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PREDICTABILITY VS. RANDOMNESS IN COSMOLOGY

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Abstract. A role of the anthropic predictability constraint in purely mathematical "theories of everything" is briefly analyzed.

One of the most interesting aspects of contemporary fundamental physics and cosmology is the structure and properties of the future unified theory of matter fields' dynamics, often known in half-jocular terms as the "Theory of Everything" (henceforth TOE). While it is rarely doubted in scientific circles that such theory will be eventually achieved (cf. Barrow 1990), people wildly differ in opinions as to its nature, notably mathematical structure and predictive powers (if any). Probably the most daring and ingenious view of this nature has been recently put forward by the famous cosmologist Max Tegmark in the form of the "ultimate ensemble theory" (Tegmark 1998), or purely mathematical TOE, devoid of any empirical parameters (like physical constants c, η, G or cosmological parameters Ω or Λ). This particular approach to building TOEs consists in insisting that everything that exists mathematically exists also in physical sense. This conceptually simple requirement is extremely far-reaching and powerful, and strongly constrains the scope of the theoretical explanation in natural sciences. It is radical, in the sense that it presents an antithesis to the still prevailing view of empirically-accessible **physical law** (of dynamics), the view which in its modern sense originates with Roger Boscovich in XVIII century.[1] Tegmark's, purely mathematical TOE is the one which answers in the negative the quintessential question formulated by Calude & Meyerstein as *Is the universe lawful?*

Such purely mathematical ("Platonist") TOE has always faced a particularly strong difficulty in how to accomodate the existence of "self-aware substructures" (henceforth SASs), i.e., intelligent observers like us and the special conditions our existence imposes upon our cosmological domain. The central problem here is that we cannot take the role of an external, passive, disembodied observer any more, so we need an additional element to describe the region which is causally connected to us. Following Tegmark, we wish to delineate this region, or "archipelago of habitability" (the term "archipelago" being used since we have no *a priori* reason to assume that whatever conditions habitability implies lie in the single topologically connected regions of the **parameter space**). "Archipelago of habitability" is defined as subset of the entire

[1] "Dear reader, you have before you a Theory of Natural Philosophy deduced from a single law of Forces," wrote Boscovich in the very first sentence of his *opus magnum* "The Theory of Natural Philosophy" (cf. Boskovich 1922).

multiverse in which self-aware subsets (SASs) could be found. What is SAS in general case is more difficult to define and no consensus has been reached so far in this much-debated field. We shall not enter into that discussion here, and will proceed with the assumption that by the time our understanding of multiverse reaches level required for an empirical discrimination of such theories, we shall learn enough in the fields of biology and psychology to define SASs unambiguously. Hereby, we would like to sketch a prescription, or an algorithm, through which the delineation of the "archipelago of habitability" may be performed. It seems clear that first the necessary criteria must be formulated; for the moment, the following three requirements due to Tegmark (1998) seem satisfactory:

I. Complexity

II. Predictability

III. Stability

Obviously, the world without complexity cannot support SASs. This, in fact, is the content of most of the "classical" anthropic selection effects (cf. Bostrom 2002). For instance, without complexity of chemical elements (arising from particular properties of stars which entail the process of stellar nucleosynthesis), life as we know it clearly cannot exist. The development of the algorithmic information theory by Kolmogorov, Chaitin and other contemporary mathematicians (e.g., Chaitin 1982, 1987) enabled us to employ a formal yardstick for measurement of complexity of particular regions in the multiverse and, in particular, our own SAS-supporting region. Although this program of quantifying cosmological complexity is still far from being realized, at least on the conceptual level the correct way to proceed seems clear.

The next step is certainly the definition of predictability as the necessary condition for SASs to appear. Here we encounter serious conceptual problems, since the predictability is commonly understood in two quite different, even partially contradictory, senses:

II.a. the immutability and sufficient power of ("background") natural laws enabling the process of prediction,

or

II.b. the entropy gradient which makes clear the direction in which a physical system will change in time (namely, toward increasing entropy).

It is important to understand fully the difference between the two if we wish to tackle these very general cosmological issues. The book containing these proceedings will not spontaneously turn into a pussy cat due to the property **II.a.** of the cosmological domain in which it is located. However, the book will exhibit some changes, like the change of temperature when brought from the cold outside into a warm room; these changes are governed by **II.b.** and are fully predictable in the colloquial sense of possible derivation of a subsequent state from previous states. Moreover, one may argue that the very notions of "books" and "cats" are possible since the processes in human brain operate in accordance with **II.b**. We can easily perceive the contact point between the two interpretations: **II.b.** entails **II.a.**, since wildly fluctuating natural laws would not allow for the definition of entropy, essential for **II.b.**. Since the Second Law of thermodynamics is a consequence of the very special initial conditions of our cosmological domain ("the universe"), it is easy to perceive that much weaker constraint **II.a.** leaves much room for uninhabitable possibilities (this way of looking at the origin of the Second Law originates with Boltzmann, and is elaborated at length in Ćirković 2003). On the other hand, if the current ideas in quantum cosmology are correct, we need a minimum set of **truly fundamental** laws obeying **II.a.** in order to create any meaningful spectrum of possibilities ("the multiverse") at all!

Thus, it seems that we need to retain **both** of these meanings of predictability in order to get a universe capable of supporting SASs. The precise mathematical form of these requirements is still elusive, and will partly remain so forever, due to the inherent randomness of complex mathematical structures (Chaitin 1982). This is both a good news and a bad news for cosmologist. Even a highly structured and completely abstract TOE as a "Platonist" one will present inexhaustive wealth of opportunities and novelties, due to the celebrated incompleteness theorems of Gödel, Turing and Chaitin; thus, if these TOEs are correct, there will always be jobs for natural scientists. However, the conventional explanatory purpose of a physical theory will unavoidably be injured by the same incompressibility of the truly random part of the (mathematical = physical) world; if one wishes to employ a "Platonist" TOE as an explanatory workhorse in the manner of employing Newton's laws of dynamics to explain the planetary motions, one is bound to be disappointed. In a sense, the "Platonist" multiverse is bound to be unpredictable in the (literally) same sense as the bits of Chaitin's Omega-constant are unpredictable. "Maximal incompressibility" of the information encoded in Omega is the same as the statement that individual pieces of the multiverse will have to be simulated totally faithfully (i.e. without any information loss whatsoever!) on some super-Turing machine in order to predict their behavior.

On the other hand, local interpretation **II.b.** is necessary for our existence, and guarantees not only that we can establish the local flow of time on a macroscopic level, but also that the complexity will eventually decrease due to the inexorable advance of entropy. This has serious consequences for our understanding of the future evolution of our (and, by analogy, other inhabited) domains, and the nascent discipline of **physical eschatology**. However, we cannot enter these considerations here. Neither we can analyze the criterion of stability, arguably the most difficult of the three primary requirements for the "archipelago".

To summarize, we conclude that "Platonist" TOEs must thread a difficult path between the non-complex uniformity and the unpredictable chaos, if they wish to account for the empirically established presence of SASs. Roughly, we conceive the universe (or multiverse) as highly structured yet randomly configured structure, characterized by local predictability in both senses. One way to visualize this is to look at the famous "Print Gallery" by M. C. Escher (Fig. 1). It can be divided into several parts (quadrants, for instance), each possessing internal coherency, which lacks in the overall picture, but the miraculous self-reference property is still present. The viewpoints of the young man in the gallery and the woman on her window above it are incompatible, and yet smoothly connected. In a sense, the "Print Gallery" is a toy model multiverse composed of parts ("domains") defined by the observational selection effects (equivalent to what we call "anthropic principle(s)" in the real universe). The elaboration of these particular effects is a daunting task still to be completed, if this approach to "Theories of Everything" is to be fully developed.

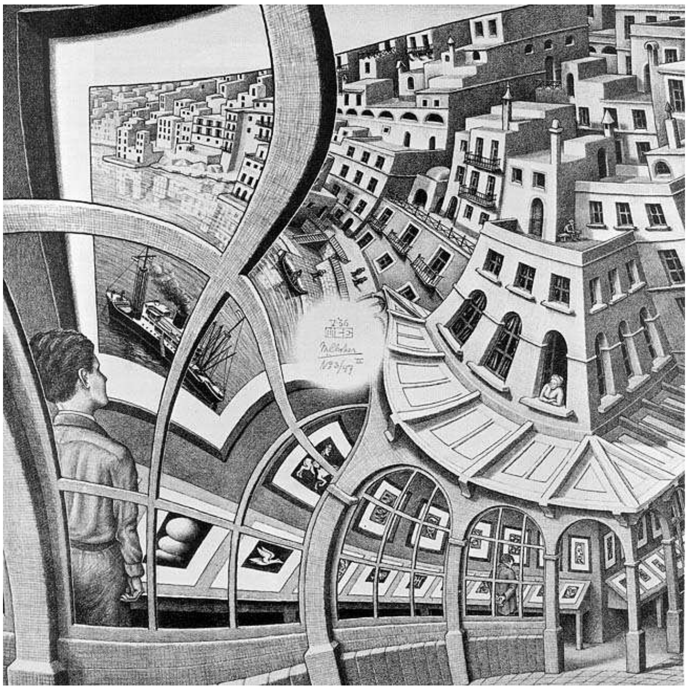

Figure 1: M. C. Escher's "Print Gallery".

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