COMPLEXITY VERSUS UNCERTAINTY: THE DILEMMA OF INERT MATTER, LIVING MATTER AND CULTURED MATTER

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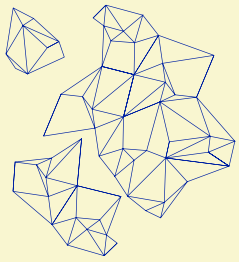

Contrary to what one might think, knowledge is not gained as one gleans the answers, but rather as one searches for the questions. In any proper construction of scientific knowledge, the answer precedes the question. A thinker, indeed, is someone who thinks up questions. The reality of this world takes care of the answers. And so perhaps the greatest of all questions is this:

If nature is the answer, what is the question?

What disturbs us about the world are the answers with which it confuses and astonishes us in our everyday life. Questions serve to address these concerns, reduce them, classify them and communicate them. To come to the realisation that two answers belong to a single question, is the equivalent of winning a point of scientific intelligibility. Understanding is always related to the task of compressing a raft of answers into a common essence —which is precisely the question to which they provide the answer. The greater the mass of answers to a question, the more important the question is and the more knowledge it provides.

A new question can mark a revolution, a new answer or pure routine. Both are important, but the history of knowledge is more a history of questions than a history of answers. A good question seldom ceases to be a good question. A good answer never fully settles a good question. The good question ages well. The question that was

good once will always come back. An old question can always be rejuvenated by a new answer. Answers, on the other hand, even those that have once been good, age badly. Answers are forgotten, or gather dust on the shelves, however glorious a past they have had.

There are even eternal, inevitable, old, ancient questions, questions with a long pedigree which reappear, and although they are asked with no new nuances, still represent a revolution for knowledge by the mere fact of their reappearance. These tend to be questions of a broad spectrum, rejuvenated by the context into which they happen to fall. And it is one of these questions that interests us here, as a starting point for this essay. Depending on how, where and in what circumstances it is asked, it can be either a banal question or a truly groundbreaking one. There is nobody who at one point or another has not asked this question with a sigh, or who has not been eaten up by it in a crisis of angst. There is no scientist, from whatever discipline, who has not given at least a few seconds of his time to exploring it; There is no philosopher who has not finally tackled it, after shying away from it time and time again; there is no politician, economist, judge or religious person who does not at some point think about it, when it comes to regulating the coexistence of people... Few treatises on natural science can avoid alluding to the question in the very first line of the first paragraph of the text. Several books, all well known, bear the same omnipresent question as their titles. And this is the question:

What is life?

There is inert matter, living matter, intelligent matter and civilised matter, and perhaps there are no more than these four main types of matter; this much is true, but what is life? In our current everyday life and in the context of today's scientific thought there are certain objects, certain events and certain concepts that look like answers wandering in search of a question of this calibre. Think for example of the following: a bacterium, a eukaryotic cell, a simple metazoan animal, a plant, a complex organism, a one-mother family, a herd or a colony, a society, a city... a citizen! A company, a museum, any institution... progress!

One might say that all these concepts are indeed related to living matter, that they are living concepts; one might say that we need to rethink the question with a different intelligibility, with a new intelligibility in which there is a place for all these answers... The plan is to start from a new question, to explore the panorama of alternative answers and later try to put new questions out for discussion on... and this is the question... on the way human coexistence is organised! The new question is:

What is a living being?

The main novelty consists of substituting the general idea of *life*, or of *living matter* by the idea of the *living being.* In real terms, this could be said to be a smaller question, a question to be tackled after clarifying what life itself is. It seems like a question that is trying to smuggle a new concept in by the back door, the concept of the individual. Perhaps not, perhaps the concept of the living individual is more easily defined than the concept of life; perhaps even one is possible to define and the other is not...

What I propose as an answer, after a brief review of the physics and mathematics of the second half of the twentieth century (however modern it may be, for a few years we shall have to speak of «last century»), is as follows:

A living being is a piece of matter that tends to maintain a complexity that is its own, regardless of the uncertainty of its surroundings.

The new definition has certain curiosities, certain advantages and some disadvantages. Let's take a look. Its meaning is broad and it is valid for a cell, a bolt factory or a composer. (From here on, I invite the reader to make a continuous counterpoint, keeping the case of human coexistence in mind). However it encloses a tense and transcendental issue. Behind the term BEING hides a slippery and highly controversial concept, the concept of the individual. The benefit is another central question:

What is an individual?

First problem. The concept of the individual may be a very confusing one in living matter; indeed it may have no meaning at all. My friend, the great botanist Francis Hallé, highlighted this problem in the case of plants. In principle, naturalists tacitly base themselves on three criteria when speaking of individuals:

1. The criterion of divisibility (etymological): the living individual ceases to be such if we split it into two equal halves.
2. The genetic criterion: the individual has a genome that is stable in space and time (its parts have the same genome and have it throughout the life of the supposed individual.
3. Immunological criterion: the individual is a functional singularity capable of distinguishing its self from its non-self.

At the level of organisms, animals clearly meet the criteria, but this distinction is not as clear at other equally interesting and transcendental levels of the biological hierarchical organisation, (cells, families, herds, societies, etc.) We shall return to this subject. Plants, however, flagrantly violate the first two criteria and paradoxically, and although

they have nothing similar to an immune system, are capable of distinguishing, to some extent, their self from their non-self, as demonstrated by certain basic events of pollination (plants which pollinate neither themselves nor plants of other species).

The definition of the living being, indeed, proposes a wider, less zoocentric, concept for the living individual, and one which more fully satisfy the intuitions driving the initial question. The individual —let us say perhaps the living individuality—is that complexity (or identity) whose independence is questioned with regard to the uncertainty of the surroundings. There is no circularity in the proposal.

Yet we need to say something about this second important term, the complexity of the individual. Any individuality has a complexity which can be measured by the variety of different states in which it can exist, i.e. by its particular panorama of available alternatives. An earthworm is a less complex organism than a jaguar, because it has fewer sensitive parameters (temperature and humidity in the former case; and a host of them in the latter); and a jaguar is less complex than an elite soldier with all his supplies of weapons, instruments of observation and measurement and communication apparatuses. A field of crops is less complex than a wild forest, which is in turn less complex than a botanical garden.

The third important term in the definition is the uncertainty of the surroundings. Nothing could be easier to interpret: following the same line of thinking, this term is no more than the biocentric name for the complexity of the rest of the universe, of the living being's surroundings. The greater the number of accessible states an environment has, the more uncertain and, in principle, unstable the landscape in question is. In the depths of the ocean, tens of thousands of metres down, in complete darkness, the temperature, for example, does not change even a thousandth of a degree all year round. There is only one accessible state and hence the surroundings have a very low degree of uncertainty. A tropical rain forest can be found in many different states; its uncertainty is high. To sum up, the most general state is the intermediary case; and we could say that there is one sure thing in this world: that the world is unsure. Here another question raises its head, and one which has all the appearance of being fundamental.

What relationship is established between the complexity of a living being and the uncertainty of its surroundings?

In other words, are there prestige laws or models in the essential sciences that regulate the relationship between such important quantities? If so, there is no doubt that new angles are gained into ultracomplex systems, such as that of human coexistence, to subject them to debate and to the attention of the experts. We have come to another

crucial question and we will come straight back to it. It deserves special attention.

And to complete this analysis of the concepts of the initial definition, the most novel term of all: *independence*, perhaps the key term in these notes. In effect, an inert being adapts tamely to the conditions of its surroundings. The laws of physics force an exchange of matter and/or energy until calm is restored, until all that had to happen has happened. Thus, for example, a glass of water taken from the refrigerator and left in a warm room will end up coming to room temperature — or to be more exact, it will end up fluctuating in unison with its immediate «rest of the universe». In contrast, what the homeothermy of any mammal guarantees is a much smaller fluctuation and a regulation in the living body, independently of external fluctuations, i.e. in practice the temperature remains constant. The air conditioning in our comfortable modern facilities is an extended version of the same idea. A living being is not only thermodynamic, in other words, it does not consist solely of exchanges of matter and energy. It is here, perhaps, that previous attempts by physics to explain the phenomenon called life have come to grief. No equation or law of physics includes the exchange of the three magnitudes at the same time to describe the way in which a living being can exchange matter, energy and information by simply fulfilling the great dream of any living being: staying alive, in other words, according to our proposal, tending towards an independence from external fluctuations.

Independence is a concept that satisfies, indeed, some very important aspects in the process of building scientific thought, albeit they are in fact pre-scientific aspects: the intuitions. Staying alive means maintaining a certain independence. And now, listen carefully: is it possible to do more than just stay alive? Perhaps it is; perhaps one can increase such independence. Why not call this term progressing? And so another question is resurrected with strong anthropocentric, cultural, ideological, and even political connotations, but starting —and this is its merit— from an entirely non-anthropocentric basis (as a biologico-centric maxim), outside culture and clearly apolitical...

What is progress?

Let us start by saying that one's strong intuition (mine, at least and I would imagine that the same is true of any physicist) is that progress exists, whatever Stephen Jay Gould might say (and the fact is that he does say it and very well, too). Whatever definition of progress we pick, one's strong intuition is that something happened between the birth of the first bacteria and the birth of William Shakespeare. And let us rapidly go on to mention, above all, what is *not* progress; in other words to briefly list all the concepts of progress that have already fallen by the wayside because they did not manage to contribute to giving such a

noble concept scientific status. For example, we can say that progress does not consist of increasing the number of individuals in a species, its mass, or its volume (it would be too much to have to admit the superiority of bacteria). Nor does progress consist of increasing the chance of survival over the next ten thousand years; such probabilities are simply incalculable... Nor does progress consist of increasing the volume of information in the genome; if that were so, we would have to make way for animals such as salamanders —and justifications such as «redundancy versus noise» would be little consolation. Let us see:

A living individual is said to go from a state A to another more progressive state B, if it increases its independence vis-à-vis the uncertainty of its surroundings.

A good marker of a landmark in progress is that what separates the «just before» from the «just after» is precisely a gaining of independence. Here is a list of progress landmarks, all taken from the evolution of the hominids to practise on:

Bipedalism
Stoneworking
Fire
Conscience
Abstract Knowledge
Arable And Livestock Farming
Money
Credit Card

Compare the gains in independence achieved between the befores and afters of these achievements. Think, to take just one, about fire: independence from predators while resting on the open plains, independence from major fluctuations in temperature, independence from fortune in finding digestible food, independence from the day ending at twilight...

And now a few pieces of good news. The first is that the concepts we have introduced, such as *complexity, individual, uncertainty and independence,* may be addressed using the equations represented by the laws of physics and mathematics, which confer hope for the formulation of something as basic as the concept of *progress*. In other words, they are concepts that acquire scientific status, in contrast to their predecessors: identity, aliveness, adaptation...

The second good news is that we already know why the key question —*What relationship is established between the complexity of a living being and the uncertainty of its surroundings?*— ran aground, which of course is still bad news. There is no way of including the information term in Gibbs' equation that would regulate the exchange of mass and energy between an open system outside the balance and its surround-

ings. It is not possible. The equations of physics refer to matter and energy. Mathematics refers to information. How can we reunite the two disciplines and thus explain the vicissitudes of a living being against the uncertainty of its surroundings?

The third good news is that it is possible to find a way. What I have proposed was published in *Biology & Philosophy* (Jorge Wagensberg, «Complexity versus Uncertainty: The Question of Staying Alive», *Biology & Philosophy* 15: 493-508, 2000). The article cannot avoid questions on physics, biology and philosophy. I decided not to send it to a journal of physics because of its strong biological content and so I sent it to a journal on theoretical biology, in which I had previously had work published. However they apologised and said they were not qualified to assess the philosophical scope of the proposals. And so in the end it appeared in a journal of philosophy of biology, which accepted it immediately without the least qualm about the judges' qualifications with regard to physics and biology. The publication sets out the basic equation of a living being versus its surroundings. Translated into the concepts introduced here, this fundamental equation would read as follows:

The complexity of a living being, minus the complexity of said living being conditioned by the behaviour of the uncertainty of the surroundings, is identical to the uncertainty of the surroundings, minus the uncertainty of the surroundings conditioned by the complexity of the living being.

There are two new symmetrical concepts. The first is the range of alternatives that remain open for the individual, once the conditions that regulate the uncertainty of the surroundings have been fixed (or are known). This term is no more than the system's capacity for *anticipation*. The fewer the alternatives, the fewer the doubts and the greater the anticipation. Let us call it simply that, anticipation. Clearly, the perception of the outside world, the immune system or knowledge per se, all favour anticipation. The other term is symmetrically stated and refers to the range of alternatives that are open to the surroundings, once the system's diversity of behaviours has been established. To name things biocentrically, i.e., from the point of view of the living being, one can choose two large families of alternatives: *mobility* (or capacity to move surroundings) and technology (or capacity to change *the* surroundings). In plainer words, we could simply say:

$$Complexity + Anticipation = Uncertainty + Action$$

From a mathematical point of view, this is more than just an equation. It is an identity. Equations are only satisfied for certain values of the variables that we call «solutions». An identity on the other hand is satisfied, must be satisfied, for any value of the variables. We are

therefore looking at a very strong law, the inviolable and foolproof balance of all the alternative ways in which a living being, faced with the threat of its environment, can seek to fulfil its greatest dream: that of staying alive.

If certainty increases, the individual can try to maintain its independence, i.e. to go on living in various ways or combinations of such ways:

By increasing its capacity for anticipation (perception, immune system, intelligence, knowledge, etc.), its mobility (agility, speed, distance, diversity of resources, etc.) or its technology (nests, tools, etc.). Another two solutions at other scales would consist, on the one hand, of isolating itself (or almost), as in the case of seeds, spores, latency, hibernation, lethargy, etc. This is passive independence, the solution that is based on not expending anything and not risking anything thus to do nothing... waiting for better times to come. The other solution consists of renouncing one's own individuality to adopt another, new, generally higher individuality in the hierarchy of biological levels. This is the new independence of the anthill vis-à-vis the ant. It is achieved, for example, through sexual reproduction, or by coming to an agreement with other individuals. This is the case of the prestigious *symbiosis* (between different species) or of the famed *associationism* within the same species (families, herds, societies, cities, etc.).

What is clear, however, is the path that has been taken first by hominids and later by humans: knowledge. Where, in our context, does this strategy fit? Clearly it is anticipation. The independence gained by the human being and by human organisations can be traced a long way back in time, but always within the term we have called capacity for anticipation. The historical process is well defined.

There was a time in which there was life, but no intelligence. Living individuals did not learn anything new during the time they were alive. Their behaviour was written into their genes. An ant can have a complex and sophisticated behaviour, but to innovate it has no alternative but to become another species, i.e., to mutate. It is at Level I: it anticipates with canned intelligence, i.e., without intelligence, or at level zero of intelligence. But one day we moved to a new level of performance, precisely because the owner of this new intelligence could, for the first time, react to uncertainty. We define this Level II as being that which, when Plan A fails, is capable of finding a Plan B. The jump from Level I to Level II is a monumental one. One invertebrate, the octopus (and it may be the only one), already has an intelligence of this kind. This can very easily be shown by experiment. An octopus will try to eat a lobster that is corked up inside a bottle; first it will try to get through the glass directly (Plan A). Having failed, it will open the screw top (Plan B). The octopus has learnt and its discovery will serve it to overcome small fluctuations in fortune when it comes to eating and not being eaten. Level II Intelligence, of course, responds to a select and inscribed instinct, hunger. And it

turns out that the uncertainty of the environment can pose unsolvable issues for Level II intelligence; for example, in cases in which two instincts contradict each other or compete in space and time when it comes to making a decision. At this point, Intelligence III, which is capable of administrating instincts, may emerge. A dog (which is not a horse or a sheep) can respect a carpet however strong the urgings of its bowels. However, it is Intelligence IV, the intelligence that accesses intelligible knowledge, that has given its owners a memorable victory of complexity versus uncertainty.

I believe there are three types of pure knowledge, as I have sought to demonstrate in the essay *Ideas sobre la complejidad del mundo (1985)*. These are *scientific*, *artistic* and *revealed* knowledge. In other words, any type of knowledge is a weighted mixture of these three. But we need to be careful. There is one aspect that is of particularly interest in the context of this debate. Only one of these three types of knowledge is, in principle, designed to order, so that it functions to favour the *capacity for anticipation*. This, of course, is scientific knowledge. The three basic principles guarantee three different and complementary aspects of the capacity for anticipation: *the principle of objectivity, the principle of intelligibility and the dialectic principle*.

Let us speed events up. The conceptual diagram that starts from the definition of a living individual and from the fundamental laws of nature provides new concepts and new relations with meaning and scientific rigour that deal with nothing less than the alternatives a complexity faces for progressing in the face of the uncertainty of its environment. The idea now is to see whether these concepts, renewed by their new scientific status, can enrich and illuminate the debate on the way human coexistence is organised. Complexity, uncertainty, progress, independence and fundamental identity are, I think, new clues for new debates in this new century. I have drawn up a few notes with which to begin the exercise:

1. At what level of individuality is the concept of independence a priority? What is it that needs to progress? The person, the family, the group, the city, society?... The thinking individuality is that of the individual; it is a mind... What a city should do for example would be to safeguard the independence of its citizens.
2. Progress is considered at any level of individuality; it is true, and it is based especially on the elaboration of new knowledge, the only thing that can face up to environmental uncertainty in space and time. An individuality, therefore —whether it is called a person, a family, a group, etc.— makes the final leap to modernity when it discovers that it cannot renounce either scientific research or scientific method; that there will always be new knowledge which no other individuality will make freely in its place.

3. Throughout history, two forms of knowledge in particular have been used to organise coexistence: revealed knowledge and artistic knowledge. Scientific method is recent and on it is based, for example, modern democracy. It is therefore important to disseminate not only the contents of science (its accomplishments), but also its method and its practice. It is an idea that will help mature democracy itself.
4. Progress does not in any way mean an accumulation of extensive magnitudes, an increase in effectiveness and a reduction of risk, but rather the gaining of independence vis-à-vis the uncertainty of the medium. This requires mobility and systems that will generate innovations. There are certain ideas that favour this new concept: stimulating forums for meeting and conversation (more cafes!), the promiscuity of knowledge, xenophilia... Two enterprises that merge increase in size and in their capacity to absorb fluctuations by momentum. This is only good if, overall, it does not affect the degree of independence.

Humankind has colonised the planet with scientific knowledge and method, but paradoxically does not use them outside the laboratory and the science classroom. In other words, human beings use science to live, but not to coexist. Starting to break down this contradiction is perhaps the beginning of the new paradigm.