approach presented, e.g., by Oleg Bazaluk [Bazaluk, 2014]. OC is used as a tool for organizing the analogies between biology, sociology, etc. — as a trunk of notions that branch into these domains. The central notion is information; its opposite is uncertainty. Characterization of uncertainty is inherent to OC and essential for capturing the fuzziness of noospheric forecasts. Acknowledging the essentiality of uncertainty, we minimize the usage of mathematics in this paper in order to preserve the fuzziness of noospheric picture reflected in the inherent fuzziness of discourse. Instead, we widely use the multivalent expressive capabilities of language, especially the reflective ones.

Limits of OC paradigm. We construe OC as a picture of information cycles. By construction, OC philosophy is a philosophy of both understanding and action. It includes the instruments of reflection, in particular, its own influence on regulation. OC is a limited paradigm because regulation is only an aspect of noosphere (admittedly, the most important one). However, OC's constraints are constructive: they limit the picture of noosphere to what *is* and *can be* not what *should be*, thus eliminating wishful thinking. Another limitation is that OC theory assumes the regulation is already running and tells little about how the noosphere is *becoming*. While helping to organize the noospheric thinking, OC as a tool developed for machines imposes a bias towards technical rather than humanitarian view. To compensate for it, we extend the notion of "information" with something absent in standard OC: "meaning". The "trunk" of OC philosophy feeds with information provided by its "branches" in biology, sociology, etc., but assimilates only what is compatible with OC's own basic notions — its informational "genotype". While this paper unfolds, these notions change and are enriched in the process of applying them in unusual settings.

OC notions that find their counterparts in GBN are as follows.

1. Regulation through feedback.
2. Optimizing a criterion, which has a material and a (contingent) informational part.
3. Accumulation of information in multilevel structures — models, meta-models, etc.
4. Bifurcations of model structures and control scenarios.
5. Explicit description of uncertainty and dependence of control on it.
6. Optimization described by entropy.
7. Optimization through a set of communicating individual searches.
8. Multi-node informational structures — "distributed control". Cooperation between nodes.
9. Reflectivity of models and control scenarios.
10. Virtual models and scenarios influence realized models and scenarios.
11. Hierarchy of frameworks for regulation: system dynamics — OC — games.
12. Hierarchy of OC types: mechanical — adaptive — evolutionary.

These notions are explained in Chapter 1. Chapter 2 constructs with them a description of matter/energy flows in geosphere, and Chapter 3 — of information flows in genetic and phenetic realms of biosphere. The follow-up leading to noospheric issues is in the forthcoming parts of this paper.

1. Basic notions of optimal control

We use OC as philosophy, thus we translate its formulas into words. For a classic mathematical introduction to OC, see, e.g., [Kwakernaak & Sivan, 1972].

1.1 Recursive filter/controller and information flows through it

Information cycle of control. Figure 1 shows the basic structure of optimal control. It consists of two main components: the observed/controlled *object* and the observing/controlling *subject* endowed with *criteria* of control. The observing part of the subject is called *filter*: it provides an estimate of the object's *state* cleaned from noise (filtered). The estimate is fed to *controller*, which calculates the necessary *impact* on the object so as to drive it toward the *desired state*. The process is disturbed by *noise* in the object and in the subject. The process runs recursively, in iterative time steps: observation — control action — object change — new observation — new control feeding back on the object etc. We call it "*object time*" and focus on *information flows* circulating in it along Figure 1. The left half of the cycle is *observed information* about the object; the right half is *control information* embedded into the object.

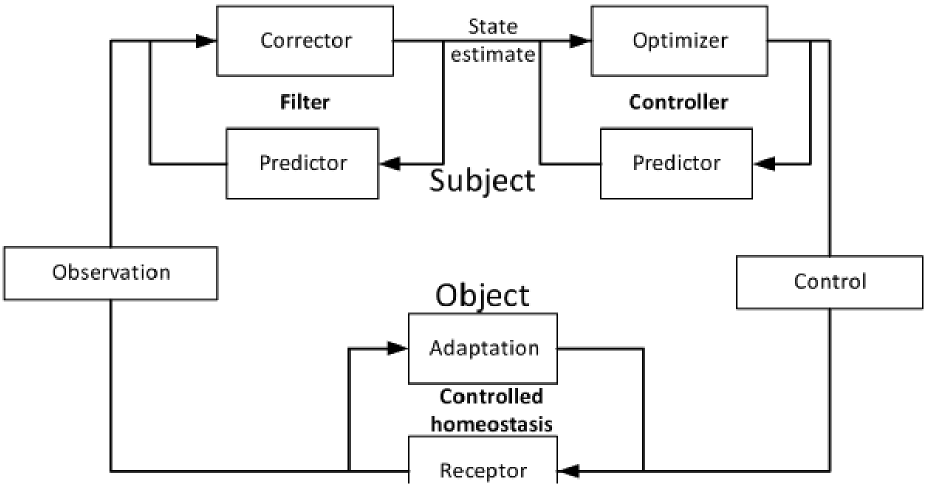

Figure 1. Basic structure of observation/control information cycle

Control as optimization. The aim of the process is to optimize a preset criterion: *accuracy* of hitting an endpoint (desired state of the object) and/or average accuracy of following the prescribed trajectory of object's state. The criterion concomitantly tries to optimize the *cost* of achieving these goals, which is measured by control effort. Technical OC focuses on *how* to attain the goal; we will assume this optimization as given and focus on *what* is the pattern of optimized information flows. This approach allows us to extend OC to geospheric and biospheric processes, which have no goal in the usual sense of the word.

Optimization involves information processing within the subject, which balances *four information flows*: incoming with observations; used in control; dissipated by noise; one due to the change of *reference frame* used to measure the information and drifting with the estimate of object's state. A reference frame is necessary for distinguishing information from noise, thus the quantitative measure of information is relative, not absolute. Reference frames can be linked to subject, or to object, to observation, or to control, or to circulation along the information cycle. *Transitions between reference frames* contribute to information balance. Information processing takes place in the "*model layer*" of the subject and involves recurrent, iterative cycles within it in search of the optimum. They run in "*optimization time*", which is generally different from "object time". In filter, iterations are direct: from the present state to a future horizon (*receding horizon*); in controller, inverse: from a postulated future state to present. Thus, OC involves two opposite *counterflows of information*. OC where information flows are stationary is called *informational homeostasis*. It reproduces the homeostatic behavior of many natural systems as information dynamics. Thus, OC looks as an exchange between two homeostases: one natural (as object), another informational (as subject). This symmetry suggests that subject and object can exchange the roles, or at least be on equal footing if the object acquires information-processing capabilities. This situation leads outside the OC framework, to game theory framework.

Models and scenarios. Information about the object resides in the model layer. It is either preset (*a priori model*) or distilled from observations (*adaptive model*). Except in simplest cases, model is used as a generator of *scenarios* of object's change under control. Optimization is an implementation of the variational principle and realizes one *actual* trajectory of control action and object state chosen from many *virtual* scenarios/trajectories. Each of virtual trajectories produces its own virtual information flow. This approach is applicable throughout the GBN spectrum in spite of geosystems and biosystems having no "goal" in everyday sense of the word.

1.2 Dual observation and control: active sounding

Duality in control. In trivial situations, filtering and control run independently minimizing discrepancies between object's state and either its estimate (filter) or its desired value (controller). These discrepancies are two parts of criterion: the former *informational*, the latter *material*, and the former is subsumed into the latter. Information transferred from filter to controller (estimate) and back (object's state) is condensed in two transfer points so that no information makes a full circle. Controller takes the filter's information "as is" and vice versa. However, in nontrivial, e.g., nonlinear situations, it is optimal to direct a part of control efforts towards information gain rather than material gain. This is called *active sounding*, or *dual control*. Then, material gain at the current step is suboptimal but the expected gain at future steps increases. Thus, the informational part of dual control cost is an investment into the future. There is an information payment by the filter for dual control since a part of accumulated information on the object becomes obsolete due to control impact on the object. This payment has to be exceeded by information gain. In this regime, information is circulating so that observation information is validated by the results of its application in control, and control information is validated by the observation of its effect.

Table 1. Correspondence between structural elements of observation and control problems

Element of information	Implementation in observation	Implementation in control
Intrinsic variable	Estimated state of observed system	Target state of controlled system
Signal	Indicator variable of observed system	Impact on controlled system
Discrepancy	Difference: observed-expected indicator values	Difference: actual-target system state values
Weights of state variables	Variance of state in observed system	Payment for unit deviation from target
Weights of variables in signal	Accuracy of sensor output	Payment for unit impact effort
Interface layer of the system	Indicator formation as function of state	Reaction of state to receptors of impact

Virtual control scenarios. Virtual scenarios are generated using optimization time but unfold in object time predicting the effect of each possible active sounding. Although the suboptimal scenarios are not actually implemented, they explore the future uncertainties and thus generate information flows. These, virtual flows can interact and influence the real flow. The full set of scenarios is an alternative form of the model, which generates them, like waves in wave-particle duality, and they can interfere — exchange information — including focusing on a *target state* at a *target time*.

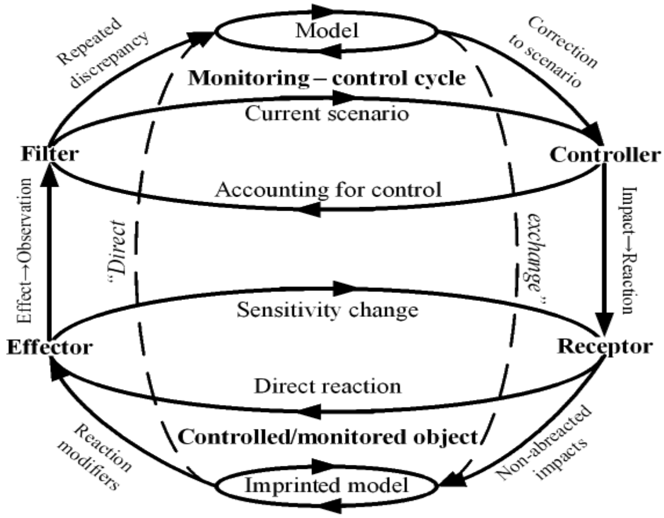

Figure 2. Model imprint in controlled object under dual control

1.3 Multilevel information accumulation in models. Reflection

Model layers. Models are information structures (in usual OC, equations), which capture the dynamics of object's state, the relation of object's state to observations, the reaction of object's state to control efforts etc. Trivial single-layer models can be preset and fixed, so that the optimal algorithm of information processing is fixed a priori. We call this type of OC *automatic* or *mechanical*: a simple feedback like James Watt's regulator. If models can change in response to observed information or to changed criteria, we call OC *adaptive*. Then, information structure acquires additional layers (Figure 3): a second-layer model defining the algorithm of adaptation of first-layer models; a third-layer model defining the algorithm of adaptation of second-layer models, etc. This structure contains the *"vertical" information flows*, in addition to *"horizontal"* ones, which form the subject-object information cycle. Ascending flow feeds the higher-level models with observational information refined from level to level; descending flow defines how higher-level models control the adaptation of lower-level ones. On passing from level to level, the reference frame for measuring the information is changed. Criteria change may be a part of adaptation or may involve an additional vertical information flow to the *designer* who defines the goals for the system.

Reflection. Virtual control scenarios include the prediction of object's reaction to realized control scenario. This reaction depends on the object's reference frame for perception of control impact. Therefore, the subject has to form an image of itself as formed in the object. This transition to another reference frame and back can iterate ("image of image", etc.) and is called *reflection*. Designer is assumed to be reflective. In dual control where information circulates, reflection includes *self-observation* of subject in the "mirror" of object and *self-control*. Self-images and images of the partner formed in reflective iterations are called *phantoms* (term borrowed from [Novikov & Chkhartishvili, 2014]). Iterative phantoms form a pyramid like the pyramid of models; the main difference is that vertical information flows in it run in optimization time rather than in object time. The zero-order phantom coincides with the model of object and is the only one when there is no reflection. Optimization of virtual scenarios, which include phantoms, involves an additional degree of freedom: distribution of information investment between phantoms of different order.

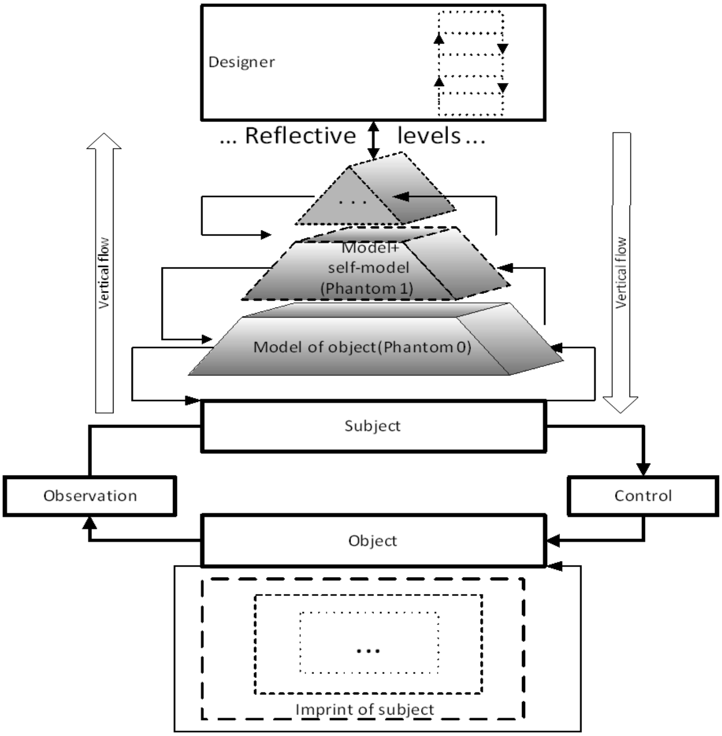

Figure 3. Pyramid of reflection. Bold lines — dashes — dots denote hierarchical levels of reflection in subject and of reflective structures imprinted into object

1.4 Distributed observation/control.

The centralized OC layout described above is not appropriate in GBN context. Rather, subject is a system of *distributed* communicating *nodes* — distributed either in geographic space, or in state space, or both. Distributed OC theory grew up in recent years. A part of control cost in the optimized criterion is the cost of communication between nodes. Communication may be untimely, its moments unpredictable, and information may be lost in communication channels. These extensions of theory, absent in classical OC, bring it closer to real GBN situations.

Communicating nodes do not duplicate each other's functions. The system splits between them the components of object's state for observing and/or controlling. The distribution of responsibilities between nodes is a part of optimization. It produces structure in the networked subject. Nodes' responsibilities generally somewhat overlap, so that information flows from/to nodes correlate and interfere like light rays. Interference is a major problem for information accounting. The problem is alleviated if there is a central node. It forms an aggregation of estimates and control plans from individual nodes and broadcasts back to them a "common estimate" and a "common plan". However, there is a huge communication overhead and less tolerance to communication disruptions.

In the centralized version, the relationship between a central node and its subordinate local nodes is like that between OC subject and OC object. Alternatively, nodes may communicate on a peer-to-peer basis. If they have similar information processing capabilities, division into subject and object becomes meaningless: rather, it is a dialogue, better described by game theory than by OC. For each node, the observation and control "object" now includes the neighboring nodes. The attempts by each node to optimize its own local criterion may lead to competition between different nodes' plans of object control or to cooperation.

1.5 Hierarchy of frameworks: system dynamics → control → game

System dynamics. OC is a middle term in the hierarchy of theoretical frameworks describing the interaction between systems. The simplest one is system dynamics (*SD*) — a term first used for interaction between humanity and its global environment by Jay Forrester [Forrester, 1973]. It is a set of coupled differential equations of dynamics, some of which may be assigned to "subject", some to "object", with no essential difference because no information processing capability is assumed in either: both "subject" and "object" behave "automatically". Information comes from the designer of equations, not from observations. SD may include embryos of OC: stochasticity, feedback, and a proto-goal — the maximum principle.

OC with a priori fixed models and criteria does not add much to SD: information flow measures are a priori known and independent on observations. Thus, we do not know *what* information will come but know in advance *how much*. Nontrivial OC begins with adaptive control where models are changeable and the object's dynamics is not known. Then, higher information levels begin being filled in a proto-dialog between subject and object where object's influence changes subject. In OC, it is postulated that object has no information processing capabilities and remains at SD level. Accordingly, the only possible reflection is *unilateral reflective dialog* within self-modeling subject as the next refinement of interaction between subject and object.

Game theory. If object has information processing capabilities, it can, in turn, adapt to subject's controlling influences, e.g., neutralize them and keep homeostasis in order to optimize its own criterion. OC theory does not cover this case, and game theory (*GT*) has to be applied. GT considers peer players, each with one's own criterion. There is, generally, no optimum good for all — rather, several kinds of *equilibria* between players' criteria. *Nash equilibrium* is "local": no player has incentives to act *unilaterally* so as to move out of it. *Pareto equilibrium* is "global": even players' *concerted* action to move out of it cannot be profitable to all.

This hierarchy of frameworks is our main tool in considering GBN through OC optics:

– Geosphere self-regulates with no information processing (SD level);

– Biosphere processes information from geospheric environment genetically but is incapable of reflection (OC level);

– Noosphere is reflective and interactions within it are more a game than control (GT level).

1.6 Homeostasis and evolution as information processes

Homeostatic regime. We focus on two specific OC regimes: *homeostasis* and *evolution*. Homeostasis means that at the lowest level of model hierarchy — that handling object's state — information flows are balanced: inflow with observations equals accumulation in higher-level models + expenditure for control + dissipation by noise. In this regime, higher levels do not feed back to the lowest one. At the lowest level, the subject-object information flow is, essentially, stationary; however, information accumulation towards higher levels goes on and may sometimes "fire". Object may have its intrinsic feedbacks, which keep it in *internal homeostasis*; the imposition of external OC shifts it to *external homeostasis*.

Evolutionary regime consists of jumps, each of which brings OC to a different optimum of the criterion (or to optimum of a different criterion) and changes model structure and control/observation applied. We call such events *bifurcations* or *catastrophes*. They can be induced externally or internally, by a gradual change of models, which brings them to an unstable state. Evolutionary information flow consists of such events, which mark the consecutive steps of *evolutionary time*. Evolution may continue unceasingly because, at each catastrophe, the reference frame for measuring information is changed, information balance disrupted, and information accumulation has a fresh start — until it induces the next catastrophe. Thus, evolution catalyzes itself — a phenomenon called *autocatalysis*.

An important type of bifurcation happens when subject splits itself into several interacting nodes. The process can repeat itself in each node again, so that a distributed control network, even a fractal structure, can grow. These structures are conspicuous in GBN both as visible objects and as informational structures.

Evolutionary time can be viewed as "main clock" in OC; then, object time will take place of the optimization time and the search of model space for optimum will be done in intervals between catastrophes. If the subject is reflective, evolutionary steps can deepen the reflection.

1.7 Information and uncertainty

Current uncertainty. Being based on information measures, OC theory can quantitatively characterize the uncertainty. Even using OC notions as a qualitative tool, we can capitalize on these quantitative features. This is a major advantage in treating such a vaguely defined subject as noosphere. Noosphere is science-based, so that it has to incorporate the major feature of science — a clear distinction between what we know and what we do not. If we look for signs of forming noosphere, we have to filter, OC-like, the uncertainties in multifarious information surrounding us, to elicit its noospheric components. The key OC feature is weighing the priori information (how we imagine the noosphere) against the observed information.

Future uncertainty. Noospheric studies involve extrapolating current tendencies into future like OC filter, which leads to uncertainty quickly growing in time. There is a horizon after which any forecast becomes senseless due to uncertainty. The full-fledged noosphere seems far beyond such a horizon. This calls for "receding horizon" approach. Even this cannot be beyond the next evolutionary jump. However, we can at least assess the current rate of information accumulation in the informational structures engaged in control of the current version of noosphere and reckon its "limits to growth"'. In the current world, accumulation of uncertainties goes in parallel with accumulation of information, and the outcome of their balance is uncertain. Such "uncertainty catastrophes" contributed to the shaping of genetic mechanisms in the biosphere [Eigen & Schuster, 1979].

Reflective uncertainty. Reflective uncertainty is, perhaps, the most important one. In reflective OC, it is induced by the flow of information up the ladder of reflective models. However, too deep a reflection can become unwieldy and useless. In OC terms, information going up the reflective ladder dissipates on the way and may be lost. Even if it does not, different levels of reflection can lead to contradictory, even paradoxical conclusions, and usually it is unclear at what level to stop. What we think about noosphere, is a part of how noosphere models itself, but can we reflectively self-correct our thinking trying to see it from future noospheric perspective?

2. Geosphere: homeostasis without information storage

2.1 Natural homeostasis as self-regulation

OC look at natural cycles. Consider two homeostatic states characteristic for geosphere: planetary thermal equilibrium and water cycle. Each includes feedbacks, and each feeds back on the other. E.g., rising temperature/humidity increases heat emission/evaporation, which lowers temperature/humidity. In addition, heat dynamics influences water dynamics through evaporation and atmospheric circulation, and water dynamics influences heat dynamics through ocean — atmosphere — land heat transfer and cloud albedo. These are cyclical processes *in time*, as those considered in Chapter 1; while unfolding on planetary "sphere", they additionally generate visible *spatial* cyclical structures, e.g. Hadley cells. These processes are usually described by SD, but we can, as well, call thermal cycle the subject and water cycle the object (or vice versa) and see them as OC. On the whole, the geosphere is in homeostasis. However, even with the same external conditions, types of homeostasis can be different, e.g. glaciation or even "snowball planet".

No-information cycles. When viewed as OC, feedback coefficients in coupled natural cycles should derive from model-based informational parameters, to be optimal. Of course, this is not the case: in natural cycles, there is no information processing and, accordingly, no model. Information can be defined only with respect to some reference frame linked to an information storehouse (model), and in natural cycles, there is no storage for information. On the other hand, when linked to human information systems (or even to biological ones — see Chapter 3) as to reference frames, natural cycles *do* carry information — generated, ultimately, by the planetary dynamics that drives them. In absence of such external reference frames, these drivers enter OC equations just as noise terms and feedback coefficients have to be taken "as is". If, on the contrary, the feedback coefficients are construed as optimized in any sense (see 2.2), this implicitly defines the respective reference frame, which assigns information flows to natural matter/energy flows.

2.2 "Optimized criterion" in natural homeostasis

Although there is no goal and no criterion in natural cycles, their feedback coefficients can be construed in OC framework as the ratio of "penalty" for deviation from homeostatic value to "cost" of control. This ratio and the choice of measures for "penalty" and "cost" define the optimized criterion for frugal suppression of deviations from homeostatic state. However, it is not clear how this criterion can be deduced from basic variational principles, e.g., physical — and we can assume no others in geosystems. Such principles work in natural cycles but internally, and to embed these cycles into the noospheric, regulated environment, we need extrinsic observables and receptors. In thermodynamics, intrinsic dynamics is externalized as intensive or extensive parameters. One should expect some analog in natural cycles.

In complex natural cycles, one can expect several possible homeostatic states corresponding to several extrema of the optimized variational criterion, e.g., current climate, glaciation, or "snowball planet." Then, evolution (in the sense of 1.6) from one homeostasis to another becomes possible. It is not problematic if driven by external changes, but if due to internal processes, it does not fit well into OC framework since we have construed such processes as bifurcations due to information accumulation in high-level models, and here, there is neither information nor model. The problem is analogous to that considered in Chapter 3 for biological evolution: if natural selection is not performed by some information-rich designer, how can it increase the genetic information content of living creatures? Alternatively, one can speak of proxies: "memory" (e.g. in the climatic system) and "information" (e.g. in spatial structures of ice sheets, circulation, etc.) Understood in this way, the proxy of information is negentropy.

2.3 Negentropy as proto-information in natural homeostasis

Information is the difference between negentropy of prior probability distribution (reference frame) and that of posterior distribution (obtained after receiving observations). Negentropy is widely applied in non-equilibrium thermodynamics to characterize the complexity of homeostatic (stationary) states. It can be considered as proto-information in simple biochemical/biological systems. Planetary water cycle or plate tectonics are, perhaps, no simpler than a bacterium, and one would expect to find proto-information accumulation in them. In fact, accumulated geospheric structures are easily found: limestone layers or coal depositions, etc. As explained in Chapter 1, it is information cycling through control actions that forms a reference frame, which provides a quantitative measure for information. Thus, geospheric accumulations and the natural cycles, which create them, should be characterized by negentropy — proto-information — rather than by information in the full sense of the word. The criterion is minimax of negentropy (minimum for constrained, maximum for unconstrained part). A full informational characterization becomes possible only when geospheric picture is embedded into noospheric one.

2.4 Distributed network of natural cycles and the role of "sphericity"

All three GBN layers are characterized by the word "sphere". It characterizes the closedness of the domain where natural cycles act. This word usage is an insight by Vladimir Vernadsky [Vernadsky, 1997] and others: while the cycles are still in the process of spatial extension, the planetary homeostasis cannot be reached. For full development of information structures, information-generating processes have to "hit the wall", to "bite their own tail". This is especially evident for biological cycles — see, e.g., closedness of the cell. It applies to geospheric cycles, as well. Only after filling the "free space", under the pressure of an external spatial constraint, natural selection starts acting for biological systems or minimax of negentropy is attained by geosystems.

Sphericity need not be only spatial. E.g., models are closed in "model space". Their external constraints and constants are separated from internal "model metabolism". This is an example of an important noospheric law: symbolic systems obey the same rules as material systems.

2.5 Evolution of geosystems

Geosphere is evolving in geological time. The term "evolution" is borrowed from biology where it implies natural selection. For geosphere, the analog would consist in optimization of some evolutionary criterion. The criterion optimized *in* homeostasis was discussed in 2.2, but what behavior occurs *between* several homeostasis states? We use OC notions to discuss two aspects: how a geosystem leaves a homeostasis to go to another one and whether there is directionality in this process. Here, we focus on internal drivers of evolution.

Crossing between homeostases. Homeostasis means that a geospheric cycle or a linked group of cycles stays in a local minimum of a criterion (energy, negentropy, etc.) — in a location in a ragged, even fractal, criterial "landscape". The "landscape" slowly changes due to accumulation of information (for geosystems, negentropy) and to interaction with other cycles. Eventually, the current minimum becomes almost flat, less advantageous, and the flow of matter/energy through it decreases shifting to other cycles/locations. As a result, the range of geosystem state variations increases and either the system as a whole crosses to a neighboring minimum or a part of it does, initiating an autocatalytic process in which other parts are drawn after it. The latter mechanism is like crystallization from a seed or like convection starting in a point in overheated fluid.

Directionality of evolution. In OC paradigm, the directionality of change in evolutionary time is determined by the tendency of the "vertical" information flow toward accumulation of information in higher model layers. Evolution in OC is optimizing this accumulation. These layers serve as memory; obviously, without memory, nothing except a random walk is possible. In geospheric cycles, there is an analog of memory: accumulation, inertia etc. For geospheric evolution to be self-directed (in other terms, autocatalytic), as described in 1.6, the reference frame, against which negentropy is optimized by distributed system of geospheric processes, has to change after each "catastrophe". At some stage of geospheric evolution, the forming biosphere may become the directing agent. Before that, geospheric evolution should be considered as a part of cosmogenetic evolution directed by the same laws that formed the Universe.

2.6 Origin of geosphere: links to cosmogenesis

Geosphere and cosmosphere. One of the founding fathers of GBN doctrine, Konstantin Tsiolkovsky, saw geosphere as inseparable from cosmosphere and the future noospheric development as not confined to the terrestrial limits [Tsiolkovsky, 2004]. Backtracking the geospheric evolution, we inevitably transgress the planetary bounds since drivers of the early stages of this evolution are cosmic. Even the later geospheric processes are dependent on cosmic environment (sunlight, tides). This "*cosmosphere*" has a common feature with geosphere: the putative absence of information accumulators/processors. Therefore, the problem of directionality stated above for geosphere can be projected to the Universe as a whole, relegating the issue to the problem of its origin, *cosmogenesis*. Although in cosmosphere, as in geosphere, there is no information in the full sense of the word (no "texts"), but there is an abundance of structures that can be transformed into information if a proper reference frame is provided. The sheer possibility of a scientific study of geosphere and cosmosphere is based on the existence of such proto-information formed in the process of evolution.

The analogy between geosphere and cosmosphere suggests that the origin of geosphere may be a more complex phenomenon than simple condensation of matter in a proto-solar nebula. The deep problems in cosmogenesis include the applicability of spatiotemporal description to the point of origin; the problem of Multiverse (multiple universes, construed as actual or virtual); compatibility of entropy growth with galactic structure formation; unexpected fitness of universal physics for the existence of conscious life, etc. These problems have their analogs in geospheric origin and development. We rely on a linear backtracking of the time scale defined by the current isotopic "clocks" to the origin of Earth. Compatibility of entropy growth and structure formation is a problem for geosphere as for cosmosphere. Multiverse's analog is the set of virtual and actual scenarios in OC (see 1.1). Fitness of the Universe for life (*anthropic principle* — see 2.7) and an analogous problem for geosphere are a part of a larger problem: senselessness or meaningfulness of Universe.

Meaningfulness in Universe and geosphere. Hard science is based on the postulate of aimlessness and, consequently, meaninglessness of what it studies. Meaninglessness does not exclude informativeness: as noted above, structures/processes assumed meaningless may provide information when approached with an appropriate reference frame. Meaningful Universe does not necessarily imply God-designed or God-driven Universe. For godless but meaningful Universe, see, e.g., Stanislaw Lem's "New Cosmogony" [Lem, 1999] where the Universe is the product of a game between super-civilizations, and Olaf Stapledon's "Star Maker" [Stapledon, 2008] where the Universe is a product of a personal game but the person is very distinct from God.

However, assumption of meaningless Universe in science contradicts observations. The visible structure of cosmos is intuitively perceived as so meaningful that Immanuel Kant compared it to the ethical law within us [Kant, 2002]. Perhaps, perception of Universe as a text is due to a kind of "resonance" between its structure and meaningful structures within us. The same type of meaning and resonance applies to the geosphere, but we perceive it less sharply because we are a part of it. Hard science strives for maximal exactness; however, absolutely exact may be incompatible with meaningful — in a kind of uncertainty principle. Therefore, the struggle for exactness becomes the struggle for preserving the meaninglessness of the world model — called by Albert Einstein "continuous flight from wonder" [Einstein, 1979].

Meaningfulness in OC and in anthropic principle. OC is an attempt to let meaning into hard science in the form of target orientation. This attempt is limited by abstaining from specifying who and why provides the criteria that form the target. In taking this approach, OC just makes explicit the logical structure present in variational principles, which form the basis of modern science, especially physics: nature, presumably, optimizes this or that (e.g., action) but we do not ask why.

An alternative attempt to handle meaningfulness of the Universe without transgressing the limits of science is the *anthropic principle*. It is a reaction to "fine tuning" of some basic physical constants characterizing the Universe that make possible life as we know it. In this approach, human meaningfulness is not created evolutionarily, on ascending from cosmo- and geo- to bio- and noosphere. Rather, meaningfulness of evolution is "inherited" from its future — from noospheric unfolding of meaning encoded in humans. For OC, this "backfiring causality" is natural: as shown in Chapter 1, information flow from future goal to preceding action is inherent to OC. Anthropic principle tries to let meaning into the physical picture of the Universe while abstracting from how meaning is formed within humans. It just takes human "as is".

2.7 Anthropic principle applied to Universe and geosphere

Anthropic principle is an attempt to "explain out" the improbable phenomenon of fine-tuning of universal constants. An analog is the fine-tuning of geosphere, which originally was just a hot ball. Both in geosphere and in cosmosphere we observe a very improbable event, and anthropic principle attempts to redress this unnatural situation by changing the probabilistic ensemble we use. Goal-orientation creates a "targeted ensemble" and makes the result we observe almost certain. In Pierre Teilhard de Chardin's concept [Teilhard de Chardin, 2008], which contains the anthropic principle implicitly, spirit is the goal of evolution, and there is no distinction between geospheric and cosmospheric evolution.

Multiverse. An alternative to anthropic principle uses the concept of Multiverse to avoid admitting the goal-orientation of our Universe. There are many universes and most of them are not fine-tuned, but we could not appear in such universes, so that they are by definition inaccessible and unobservable. The geospheric analogy applies to other planets instead of other universes: they are mostly unfit for what we call life but our planet surely is, provided we are here (conditional probability). This approach substitutes our subjective probability for objective probability, changing the probabilistic ensemble to explain out the fine-tuning. However, sacrificing the objective probabilities seems no smaller a digression from the principles of hard sciences than goal-orientation.

Universality of humans? Another principled objection to the anthropic principle asks, why just our own version of life/reason/meaning is the goal, can there be no other? Could not other constants produce a different universe, which would have its own kind of life, reason and meaning? Using the analogy between cosmosphere and geobiosphere, in the latter, there are many different kinds of life. However, all of them form a coherent whole — a "sphere". Special position of humans in this whole is obvious (a rare point where science and Bible agree) but, still, meaning and goal associated to humans are a feature of the whole. Analogously, virtual presence of other forms of life/reason in the Universe or Multiverse would not disprove the anthropic principle: all of them/us would be carriers of the same universal meaning since it by definition resides only in the whole. Universal constants can be changed without impairing meaning no more than letters in a multi-page book can be changed from page to page (unless it is a dictionary). Consider DNA: its four "letters" are universal for earthly life and cannot be modified.

3. Biosphere: information storage without reflection

3.1 Living matter: information accumulation in genetic cycles

In OC terms, biosystems can be defined, in contrast to geosystems, as those, which accumulate information and use it for control of their relationships with environment, including self-control. Biosystems' information structures have a ladder of scales: DNA/nucleus → cell → organism → ecosystem → biosphere. We first focus on the genetic level — the root of informational capabilities of biosystems. We consider it in the "homeostatic" regime.

Genetic mechanisms as OC. Information is accumulated through heredity mechanism, therefore the time step in OC cycle is a generation. Genetic level can be construed as the subject and phenetic level as the object in OC cycle (*first-level cycle*). Phenetic level is embedded in environment, and the criterion optimized by OC is environmental *fitness*. The first-level cycle generates the first-level model: the part of DNA coding for proteins and other elements, which are directly engaged in the interaction of cell with its environment. Prokaryotes have only this model; in eukaryotes, the second-level model appears — the regulatory part of genome, *regulome*, which controls the expression of the first-level model. This regulation is a *second-level cycle* running between genetic apparatus in the nucleus and translational apparatus in cytoplasm. First-level cycle and second-level cycle obey OC pattern: feedback reaction to discovered discrepancies between reality and model. This applies to homeostatic regime; however, the regulome has probably appeared in autocatalytic regime (see 1.6) as a part of evolutionary catastrophe, which created eukaryotes. Transcription of DNA into RNA corresponds to transformation of control model into control scenario. Diverse virtual readings of DNA correspond to virtual scenarios. Translation of RNA into protein corresponds to transformation of control scenario into control impacts (enzymatic and other actions by proteins).

Information conservation vs. adaptation. Random mutations and/or random horizontal gene transfer are the primary sources of new genetic information. (More precisely, they become such sources when new genetic structures are assimilated into existing DNA reference frame, else they are noise not information.) This is essential for evolutionary adaptation to new environment. However, at the same time, these random events destroy already accumulated information, which secures homeostasis in a stable environment. This can lead to so-called error catastrophe, which severely limits the amount of accumulated and reproducible information. The entire genetic-phenetic OC apparatus, presumably, appeared to solve this problem. However, for this apparatus to persist, the problem of accurate information reproduction should have been already solved, in the first place. A putative solution to this paradox is proposed by Manfred Eigen [Eigen & Schuster, 1979]: a hypercyclic structure of interaction between information in DNA, which includes codes for enzymes, and enzymatic catalyzers, which are necessary for proper functioning of DNA translation. A hypercycle of mutually catalyzing autocatalytic units locked in OC may be an archetypal solution for the catastrophe-like appearance of complex OC structures, which cannot develop in a step-by-step manner.

Virtual information structures. Typically, a single DNA structure can be transcribed in many different ways: starting from different spots, excising different noncoding fragments (introns) etc. This is so widespread a phenomenon, especially in eukaryotes, that it surely plays a role in optimization of genetic OC. We interpret it as an instance of virtual control scenarios (see 1.2). One might call the model embedded in DNA *holographic*: readable in different ways in different reference frames. Analogously, a single sequence of peptides gives rise to different variants of protein folding. All this is genetic virtuality; phenetic virtuality exists, as well, e.g., in the form of undifferentiated stem cells. From OC perspective, supporting several virtual information structures instead of one actual means deferring actual information investment to some future time when it might prove more profitable for criterion optimization than now.

3.2 Dual genetic and phenetic information flows

Collective interaction with environment. The discussion above was constrained to regulative processes within cell. They take place more or less independently in each cell, thus both subject and object of OC belong to an individual cell. Now, let us consider the interaction of cells with their environment (ecosystem or embedding organism). This situation is more complicated: OC subject and object are *collective entities* (population or species) characterized by the probability distributions of their genetic and phenetic features, respectively; however, OC acts through *individuals* drawn from these distributions. This picture can be projected on the probability distributions of intracellular regulation, as well, understanding nucleus and cytoplasm as system and its environment.

Genetic "portrait" of environment. Phenetic features are, in OC language, the object's state. They increase fitness if they are adapted, i.e., reflect the features of environment. This reflection exists in genome, as well. Genetic informational structures as a probability distribution are filtered through differential reproduction and transformed into encoded structure, which provides the necessary probability distribution of phenetic features, thus forming a "symbolic portrait" of the environment. The portrait exists at two levels: one coding the environmentally important proteins (e.g. those exported from cell) and the other coding the intra-cellular regulative proteins.

These two use different "languages", and their information about environment is of different quality entering the optimized criterion with different weights. Assuming that proportion of information at these two levels is optimized by evolution, preponderance of the regulatory part of genome (at least, in eukaryotes) means that quality and weight of second-level information are higher than for first-level information. However, second-level information cannot be even considered information until read into an actual intra-cellular regulatory cycle as control. Analogously, first-level (environmentally relevant) structures in DNA cannot be considered information until read into phenotype of environmentally active individuals. Symmetrically, differential reproduction rates of various phenetic features acquire the status of information in OC cycle only when their difference with standard, genetically programmed proportion of phenetic features is transcribed back into genetic change.

Limited information flow from genetic subject to phenetic object constrains expression of genetic variants as phenetic features. Symmetrically, information flow limitations constrain the assimilation of complex features of "environmental portrait" (scanned by the collective of phenetically different individuals) into genome. Differential reproduction rates are only the most primitive feature of this portrait. OC theory includes the tools for describing these constraints: matrices of *controllability* and *observability*. They formalize the translation from genetic into phenetic language and back.

Variability and selection as active sounding. In OC terms, individuals with different phenetic variants generated by virtual genetic variants are a tool of active sounding (see 1.2) — "virtual particles" that test the form of fitness landscape. Active sounding degrades the current value of criterion, but it is an investment in future, insurance against virtual events that could drastically increase the uncertainty and decrease the fitness. "Virtual particles" test the virtual modes of interaction with environment, which may be required at some future time. Information carried by them was generated in genome from scratch, it is virtual, and, unless confirmed by the environment, dissipates as mere noise. If, however, it meaningfully interacts with the environment (e.g., producing differential reproduction rates), it is actualized and intertwined with environmental information as a reference frame coupled with measurement. Then, it can be assimilated back into genome enriching it informationally. This process is known in OC as *multi-particle filter/controller* and, to avoid the degeneration of information matrix, it requires regeneration of differently weighted particles after several time steps — an analog of differential reproduction.

In [Saridis, 2001], it is shown that active sounding carries the risk of forming a parasitic circular information flow when a model error passes through control and observation and returns as a self-supporting model change. This autocatalytic mechanism may be behind the formation of maladaptive features, such as deer's antlers or cock's comb.

3.3 Information flows and natural selection in ecosystems

OC perspectives on ecosystem. Here, we consider ecosystems only phenetically. As in 3.2, the subjects are collective: populations belonging to different species. Control actions are behaviors of species. We consider two ways of mapping an ecosystem into OC framework. One called "*ecosystem perspective*" means taking all species in the ecosystem as integrated subject, the geospheric component of ecosystem as object, and the external geosphere as environment. Another is the "*species perspective*", which means taking a single species' population as subject, the remaining species taken together as integrated object, and the geospheric part of ecosystem as environment. Both kinds of OC, indeed, run concurrently in real ecosystems. There are various types of ecosystem homeostasis, stationary or oscillating, e.g., predator-prey dynamics in the "species perspective" where predation appears as control. In the "ecosystem perspective", a natural model is the distributed control with different species' populations as nodes. They cooperate and compete in their control of the object (geospheric resources).

Information flows. Nodes can exchange information either indirectly through observation of other nodes' controls (behaviors) or directly as in prokaryotic communities where horizontal gene transfer leads to direct exchange of phenotypic features between species. The ultimate source of information is either genetic variability, or environmental variability, or both. In either case, variability is sheer noise until connected to an informational reference frame — phenetic or genetic, respectively. Ecosystems can be described in SD framework by equations of population dynamics including feedback. However, this form does not elucidate information flows. Still, there are approaches that introduce entropic form of proto-information into description of ecosystems [Ulanowicz, 1986]. Currently, this is the predominant method to formulate the maximum principles, which ecosystems should obey (in OC terms, criteria optimized by natural homeostasis).

Natural selection in ecosystems. Natural selection operates on collectives, which corresponds to ecosystem description above. However, it involves two levels — genetic and phenetic. We can describe natural selection, while remaining at the phenetic level, by using the notion of fitness, which belongs to this level. In "species perspective", different virtual behaviors of a species are active sounders of this species' particular fitness landscape (other species' behaviors assumed fixed or changing slowly). Fitness can be measured directly, e.g., by resource consumption; natural selection is the rule translating fitness into population size.

In "ecosystem perspective", different species can be viewed as interacting particles in multi-particle active sounding of the entire ecosystem's fitness landscape. This type of fitness can be defined only indirectly, e.g., in proto-informational form. Then, natural selection is a rule for assigning weights to different particles according to their contribution to collective fitness. Thus, natural selection becomes a *tool* rather than *criterion*, and the criterion is informational. This approach reproduces the OC view of intra-cellular gene optimization; here, species play the role of genes. This analogy suggests another OC framework for "ecosystem perspective": considering the fitness and natural selection of ecosystem as a whole rather than those of individual species.

3.4 Biosphere + geosphere vs. Gaia: biosphere as regulator

Gaia concept. In the foundational approach to geo-, bio-, and noosphere by Vladimir Vernadsky [Vernadsky, 1997], regulation of geosphere by biosphere does not mean that geosphere is a live entity: geo- and bio- add but do not fuse. The notion of "living planet Gaia" goes back to myths but its scientific avatar is associated with James Lovelock [Lovelock, 2000]. Initially, the idea was that biosphere provides a feedback to changes in geosphere and thus participates in global homeostasis. The novelty of this idea is its global scale — its "sphericity". Consequently, this idea was extended to the Gaia concept, which perceives Earth as a kind of living entity. Vladimir Vernadsky's and Pierre Teilhard de Chardin's concepts are coming close to this: the geological history of Earth looks like ontogenesis of a noospheric "infant". Here, we try to look at James Lovelock's concept through the prism of OC.

Information flows in Gaia. In James Lovelock's approach, the feedback, by which biosphere contributes to geospheric homeostasis is automatic and does not involve information accumulation. The question what criterion is optimized in this homeostasis was not put. It is more like energetic/entropic geospheric criteria than like balance between current and future gains realized by genetic mechanisms. However, biosphere is capable of information accumulation, and James Lovelock's approach can be extended in this direction. In OC terms, biosphere would contain a "model" of geosphere — of course, in translated form, like the "portrait" of environment in genetic code. The informational impact of biosphere on geosphere should be less visible in homeostasis than in geospheric catastrophic points induced by internal dynamics of biosphere like the oxygen catastrophe ~2 billion years ago.

From Gaia to noosphere. Even if biosphere could use information for its control of geosphere, this control could have no goal because of the lack of reflection in biosphere. Gaia with reflection would be noosphere. If we see Gaia as a living entity, we can apply to it the notions developed in 3.1 - 3.3 and see the appearance of noosphere as formation of a new "species" induced by internal "genetic" reconstruction of biospheric information structures into much more powerful noospheric information channels.

3.5 Origin of life in OC language

We apply OC paradigm to the origin of life in search of an archetype of "origin" applicable also to noosphere. The archetypal problem, as mentioned in 3.1, is that life can only originate in a leap from "nothing" (from geospheric level) because, to start the OC cycle of natural selection which accumulates information in genome, the basic genome has to be already in place. Manfred Eigen's hypercyclic approach [Eigen & Schuster, 1979] does not fully solve the problem: the formation of hypercycle itself needs an initial investment of information.

The key point is the change of criterion optimized by OC at geospheric level: to become biospheric, it has to incorporate information as insurance against future disasters. The difference between simple and adaptive OC can give a hint at this change of criterion. In the simple (linear quadratic Gaussian — ***LQG***) OC, the criterion is profit minus cost, and the informational term is subsumed within the profit so that information is not a value in itself. In the adaptive OC, information enters the criterion as a standalone term and is explicit and measurable. A virtual control scenario, which is not optimal in the "old" criterion and thus has no chance to be realized, may use information to predict future and autocatalyze itself by means of a "*loan from the future*" (current suboptimal profit compensated by future advantage). Choosing such a scenario is equivalent to switching to a new criterion — an adaptive one with a separate information term. If the subject has some way to memorize this criterion, it can be used further on.

Another example of "originating from nothing" is the current view of the beginning of Universe. In the inflationary scenario, there is a short period of expansion without entropy increase followed by a sharp entropy increase. This archetype can be applied to the origin of life (expansion understood as growth of genetic apparatus). The un-entropic period would give the primeval organisms a respite to accumulate information without losing it in the "error catastrophe". Entropy growth is deferred to a later time when it can be neutralized by already formed genetic apparatus. This is another form of "loan from future".

Noogenesis is yet another example of this archetype. By definition, it is a goal-oriented, reflective activity, but until noosphere appears, there is little goal-orientedness and reflection on the global level. The change of criterion would mean including terms, which represent reflective phantoms associated to how "others" (construed as objects) perceive the subject. Thus, the issue is the relationship between collective and individual. In Pavel Florenskii's terms [Florensky, 2000: 449], there is an essential similarity between microcosm and macrocosm: they are two "spheres" linked by a conformal mapping of one onto the other. In noosphere, individual reflective capabilities, however imperfect and unprofitable in material sense, can be collectively amplified within the model layer and then fed back to the individual level forming an autocatalytic loop, which implants these new information structures. An analogous phenomenon in the distributed OC theory is the feedback from the central node (representing the collective) to peer nodes whereby an informational "insight" by an individual node can be supported if favorable collectively even if unfavorable individually.

This archetypal relationship individual-collective may be applicable to the origin of life. OC originates in two interlinked and similar versions at once: individual within the cell and collective between the cell and its "ecosystem". In early biosphere, the mechanism of amplification is horizontal transfer: paradoxically, parasitic information structures might have been an essential element of the biogenesis.

3.6 Evolution of life as OC and its criterion

Life as OC cycle could have originated only where there were geospheric energy and matter flows driving this cycle. To survive, life had to expand into different environments. This depended, first, on the initial robustness of primeval "model" to breaks of information inflow, and second, on the adaptive potential of information flow. These qualities are well described by OC framework suggesting its expansion into novel "environments". OC approach assumes several characteristics fixed a priori. In biospherical application, they have to be either fixed by natural selection, or frozen to some random value, or provided externally.

Criterion optimized by evolution. The most important of these characteristics is the criterion optimized by evolution. In OC, as shown in Chapter 1, criterion contains two components: "material" ("profit" minus "cost") and informational. In Darwinian approach ("survival of the fittest"), there is no independent way to measure fitness and optimized value is simply the survival rate. In OC terms, the material equivalent of survival rate is the sum of values of individual lives, and the informational equivalent is the genetic information carried by survivors. Evolution balances the weights of material and informational parts of the criterion it optimizes. The weights define the balance between investment in present and in future. Conceivably, the optimal balance depends on the variability of environment and on time horizon. OC has tools for accounting for both. In an ideally stable environment, no investment in the unpredictable future is necessary and the time horizon is infinite. Then, OC is homeostatic, criterion contains no separate information term, and evolution is at a standstill. This is a satisfactory approximation for many species, which survive unchanged from early epochs because environments, to which they are adapted, do not change.

Loan from the future. In evolutionary regime, the current investments into information are compensated by the future gain this information is expected to bring, so that there is a loan from the future. This counterintuitive term is natural in OC where there is information flow directed backward in time. It results in selection of criteria complementary to natural selection, which acts forward in time. Virtual scenarios are optimal solutions to different criteria of control, and selecting one of them is equivalent to changing the optimized criterion. These virtual scenarios are collective; different individuals may realize additional virtual scenarios corresponding to different criteria. Each individual scenario corresponds to a particular mode of interacting with the environment, which may turn out relevant in the future, so that this set of individuals performs an active sounding of the future and brings the information about the results to the present.

Evolutionary bifurcation and speciation. Living systems can emerge from unfavorable extrema of criteria either by increasing the range of variation around the homeostatic state or by "following a perspective mutant". In both cases, there is a price to pay in the form of partial extinction, so that exit is through a bottleneck. This, generally, changes the type of interaction with environment and hence the optimized criterion. Outside the old extremum of criterion and until the system establishes in a homeostasis corresponding to a new criterion, the dominant type of feedback is genetic drift and accumulation of neutral genome changes rather than natural selection. This increases diversity and entropy (transformable into information later on).

While a system does not emerge from a local extremum, natural selection polishes its environmental adaptation up to a limit determined only by genetic and environmental variability, so that the system approaches a "perfect homeostasis". Adaptation accumulates the currently relevant information, information matrix approaches singularity, and information flows become less robust to perturbations. Another component of information — that produced by active sounding — could add to robustness but it decreases because active sounding in homeostasis does not pay. As a result, when the profile of current extremum happens to change drastically, the system risks extinction, being over-specialized to its safe harbor. In contrast, systems that put out to the sea of evolutionary change are permanently in the state of balancing adaptation by natural selection and the accumulation of diversity by genetic and phenetic drift. They never stop unless trapped in a local extremum of their current (changeable) criterion.

Often, emergence from a local extremum is accompanied by speciation. This happens because many control strategies that stimulate emergence lead at the same time to reproductive isolation: spatial isolation, which creates bottlenecks and genetic drift; genetic recombination, which makes the new genome incompatible with the old; phenetic/behavioral "invention" of new lifestyles. Speciation refers to reproduction only, while emergence from homeostasis is a wider notion including new dimensions added to the reference frame, which measures the relevant information. As new dimensions are added, variability in old dimensions is reduced by shielding them from external influence. Shields can be reproductive, spatial etc. This phenomenon is observable both in phylogenesis and in ontogenesis as a visible expression of a hierarchy of information concentration: shells of nuclei, cells, organisms, etc. Each consecutive shell serves as a reference frame for measuring the more concentrated information within it and, hence, for a more refined optimization.

Evolutionary and co-evolutionary information flows. Changes in organisms/ecosystems can feed back on their environment. Defining "environment" is arbitrary: it can be considered an object controlled by a living system as subject or vice versa. Generally, this is a dialog. Therefore, evolution of a species within an ecosystem or of biosphere within geosphere, or of noosphere within biosphere is, in fact, *co-evolution* of both. The Gaia model developed for homeostasis should be extended to co-evolution: geosphere "uses" biosphere, as its most dynamic part, to emerge from suboptimal extrema of geospheric criteria, and both evolve in the process. In co-evolution, what was a noise-like variation of environment in the standard OC picture, turns into dialogical information exchange with a partner. In the system-environment framework, the ultimate source of information is usually identified as environmental variation. As noted above, this view has to be refined: information is first generated "from nothing" within the system (e.g. as genetic variability), but so far, it is *virtual*. It becomes *actual* only when intertwined with the variation of environment, which "confirms" it. Thus, e.g., genetic variation produced by neutral mutations actualizes only when it proves to be useful for a living system passing through a bottleneck. In co-evolution, instead of "system" and "environment", there are two equivalent mutually approving partners, but otherwise the picture remains the same. Each reference frame ("informational environment") is a question, and a system optimized to it is an answer, but each answer is a new question. As Rajneesh (Osho) said, 'we are the walking bundles of answers to questions no one evermore asks'. However, these seemingly obsolete rough drafts are irremovable virtual companions of the actual fair copies [Mandelstam, 2012].

Identity of evolving systems. In the discussion above, we spoke of a "system", which passes from bifurcation to bifurcation, as something with a clear identity. However, in what sense can a sequence of generations, which passes from speciation to speciation, be considered a single "entity"? Does the similarity between ontogenesis and phylogenesis mean that phylogenesis is ontogenesis of a kind? Of course, the "entity" has to be understood as diachronic, like a track of control scenario, which is diachronic in OC and has an identity no less than any instantaneous state. In this view, evolution is an unfolding plot, a paging book. As in a book, the meaning of the plot is beyond its events, in a different plane. The possible meaning of evolution will be discussed later on.

3.7 Proto-reflection: enters goal-orientation

Goal-orientation as proto-reflection. Usually, the existence of identity implies reflection and hence goal. However, we have adopted a definition of biosphere, which makes its self-identification impossible. Nevertheless, the usual language by which scientists describe evolution is goal-oriented and includes "in order to". Note a characteristic formula by Nikita Moiseev [Moiseev, 1999]: "the tension of struggle (between hominids) for the right to become the modern human". Obviously, goal-orientation implies self-perception of one's identity. Even if goal-orientation is a self-projection onto biosphere by the fully reflective humans, humankind can be considered a/*the* goal of the biosphere and this projection is just a downward strand of a vertical self-supporting logical cycle. This cycle is a dialogical solution to a monological question: is humankind for nature as its "brain" *or* is nature for humankind as its resource and support?

Genetic proto-reflection. Genome is, in a way, a symbolic reproduction of environment. Then, its regulatory part (regulome) is a symbolic reproduction of itself supporting the genetic identity, and this comes close to (biochemical) proto-reflection. Another instance of proto-reflection is the unique biochemical identity of an individual organism, as recognized by the immune system. Recently discovered several overlapping levels of feedback in the immune system can be considered as the mechanism supporting its proto-reflective OC cycle.

This identity extends from genetic to phenetic layer since phenetic features are genetic symbols incarnated. Analogously, the entire biosphere can be viewed as a symbolic self-representation of the geosphere and noosphere — of the biosphere. Then, goal-orientation can be backtracked to geospheric level. E.g., accumulation of fossil fuels can be considered as goal-oriented towards energy support of the forming noosphere. This might seem tracking back too far but the strong anthropic principle considered in 2.7 tracks goal-orientation back to genesis of the Universe!

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