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Knowing Reality: What Is Scientific Truth?

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DOVE ABITA LA VERITÀ?
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What is scientific truth

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We have to distinguish the truth in logic and mathematics, that is, in formal sciences, on the one hand, and in natural sciences (physics, chemistry, biology and so one) on the other hand.

Truth in mathematics

Sometimes one confuses truth and provability. But it is important to distinguish the former from the latter. Provability of a statement is its property to be deduced step by step from the axioms of a formal language using the rules of deduction (the logical rules). This is a purely formal or syntactic process. On the contrary, the notion truth of a statement of a formal language requires to work with a model of this formal language.

What is a model? It is a collection of intuitive objects (intuitive natural numbers, intuitive points, lines and planes in geometry etc.) in which the axioms and the theorems of a formal language are satisfied. If we are considering formulae or axioms in a given formal language, we can build what one calls an interpretation of this language, translating the formal statements into statements that have some meaning in the collection of intuitive objects we are using. Let us take a simple example: let us consider the formula X*Y ⇔ Y*X . One gives the set of intuitive natural numbers (0,1,2,3,…) If we interpret X and Y as intuitive natural numbers, ⇔ as the equality on the set of these numbers and * as an addition, the interpretation of the formula is satisfied and one can say that the set of intuitive natural numbers is a model for this formula. What is worth noting is that we have not given a formal definition of the natural numbers. We took as granted this set and we considered it as pre-understood. This is a kind of mathematical reality, a "*res*", a mathematical "thing" to which the formulae are referring.

Thus, in mathematics and even in logic, we have already the prefiguration of a correspondence between a sentence in a formal language and a kind of objects of thought (a mental reality). Mathematics is in fact performing a kind of internalization of a correspondence between the language and the alterity to which it is referring (and that gives it its meaning).

Even in mathematics the truth correspondence is very rich. A theorem proved by Gödel proved that every non-contradictory formal language has a model. There exists always a way to define truth if you start with a coherent thought. But there is more! Löwenheim and Skolem proved that if a formal language has a model of infinite cardinal, it has models of all cardinalities. This is surprising but also very interesting with regards to philosophy. Because it means that a language (sufficiently rich) is unable to grasp univocally the correspondence to a "world" that is describing. Today there are many very deep works concerning the links between language and the collection of all its models (what is called the category of its model). Olivia Caramello and Laurent Lafforgue wrote nice paper describing a category involving a universal model of a language, a model that is generating all the models of the language and containing if you want the core of the language's semantics. The truth in mathematics is thus not only contained in formal axiomatic but it emerges from the links, the back and forth between this axiomatic and its models.

It is really important to grasp this model idea. The contemporary logic has given many important results concerning the mathematical truth. Let us refer to first to Gödel's incompleteness theorem. The the theorem states that in any formal language that involves the axioms of elementary arithmetic (Peano axioms) there exists always a statement that is not provable, its negation is also non provable but nevertheless this statement is interpreted as true in an intuitive model. Thus contrary to what Leibniz and also Hilbert sais there exists truth that are not provable. What is very important here is to realize that truth is not completely computable! Indeed, a proof is a step by step process that produces a theorem from axioms in finite time. But this is precisely what a computation is. Gödel theorem shows in a certain sense that truth in formal sciences cannot be completely be obtained by a computation, by an algorithm. Intuition and reflection is needed.

In mathematics there are many questions that cannot be answered using only algorithms, computations. For example, let us mention the famous Turing Halting problem. You address the following question: if I give you an arbitrary computer program and also some arbitrary initial data that can be introduced to launch the program. Is there some general algorithm able to decide if a machine using this program and these data will stop or not? The theorem of Turing answers negatively. There does not exist such an algorithm!

Even if we consider complete formal language – i.e. language such that any truth is provable (and any theorem is true in all the models of this language) – it does mean that one could decide by an algorithm if such particular statement could be proved? We can understand this using Turing's theorem. To prove that a particular statement is provable is the same as to prove that there exists an algorithm (the proof) that will stop if we use as initial data the axioms. But the theorem says precisely that there exists no such algorithm! Thus, if we consider for example the first order predicate logic, the Aristotelian logic of syllogisms, this logic is complete (every true statement in a model is provable) but there is no general decision to decide if this statement is provable or not. In order to know if the statement is provable we have to prove it and for that we have to need some intuition, some hints, some clues, etc. that are emerging in the mathematician's thought but are not produce immediately by an algorithmic procedure. To reason about the truth is thus more than a computation.

Maybe you are considering that this detour inside mathematics is not necessary to study the status of the truth in sciences. But it is important to refute some new epistemological assessments of natural sciences.

Questioning the reference to a theoretical scheme

Today there is a questioning concerning what science is about. And there exists a trend saying that theory is not yet needed. We need only data and analysis of these data via artificial neural networks that performed deep learning and extract regularities without an a priori explanatory scheme. Let us quote for example the paper published in June 2008 by the redactor in chief of the famous review *Wired*: "The end of theory: the data deluge makes scientific method obsolete" or the paper written by Schmidt and Lipson (*Nature*, 2009, 324, pp.81-85) on "Distilling free-form natural laws from experimental data". They did not presuppose the principle of mechanics and derived laws only from experimental data. This means that science could be derived from algorithms that not only reproduced the observations or the experimental data as in the classical conventionalism of Pierre Duhem and Henry Poincaré (sciences are only saving the facts – *Sozein ta phainomena*, *salvare apparentias*!) but gives you a path to theory. However, this is questionable since, as we have seen, truth implies some intuition, some thought in order to choose axioms and to find the details of a proof even in formal sciences.

Is there some hope to find truth in natural science? Crossing the points of view and discovering stable invariants!

The question here is to know if science can effectively build a correspondence between a theory and a reality? One can object immediately that this reality is described by a theory then we cannot be sure that the reality is not produce by the theory of by the instruments used to detect some features of reality.

In order to answer this question, we have to dig deeply inside the scientific practices. And what is interesting is to discover that all the structure of the scientific activity is in fact organize as if the intention would be to track an alterity, a reality at least partly independent from us.

Let us start with experimental or observational practice. All the experimental protocols in physics are organized to extract data that are stable under some changes. The physicist has to be sure that the signal, revealing a reality, is not produced by the instrument itself.

Examples:

(A) *The discovery of the CMB: Penzias and Wilson, Dicke and Peebles*

In 1964 Penzias and Wilson detected some noise in the signal coming from a radio-telescope. Their aim was to improve the quality of wave transmission between continents. They tried to eliminate this noise using several means: cleaning the antenna (trapping the pigeons flying around the antenna) changing the orientation of the antenna. The noise remained. But at a certain moment, Dicke and Peebles (he just received the Nobel prize of physics some days ago!) realized that the energy of this noise corresponded exactly to the temperature of the universe if the latter would have expanded as Lemaître cosmology said. The theoretical prediction coming from Lemaître big bang cosmology was therefore put in connection with this stable and invariant observation made by Penzias and Wilson.

This observation of the Cosmological Microwave background (CMB) temperature, was important because it showed that the steady state cosmology of Bondi, Hoyle and Gold was in fact not true! If we consider only the expansion of the universe that is well confirmed by the observations on the galaxies steady state cosmology could have had some truth value. But if we cross this observation with the discovery of the CMB the steady state cosmology is not at all valid because it cannot explain the dense and hot state of the early universe implied by the CMB. The rejection of the CMB shows that truth (a relation between our instruments and something that is invariant under the change of point of view or instruments) is at the foundation of the scientific activity.

The question very often arises to know if cosmology reached a truth, in the sense is able to reach a correspondence between a theory (a cosmological model arising as a solution of Einstein's equation of general relativity) and astronomical or astrophysical observations. In fact today cosmology is become precisely a real scientific field because it is able to show that theoretical statements can be confirmed by very different approaches. For example: we can extract information on the early universe using a deep study of the CMB, but we can follow a very different track studying the observation of the amount of chemical elements (the ratio between helium and hydrogen) that is depending on the conditions at the beginning of the universe. These different observational tracks have to give you converging results. If not, you have to give up some features of the model or even the model itself.

In the same vein, I know a very interesting work dedicated precisely to reject some theoretical models (Randall-Sundrum) based on "branes" (parallel universes). If these parallel universes exist, we can predict that some particles could be observed coming from them and the detection could be a clue for the existence of the "brane". This work would have no meaning without the idea of truth as a correspondence between a theory and some realities existing in the "branes" and that could be detectable in our universe.

(B) *N-Rays of Blondlot and the "anomalons"*

Blondlot in Nancy (France) and his students pretended that they have discovered in 1905 a new type of rays (like X-rays) called N-Rays (N for Nancy!). But in fact it was not true. It was only a side effect of the observations (more precisely of the photographic plates used to detect the effects of these rays on cathodic rays). An assistant changed the experimental device removing the source of N-rays, and in fact one realized that they did not exist, nearly everybody continued to observed N-rays in the absence of the source but they observed something else: a phenomenon that emerged from the plates! Long after, some teams pretended to have discovered nuclei with extremely high weight (the "anomalons"). But in fact the signal was in fact produced by the detection instrument and not by a nuclear reality. Modifying the instrumentation device showed the instability of the signal and the absence of the "anomalons".

(C) I want to emphasize some important point. In physics now we are tracking side effect or the noises in order to exhibit something that is not dependent on noise. This is done frequently, using numerical simulations, modeling noise coming from the environment. Signal analysis is a very important task and it is dedicated precisely to detect and information that is stable and independent of the background noise. In the CERN this is vital to detect new particles such as the "Brout-Englert-Higgs boson" for example.

(D) In Biology we have the same conception of truth. If you consider for example the theoretical proposition that snakes have in fact emerged evolving from the lizards that lost their legs. You cannot be content only searching some fossils (and comparing morphologies). You try to complement this observation by other ones: for example, epigenetic mechanisms explaining how some dialog pathways between genes have disappeared in the snakes. And this can be done performing experiments on snakes.

All observations and experiments in natural sciences are based on a methodology that is trying to extract a "signal" that remains stable under changes: change of instruments, change of point of view, etc. But this can only be understood if you are considering that science is trying to establish a connection between a language and a reality that is at least partly independent of the scientific point of view.

The frequent objection that we are not able to bring to light reality elements because our theories and instruments are always dependent of us is not defensible. Indeed, the stable crossing point of many approaches that are depending on us, on our languages and understanding, can bring us something that is independent on us. Thus truth has a meaning: it is a link that is established between a point of view, a result and a reality by the mediation of a stability or invariance proof that highlight an invariant under point of view changes. It is worth noticing that if we would not have been able to change our point of view or our approach, we would not have been able to reach some reality element and a truth relation. But in general experimental or observational scientific activities is precisely the implementation of an invariant extraction procedure.

The search of truth is written in the structure of the physical theory? The requirement of covariance!

Let us have a look now at the structure of the mathematical theory of physics. There is something that is very interesting. The theory has to be *covariant* under some transformations. And this is a general feature of physical theories: in classical mechanics, equations have to be covariant under the Galileo group (the form of Newton equations for example does not depend on the change of inertial reference frames), the Einstein special relativity theory is covariant under the Poincaré group (Loretnz group and translations), Quantum mechanics is invariant under unitary group etc. Covariance groups are at the root of the building of all theory of physics. We impose a covariance group of transformation, then we build a Lagrangian and then we compute the fundamental equations using a variational principle. There is a link between covariance group and invariant quantity that corresponds to quantities to be measured. The covariance expressed the possibility to exhibit something that is not dependent on particular reference frames, scales or point of view. And the link with the invariants quantities (that is a consequence of the famous 1918 theorem of Emmy Noether) revealed that the change of point of view leads to the possibility to highlight some element of reality.

To make a long story short, we can say that the algebraic structure of physical theory implements the necessary condition of exhibition of elements of reality and thus of the necessary condition to link the language to an alterity : thus one can say that in its structure the theory implement the necessary condition of the truth relation.

The requirement of this covariance would be meaningless without this quest for the truth, without this quest to establish a link to reality.

Commensurability and truth

An important point here is to note that theory that are discovered in theoretical physics at different times are not at all independent. Sometimes some philosophers pretended that the history of physics is described by paradigm changes and that those paradigms are not commensurable i.e. cannot be compared having radically different conceptual frames. But it is not true. In fact quantum mechanics for example that is very different from classical mechanics can nevertheless be compared with the latter. The algebraic structure of quantum mechanics is in fact a noncommutative deformation of the symplectic structure of classical mechanics (the Poisson brackets of classical mechanics become the commutator of quantum mechanics!). If one studies the general relativity we check that the limit of this theory when the speed of light is infinite and the gravitational field tends to zero is in fact the classical theory of Newton of universal gravity. Then one can say that something is preserved in the theory that is invariant under theoretical change. And this is the clue of some truth relation: relation to a reality that is not invented by our languages as a thought artifact.

In renormalization theory we can build some theories describing a reality involving many scales. And what is interesting for us is the fact that what is physically relevant is the invariance under scale change. Some irrelevant parameters are vanishing during the renormalization process and what is important is what is preserved as an invariant under scale change i.e. under observational point of view.

Conclusion

Even in formal sciences, the truth relation (the relation between formal languages and models-formal reality- where theorems of such a language are satisfied) is emerging. Back and forth procedures between language and models seem internalizing the relation between theory and reality in empirical science.

In empirical science the necessary conditions of a search for truth are present in experimental protocols and in theories. In experimental protocols: invariance, stability of the signals under instrumental changes, under stochastic noises, etc. In theory: covariance requirement (i.e. the fact that the form of the laws or equations are to be invariant under changes of reference frames, scales, etc.) If we consider the history: we see that the theoretical frames are not at all independent: they are related (by deformations or approximations) showing that something is invariant.

Invariance is in fact the clue of a relation with a reality (we are changing something that depends on us and something remains invariant). The importance of symmetries and invariance inside physics is a clue of the fact that in this field we are tending to find relations with something that is not dependent on us. And what is worth noting is the fact that we are able to translate the necessary conditions of these relations in our theories and to implement the latters in our experimental and observational protocols.

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Letture suggerite

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