C Since the division in question is the separation between subjective experience and the (supposedly underlying) physical structure, it follows that Capra equates mind with the subjective experience.

« 18 » The amoeba's organization is circular and maintains continual regeneration, as is the case for the oak tree and the vegetative-state person. These are the processes that (according to Capra, §14) Maturana identifies as cognitive. As Capra equates cognitive processes with mind (see A) and also uses the term "mind" to indicate subjective experience (see C), then it should follow that all aforementioned organisms have subjective experience.

« 19 » I hope I have managed to show that such a belief is unfounded. It originates in the naturalistic blind spot for consciousness, and is maintained by placeholder terms like "mind" or "cognition" that encourage the ambiguity as to which domain they are describing.

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Reflections on Autopoiesis, the Signature of Life

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> Abstract • I agree with Capra that autopoiesis is the signature of life and that Maturana did well to reject Cartesian dualism. Contrary to how mainstream biology defines life, I point out that reproduction is a consequence of life, not its origin. Furthermore, I address the questions of whether both autopoiesis and cognition together are necessary for life and whether autopoiesis can be extended beyond the molecular domain. I also have words of criticism for Maturana, who called for "objectivity" to be put in parentheses, and conclude with a reminder that it was Varela who was instrumental in making autopoiesis a household term.

Autopoiesis and life

« 1 » Fritjof Capra's target article is much more than a review. It is the integration of Humberto Maturana's view with most of the main concepts that characterize the contemporary conception of science (including notions such as network, patterns and processes), and the systems view, namely the mutual relations among the parts that constitute a living or a non-living complex structure. Capra focusses on the two most commonly known notions of what he calls the Santiago theory, autopoiesis and cognition, claiming that autopoiesis is the best answer ever provided by science to the question, what is life? And since life on this planet is cellular, and only cellular, Maturana and Francisco Varela, in their analysis, as Capra (§§50ff) indicates, in order to answer such a fundamental question, focus on how a cell works. Their analysis led to a discovery that autopoiesis characterizes not only a single living cell, but any higher form of life. Increasing the complexity of organisms changes the structure, but not the basic organization, an organization that recursively regenerates itself and its boundary. Autopoiesis is the signature of life.

« 2 » If autopoiesis is the best answer to that question of what life is, then why is it not

more widespread and discussed in scientific meetings and publications on life, its origin, and its evolution? The possible answer reveals much of the bias and prejudices of the scientists of a certain epoque. One of these prejudices is: if you do not use DNA as the main agent in your argument, you are out of the game. I remember a discussion between Varela and some noteworthy American biochemists at a meeting expressly organized for the visit of Francisco Varela to the Salk Institute for Biological Studies, where members of this institute repeatedly claimed that life is essentially reproduction, i.e., a process in which DNA is the main hero. (The recursive nature of self-production, as a description of autopoiesis, is misunderstood to mean reproduction of like offspring). This definition is still mainstream today despite the strong objection that Varela and I were offering (Luisi 1993; Luisi 2003), i.e., that reproduction is a consequence of life, not its origin. In order to demonstrate the validity of this objection, one can simply ask: Are there organisms that can reproduce without being alive? However, our opponents were just shaking their heads, considering us naive beginners who did not take DNA seriously.

« 3 » The mainstream perspective still prevails, in the US and elsewhere. Any doctoral student of biology or molecular biology will confirm: life is self-reproduction. As Evelyne Fox Keller (2002) wrote, we live in the century of the gene and this is the prevailing paradigm to which many (if not too many) scientists subscribe. It may take one or two generations before a paradigm shift will occur.

Autopoiesis and cognition

« 4 » The significance of Maturana's concept of autopoiesis gives rise to a very specific question. Maturana and Varela explicitly wrote that "autopoiesis is necessary and sufficient to characterize the organization of living systems" (Maturana & Varela 1980: 82, 112). Does this mean that whatever is living must be autopoietic, and that conversely, whatever is autopoietic must be living?

« 5 » In a paper I wrote together with Michel Bitbol, we pointed out that one main reason why this equation goes too far is the logical discourse: if cognition is a primary feature of life, and if there is an equivalence between autopoiesis and life, cognition should be included explicitly in the definition of autopoiesis. Otherwise, "autopoiesis and cognition are distinct processes, and autopoiesis alone may not be sufficient for defining life" (Bitbol & Luisi 2004: 100).

« 6 » However, instead of considering theoretical models, our criticism focused on synthetic models of chemical autopoiesis. They have the advantage of considering simple laboratory systems. A synthetic model is based on a vesicle made by the surfactant S, with the vesicle that adsorbs chemicals (a precursor of the surfactant S) and by doing so is capable of self-generation from within, either in the mode of homeostasis (Zepik, Bloechliger & Luisi 2001) or in the mode of growth and self-reproduction (Walde et al., 1994).

« 7 » Based on the concepts developed by Jean Piaget (1967), the first point of our analysis in Bitbol & Luisi (2004) was that all that has been said about cognition can be abstracted from the notion of metabolism. When an amoeba or any other living cell chooses the metabolites from the environment and rejects catabolites in it, this corresponds to a dynamic interaction that permits the enacting and the coming into being of both living organism and environment.

« 8 » In particular, Piaget (1967) emphasized two aspects:

- The ordinary homeostatic metabolism that corresponds to the normal life and self-maintenance of the cell. This can be defined as *assimilation*.
- The aspect that corresponds to what Piaget called *accommodation*, in the context of human cognition: drastic reorganization of the subject's scheme of motor activity in order to assimilate new objects. For a bacterium or any other cell, however, we would rather call it adaptation.

Applying these aspects to the case of vesicle synthetic systems (Zepik, Bloechliger & Luisi 2001; Bachman, Luisi & Lang 1992; Wick, Walde & Luisi 1995) in Bitbol & Luisi (2004: 105f), we came to the conclusion that in such systems there is no cognition, not even the lower variety of cognition implied by the notion of assimilation. Therefore, these simple fatty-acid autopoietic systems are definitively not living.

« 9 » Paul Bourgine and John Stewart (2004) arrived at similar conclusions, based on an elaborate mathematical treatment. Their autopoietic three-dimensional tessellation automaton is autopoietic, but not cognitive, and therefore, they claim, not living.

« 10 » So, even though autopoiesis and cognition are indissolubly linked to each other, they are not identical. Autopoiesis is a pre-condition of cognition, cognition is coextensive with life, but since not every autopoietic system is thereby undergoing cognition, not every autopoietic system is a living entity. In principle, synthetic systems in addition to being autopoietic, could be cognitive systems. However, for the systems presented so far in the literature this is not the case. It remains an exciting item for further research.

Scope of autopoiesis

« 11 » Interestingly, Capra (§56) attempts to extend autopoiesis to the Gaia hypothesis (Lovelock 1988). The main argument is that nature and the Earth, in particular, regenerate themselves continuously, and that, therefore, the Earth is self-maintaining. So, is Earth itself alive? This question may take us back again to a previously discussed point, whether autopoiesis is equivalent to life, or whether it is, instead, only a necessary yet insufficient condition.

« 12 » In a personal discussion in his house in January 2017, I recall Maturana strongly emphasizing that autopoiesis is only molecular. He expressed his regrets that he did not put the term "molecular" in the very definition of autopoiesis as this would have avoided much confusion in the literature. Unfortunately, as far as I know, he never put this regret in writing.

« 13 » In this discussion, his emphasis on the molecular dimension of autopoiesis made me wonder and so, as a biochemist who knows that until now nobody has been able to synthetize life starting from scratch, I asked him why, if life was just chemistry, chemists could not create it in the lab? Unfortunately, Maturana did not give me any answer, nor was I expecting one.

Maturana's epistemology

« 14 » Maturana is well known for his statement, "everything said is said by an observer to another observer" (Maturana 1975: 315). According to him, the term "objectivity" must be put between parentheses be-

cause there is no transcendental reality. This, of course, is a very strong affirmation. Perhaps Maturana was too rigid about the subjectivity–objectivity distinction in the daily praxis of scientists. Over twenty pages of my book, *The Emergence of Life* (Luisi 2016), are devoted to discussing this distinction, which from my point of view boils down to saying that any observation is only in the mind of the scientific observer. I objected, arguing that in this way, one could not educate students in the study of nature. In my lectures, I asked the students whether the binding of oxygen to hemoglobin is an objective insight or just my subjective consideration? Obviously, from an educational point of view a good strategy has still to be devised that helps students understand Maturana's revolutionary idea rather than dismiss it as arbitrary solipsism.

« 15 » Another important point in Capra's target article is the part devoted to the mind–body problem. René Descartes aligned it to the dualism between *res cogitans* and *res extensa*, a dualism which has characterized Western science and philosophy for a couple of centuries. Among others, this dualism has made us see the body as a machine and, opposite to that, the brain/mind as a computer and thinking device. In contemporary science and philosophy, mind and body are considered strongly interacting entities. I agree with Capra (§47) when he points out that the Santiago theory is one of these modern views that rejects the sharp Cartesian dualism. The link to Gregory Bateson in §16 is then appropriate. Bateson saw the mind not as a thing, but as a process, and this is what Maturana does when talking about human cognition, i.e., a mental process that has at its basis the circularity of the brain.[1] Maturana's account of cognition adds yet another reason as to why the Santiago theory should be considered a fundamental way of seeing our living world. So, one keeps wondering why, as a theory, it is not more generally cited and appreciated in the mainstream scientific and philosophical literature.

1| A major question is whether the circularity process is fundamentally different in organisms that do not have a brain but a simple sensory apparatus.

Conclusion

« 16 » Today, the term autopoiesis is linked to both Maturana and Varela. I agree with Capra when he emphasizes the historical priority of Maturana: They were certainly an admirable duo of scientists, but Maturana was senior and Varela's teacher. Still, let me conclude with a personal remembrance from our discussions in January 2007. Maturana told me that when they were both working in Heinz von Foerster's Biological Computing Lab at the University of Illinois, von Foerster said that he often could not tell who was the professor and who was the student. What is more, I witnessed several lectures by Varela when he was teaching at the Paris university, and at his conferences in France and Italy. They were always crowded with students, and it was difficult to find a place. Varela "galvanized" the audience with his open, clear exposition. Maturana, on the contrary, was not as outgoing, and his lecturing was often very difficult to follow. So, I dare say that the notion of autopoiesis would be less known today without Varela's many years in Paris and the work he did there, as expressed, in particular, in his co-authored book, *The Embodied Mind* (Varela, Thompson & Rosch 1991).

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