Emergence of Organization.
On the Co-Evolution of System and Structure.[1]

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It has been shown during the last twenty years that the two essential questions concerning the structure of the world are still unsolved, but may be accessible by means of some suitable approach that is based on aspects of *relationality*, in particular, when following the line of argument as introduced by Leibniz within his philosophy.[2] A comparatively recent book of Lee Smolin's (his 1997 „The Life of the Cosmos", in fact[3]) is one of the crucial sources for relationality in physics: Smolin discusses relationality in the case of classical physics on the one hand, incorporating Einstein's relativity theory in a straightforward generic manner, and in the case of quantum physics on the other. With respect to the latter, an epistemic bifurcation is taking place, because quantum physics is chiefly relational with respect to gauge invariance, but it is still atomistic with respect to the particle description proper. Obviously, traditional atomism puts *simplicity* against relationality's *complexity*. And this aspect is immediately connected to the concept of information: Smolin defines what is called *variety of a system* which is a measure for how much information is required in order to distinguish each part of the system from others by describing their interactions.[4] In fact, the more variety a system possesses, the less information is needed in order to distinguish it from others.[5] It is important to notice here that hence, a completely homogenous universe, as it is often assumed as a starting point for doing standard cosmology, cannot be useful within this context, because it would not enable an explicit extraction of information, very much on the line of the Leibnizian principle of the identity of the indiscernable.[6] This result corresponds nicely to the fact that complete symmetries cannot serve to gain information about states of a system, unless these symmetries are broken from time to time.

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[1] Contribution to the International Leibniz Congress X (2016), Hannover, Panel on Relationality and Information in Leibniz, 19th July 2016.
[2] We do not discuss here the issue whether the underlying concepts of space and time should be actually based on the viewpoint of Spinoza rather than on that of Leibniz. Instead we refer to earlier work for this. See e.g. Rainer E. Zimmermann: Loops and Knots as Topoi of Substance. Spinoza Revisited. In: http://www.arXiv.org/pdf/gr-qc/0004077 v2. (2000) Also id: Spinoza in Context: A Holistic Approach in Modern Terms, in: E. Martikainen (ed.), *Infinity, Causality, and Determinism, Cosmological Enterprises and their Preconditions*, Finish Academy of Sciences Colloquium. Lang, Frankfurt a.M. etc., 2002, 165-186. And finally id.: On the Modality of the World. Space and Time in Spinoza. In: F. Linhard, P. Eisenhardt (eds.), *Notions of Space and Time, Early Modern Concepts and Fundamental Theories*, Zeitsprünge, Klostermann, Frankfurt a. M., II (2007), Heft 1/2, 217-242.
[3] Lee Smolin: *The Life of the Cosmos*. Oxford University Press, 1997.
[4] Ibid., 218. (par.)
[5] Ibid., 220. (par.)
[6] Ibid., 219. (par.)

The whole argument moves within the philosophical tradition as put forward originally by Leibniz, but also by Ernst Mach and Albert Einstein (at least partly), as to physics more recently also by John Baez, Lee Smolin, and Carlo Rovelli, when they are engaged in the development of *loop quantum gravity* which is closely related to *quantum information theory*. Lee Smolin has also shown in a conceptual summary later on[7] that relationality is closely related to *background independence* in space-time physics.

The essential idea is as follows: There are five unsolved issues in modern physics, the problem of quantum gravity, the problem of unification of forces and particles, the problem of explaining the choice of standard parameters, the problem of dark energy, and the problem of the foundation of quantum physics.[8] When starting the discussion in terms of two principles formulated by Leibniz, namely the *principle of sufficient reason* and the *principle of the identity of the indiscernible*, then it becomes obvious that choosing a background at random violates the first principle, while introducing global symmetries violates the second. The same is true for a free choice of parameters.[9]

This point can be clarified by means of introducing active and passive *diffeomorphism invariance*: In fact, as it turns out, physical space-time M corresponds to an equivalence class of manifolds with metrics and fields under all actions of the group of diffeomorphisms Diff (M). Hence, dimension and topology (and thus signature) are coded into M. But all other aspects of M are systems of relationships among events. And the latter are not actually points, but rather coincidences among values of fields preserved under the action of Diff (M).[10] These relations are of two types, namely of *causal order* (relating events by means of the underlying light-cone structure) and of *measure* (relating volumes of sets defined by causal order in the first place). The information about M is then completely characterized by these two.

While the physical aspects have been summarized in Smolin's work more recently, in biology, it has been Robert Rosen who as early as in the 1970s and 1980s developed what was called *relational biology of anticipatory systems* at the time.[11] Different from the physical approaches later on, Rosen visualized the fundamental relations in nature as information transfers between natural systems and their organization as expressed by models. Referring to Gödel's results, he also implies a non-computability assertion whose counterpart in physics may be found in the more general work of Roger Penrose who tries to connect physics with the research on consciousness.[12] Hence, turning back to Schrödinger's essay "What is Life?" of 1944[13], Rosen proposes to discuss the ancient problem in terms of a contextual rather than purely formal approach, and, by doing so, to stress the aspect of complexity. He thus quotes from the Einstein book of R.W. Clark when reminding on a statement of Einstein's in a letter to Leo Szilard, that "[o]ne can best feel in dealing with living things how primitive physics still is."[14] The consequence for Schrödinger was to assume that organisms would be a kind of

[7] Lee Smolin: The case for background independence. www.arXiv.org/pdf/hep-th/0507235 .
[8] Ibid., 7. (par.)
[9] Note that *identity* is also an equivalence relation that satisfies the conditions of reflexivity, symmetry, and transitivity.
[10] Smolin, op. cit., 12. (par.)
[11] Cf. Robert Rosen: *Essays on Life Itself*. Columbia University Press, New York, 2000. (ed. Judith Rosen)
[12] Roger Penrose: *Shadows of the Mind*. Oxford University Press, 1994.
[13] Erwin Schrödinger: *What is Life?* Cambridge University Press, 1944.
[14] Rosen, op. cit., 7. (Rosen refers to R.W.Clark: *Einstein. The Life and Times*. Avon, New York, 1972.)

repositories of what he already called “new physics”.[15] This point has been topical in the later works of Bertalanffy (1952) and Prigogine (1947), respectively.[16] Rosen himself referred explicitly to the earlier work of Nicolas Rashevsky[17] who assembled the methodological and formal elements of this approach, guiding Rosen’s attention towards a formalization by means of (mathematical) category theory.[18]

Now, what we would like to do here in this present paper is to illustrate the relationship between the aforementioned aspects on the one hand, and category theory on the other, in particular, because the essentially categorial concept of “systems of systems” as discussed recently at another occasion[19] is also relevant for the whole-part relation of systems altogether. There is an obvious connection of all of this to the concept of relationality. And the ancient question of traditional philosophy (namely: why there is anything at all, rather than nothing) is found to be equivalent with asking for the *emergence of organization*, if we understand the latter as the relational constitution of systems of systems. We start then from a generalization of Rosen’s approach offered by John Kineman.[20]

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For Kineman, it is crucial to realize that “[t]he holarchical property of natural systems is represented in the case of *categories of categories*, in which the roles of morphism and functor become analogous. Holons may then be treated as special kinds of objects which are dualistic and infinitely holarchical. Specifically we must define two categories and their associated mappings corresponding to the left and right side of the holon; that is, categories representing the dualism between locally *realized* and non-locally *contextualized* causes.”[21] This is an essentially categorial approach that is called *R-theory*, onto which Kineman’s attempt of the aforementioned synthesis is actually pointing. The idea is here to differ systematically between *causal entailment* on the one hand and *contextual entailment* on the other: The one is covered in terms of the morphisms in the sense of categories, the other in terms of the modelling relations which imply complementarity between descriptive and prescriptive potentials of a given system and their generic actualizations mediated by the available information.

In his work Kineman refers to an earlier book by A. H. Louie[22] who gives the most comprehensive presentation of categories within this topical context: Borrowing the

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[15] Ibid., 8. (par.)
[16] Ibid., 19. (par.) (Rosen refers here to Ludwig von Bertalanffy: *Problems of Life: An Evaluation of Modern Biological and Scientific Thought*. Harper, New York, 1952, and also to Ilya Priogine: *Etude Thermodynamique des Phénomènes Irréversibles*. Desoer, Liège, 1947.)
[17] In fact, Rosen was a student of Rashevsky’s, together with Anatol Rapoport. Cf. Rosen, op. cit., 259 sqq.
[18] Nicolas Rashevsky: Outline of a Unified Approach to Physics, Biology and Sociology. *Bull. Math. Biophys*. 31 (1969), 159-198. See also Robert Rosen: Pattern Generation in Networks. In: id. (ed.), *Progress in Theoretical Biology*, vol. 6, Elsevier, Atlanta (GA), 1981, 161-211.
[19] Rainer E. Zimmermann: Systems of Systems as Represented by Categories. In: Emergent Systems, Information, and Society. emcsr2016, FU Vienna, 2016, to be published.
[20] John J. Kineman: Relational Science. A Synthesis. *Axiomathes*, DOI: 10.1007/s10516-011-9154-z, 2011.
[21] Ibid., 21.
[22] Aloisius Ho-Yin Louie: *More than life itself. A synthetic continuation in relational biology*. Ontos, Frankfurt a.M., 2009.

terminology from Arthur Koestler[23], both Louie and Kineman talk of a *holon* which is a unit or item that is simultaneously part and whole. (We see the immediate connection to systems of systems or categories of categories.) For such a holon, there is a logically inverse category which serves the exchange of roles between function and structure. However, it is not quite clear why both authors insist frequently on the re-construction of the Aristotelian causalities, because it is apparent that nowadays Aristotelian logic could be easily replaced by a non-Aristotelian version which comes close to what in the tradition of the nineteenth century is being called *dialectics*.[24]

Nevertheless, the important aspect of this approach is that with a view to the universe altogether, it is possible to extract a consistent interpretation of self-reference: This is mainly because it is possible to introduce a *self-entailment mapping* which is a mapping of some representation of a given system A onto its own generating function f such that simultaneously, $A \hookleftarrow f \wedge A \hookrightarrow f$. But for achieving logical closure, it is necessary to introduce some intermediate result of the action of A, S say, such that the gap between S and f is filled by a suitable context. Hence, what is needed is a complementary entailment that closes the composition of A and f, respectively. And indeed, this shows up as a natural inverse of the generating map.[25]

In order to understand the achievement of the categorial approach, we have to shortly refer back to Louie's work of 1985.[26] The idea is to introduce an object of a formal system S as a pair (s, f), where s is a set and f another set of real-valued functions on s. The elements of s are called *states*, the elements of f *observables* of S. Given two states s_1, s_2, respectively, then an S-morphism ϕ is a pair $\phi_s \in$ Ens (s_1, s_2) and $\phi_f \in$ Ens (f_1, f_2) such that for all $\xi \in f_1$ and for all $\sigma, \sigma' \in s_1$; $\xi(\sigma) = \xi(\sigma')$ implies $(\phi_f\, f)\, (\phi_s\sigma) = (\phi_f\, f)\, (\phi_s\sigma')$. Here "Ens" is the category of sets and functions.[27] In particular, the category D of dynamical systems can be analogously defined: If the dynamics on a set S is a mapping T from a subset of S x R into S (plus compatibility conditions including the initial value property and the group property, respectively), then a D-object is a pair (S, D), where S is a set of states (usually called *phase space*) and D is a set of dynamics on S. Consequently, a D-morphism is a pair of functions ϕ_S: $S_1 \rightarrow S_2$, and ϕ_D: $D_1 \rightarrow D_2$, such that for every $T \in D_1$, the following diagram commutes:

[23] Cf. Arthur Koestler: *The Ghost in the Machine*. Penguin, Harmondsworth, 1967.
[24] Kineman, op. cit., 5. (par.)
[25] Ibid., 18. (par.)
[26] Aloisius Ho-Yin Louie: Categorical System Theory. In: Robert Rosen (ed.), *Theoretical Biology and Complexity*, Academic Press, Orlando etc., 1985, 69-210. – On the controversy about Louie's work see also Claudio Gutiérrez, Sebastián Jaramillo, Jorge Soto-Andrade: Some Thoughts on A. H. Louie's "More than Life Itself [...]", *Axiomathes* (2010): DOI 10.1007/s10516-010-9118-8, and Louie's answer in A. H. Louie: Essays on More Than Life Itself, *Axiomathes* (2011): DOI 10.1107/s10516-011-9153-0. For more general conclusions on this debate see also Paul Cull: The mathematical biophysics of Nicolas Rashevsky, *Biosystems* 88 (2007), 178-184, and Yuri Shalygo: The Kinetic Basis of Morphogenesis, www.arxiv.org/pdf/1503.03321 (2015).
[27] Louie (1985), op. cit., 85. (par.)

$$\begin{array}{ccc} \mathrm{dom}\ T & \rightarrow_{\phi D \times 1R} & \mathrm{dom}\ \phi_D T \\ \downarrow T & & \downarrow \phi_D T \\ S_1 & \rightarrow_{\phi S} & S_2. \end{array}$$

These definitions Louie exploits later on for a definition of organisms in terms of dynamical systems, following the line of argument as presented earlier by Robert Rosen.[28] As we can clearly recognize from the afore-mentioned, this view of dynamical systems is well compatible with what we have said above about the concept of "systems of systems". Note in particular, that observation shows up within this context as a projective mapping. This is actually the convention usually applied also in quantum physics.

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For concluding we go back to relationality: What we realize here is that this concept would be meaningless without the notion of objects and morphisms. However, as it turns out, we have to take care of the fundamental difference between *the world as it really is* and *the world as it is being observed*, respectively. But this does not mean that we would have to dispense with an inspection of the real world altogether, because it is possible, in the tradition of Schelling, to develop a (metaphysically grounded) theory of absolute structure which is certainly a theory of speculative type, which can unfold its heuristic power though.[29] In fact, it is modern physics again that offers us some insight into how such a theory could function: According to recent results in what is called *quantum de-coherence*, the world as it really is can be described as a continuous soup of mixed entangled (coherent) quantum states. Because the world as it is being observed can be cognitively perceived within the context of classical physics (i.e. within a certain macroscopic length and time scale), this can be interpreted as a process of de-coherence that destroys quantum coherence above a certain order of magnitude. Note that only under this action of de-coherence can we actually perceive well-isolated and differentiated objects and their interactions. But in terms of the real world, this cannot be done at all, because there is no possibility of assigning unique states to individual objects due to their intrinsic entanglement. At another occasion[30] I have shown how this (physical and thus mathematically formalized) ontological difference can be utilized in order to re-introduce the classical notion of substance. For us here, it is important to realize that relationality is a suitable concept, if the world is visualized in terms of systems. However, the concept of system in turn, is a concept which is derived on the ground of human cognition. Hence, it is part of the modelling procedures and thus of epistemological nature, but it is not intrinsic to the world and thus not of ontological nature. This is also true for the concept of relationality.

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[28] Ibid., 100 sqq.
[29] Cf. Rainer E. Zimmermann: *Nothingness as Ground and Nothing but Ground. Schelling's Philosophy of Nature Revisited*. xenomoi, Berlin, 2014, chapter 5, 159 sqq.
[30] Cf. Rainer E. Zimmermann: *Metaphysics of Emergence. Part 1: On the Foundations of Systems*. xenomoi, Berlin, 2015, chapter 14, 205 sqq.

For Leibniz, the observable world was macroscopic, and the notion of space was bound to the mutual relation of observed objects. While for Newton, empty space had the role of a container of physical phenomena, for Leibniz, empty space did not exist, because *without objects*, space lost its function in terms of a set of relationships among objects. But the notion of an object was essentially classical then. Spinoza's approach did not possess this problem, because for Spinoza, there was nothing but space, and that one could observe objects simply meant that one encountered a place that was object-like (i.e. the spatial properties were such that its structure was being perceived as material objects for human cognition).

If we follow the idea that the quantum world is more fundamental than the classical world, then obviously, relationality in this traditional sense has to be given up. Not altogether in principle, perhaps, because "entanglement of quantum coherent states" might be interpreted as relationship on a different methodological (and probably also ontological) level, but it turns out as a property that is limited to the treatment of systems of systems after all. Hence, in terms of worldly modality, organization shows up as something that evolves from a certain order of magnitude on. With a view to the concept of "systems of systems", we deal thus with the co-evolution of system and structure. And the beginning of this co-evolution can be localized with respect to the critical order of magnitude above which de-coherence becomes relevant. Nevertheless, the question for the origin of de-coherence (or rather: for its ontological ground) cannot be solved yet: Obviously, when we see the necessity that de-coherence acts on macroscopic systems, this phenomenon is bound to the actual size of objects. All of them consist of elementary particles of one or another kind. Hence, the question is finally, why these particles (or sub-structures) agglomerate at all in order to eventually create objects that fulfil the macroscopic requirement. In other words: We are back to the question why there is anything at all, rather than nothing.