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A BRIEF HISTORY OF HUMAN POWERED FLIGHT: FROM PHYSIOLOGY TO PHILOSOPHY

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ABSTRACT

The development of a scientific theory (T) can be separated into successive phases: i) Fantasy, to conceive T ii) Analysis to couch T into formal language iii) Action, to apply in practice the predictions of T. The history of human powered flight, in which case the three phases are stretched over several thousand years, allow us to better appreciate their intrinsic characteristics. Fantasy, dating back to the myth of Ikarus, must be experimentally testable, as indeed were Daedalus' wings. Analysis must state in quantitative terms the laws governing the matter at stake. Action, from Leonardo's unsuccessful attempts to the crossings of the British Channel in 1979 and of the arm of the sea separating Crete from mainland Greece in 1988, has the aim of shaping the world according to our will. The kernel of any "proper" T is a formal system wherein a set of operational rules allows us to manipulate a set of symbols, representing the objects of T, on the bases of a limited number of axioms. In such formal systems, "theorem" is a string of symbols that can be arrived at in a finite number of steps from the axioms, applying the canonical operational rules. However, as Kurt Gödel showed in 1931, it is possible to demonstrate that, within a sufficiently powerful formal system, there exists demonstrably true strings of symbols that are not theorems. Thus, even in an ultra-powerful theory of everything, there will still be truths that can not be arrived at within the theory.

Keywords: scientific method, flight by birds, human-powered flight, maximal aerobic power, body mass, scientific truth

KRATKA ZGODOVINA LETENJA NA ČLOVEŠKI POGON: OD FIZIOLOGIJE DO FILOZOFIJE

IZVLEČEK

Razvoj znanstvene teorije (T) se lahko razdeli na naslednje faze: i) fantazijo, ki zasnuje T, ii) analizo, v kateri se T ubesedi v formalnem jeziku, in iii) akcijo, kjer se predvidevanja T uporabi v praksi. Zgodovina letenja na človeški pogon, v kateri se te tri faze razpotegnejo skozi nekaj tisočletij, nam omogoča bolje razumeti njihove značilnosti. Fantazijo, ki jo lahko datiramo vse do mita o Ikarusu, se mora dati eksperimentalno preizkusiti, kar se je v tem primeru dalo z Dedalovimi krili. Analiza mora v količinskem pogledu opisati zakone, ki opredeljujejo zamišljeno zadevo. Akcija, od Leonardovih neuspešnih poskusov do prečkanja Rokavskega preliva leta 1979, 1875 in morja, ki loči Kreto od celinske Grčije leta 1988, ima za cilj oblikovati svet po naši volji. Jedro vsake "prave"T je formalni sistem, v katerem nam nabor operativnih pravil omogoča operirati z naborom simbolov, ki predstavljajo predmete T, na podlagi omejenega števila aksiomov. V takih formalnih sistemih je "teorem" niz simbolov, do katerega se pride s končnim številom korakov iz aksiomov z uporabo kanonskih operativnih pravil. Vendar, kot je leta 1931 pokazal Kurt Gödel, je možno dokazati, da obstajajo v dovolj močnem formalnem sistemu dokazljivo resnični nabori simbolov, ki niso teoremi. Torej bodo tudi v zelo mogočni teoriji vsega še vedno resnice, do katerih ni mogoče priti znotraj teorije.

Ključne besede: znanstvena metoda, letenje ptic, letenje na človeški pogon, največja aerobna moč, masa telesa, znanstvena resnica

INTRODUCTION

The interest in the philosophy of science has gained substantial momentum not only among philosophers, but also among scientists and cultivated laymen. The reasons for this will not be discussed here; however, it is likely due (at least in part) to both the spectacular success of applied science and technology and to the fears that this success inevitably brings. Be this as it may, it seemed to me that the viewpoint on this matter of a professional physiologist and "naif philosopher" may be of some interest to the reader. So, the aim of what follows is a brief outline of the structure of science. After having stated the basic tenets of the Galilean scientific method, I will attempt to demonstrate that the development of a scientific idea can be separated into successive, partly overlapping phases: i) Fantasy, to conceive a scientific theory ii) Analysis, to couch the theory into formal language iii) Action, to apply in practice the prediction of the theory. To this aim, I will briefly summarise the history of human powered flight, in which case the more than two millennia over which the three phases are stretched allows us to better appreciate them.

Many historians and philosophers of science have pointed out, however, that the Galilean method, wherein the agreement between facts and theory plays a pivotal role in the acceptance of a given theory, is a somewhat simplified idealisation. Indeed, several other characteristics foster the acceptance of a theory in addition to the agreement between predictions and facts. These points of view can be reconciled with the more traditional Galilean science by means of "The Catastrophe Theory", as described by René Thom, which allows us to view the acceptability of a given theory within the scientific community as being dependent not only on the agreement between predictions and facts, but also on several (indeed as many as we can possibly conceive) other factors.

In the concluding paragraphs I will address the meaning of "scientific truth" and I will try to convince the reader that even assuming that in the very distant future science will be condensed in a "ultra-powerful" Theory of Everything, as shown by Kurt Gödel in 1931 for sufficiently powerful formal systems, there will still be Truths that can not be arrived at within the theory.

THE GALILEAN SCIENTIFIC METHOD

The Galilean scientific method can be schematically represented as in Figure 1. Here the predictions derived from a given theory are compared to the results obtained from appropriated experiments and/or from observations of the external world. This process is assumed to yield a continuous refinement of the theory at stake, thus gradually approaching "scientific truth".

The process summarised in Figure 1 has probably been, albeit implicitly, at the root of human knowledge since the dawn of mankind. However, it has been made explicit, at least in western culture essentially by the works and writings of Galileo Galilei (1564–1642), and has since become the main pillar of the scientific method.

As shown in Figure 1, the Galilean method can be loosely, if somewhat artificially, separated into three phases. In the first phase, which will be defined here as "Fantasy", scientific theories are forged. This is followed by a second one "Analysis" in which scientific theories are couched into quantitative formal language, necessary for extracting predictions from theories and for planning experiments and/or observations allowing the investigator to compare facts and theories. Finally, in the last phase "Action", theoretical knowledge is utilised in practice to shape the external world according to our will. Furthermore, as briefly discussed below, the main intellectual and practical tools utilised in the three phases are widely different; a few examples are indicated in Figure 1.

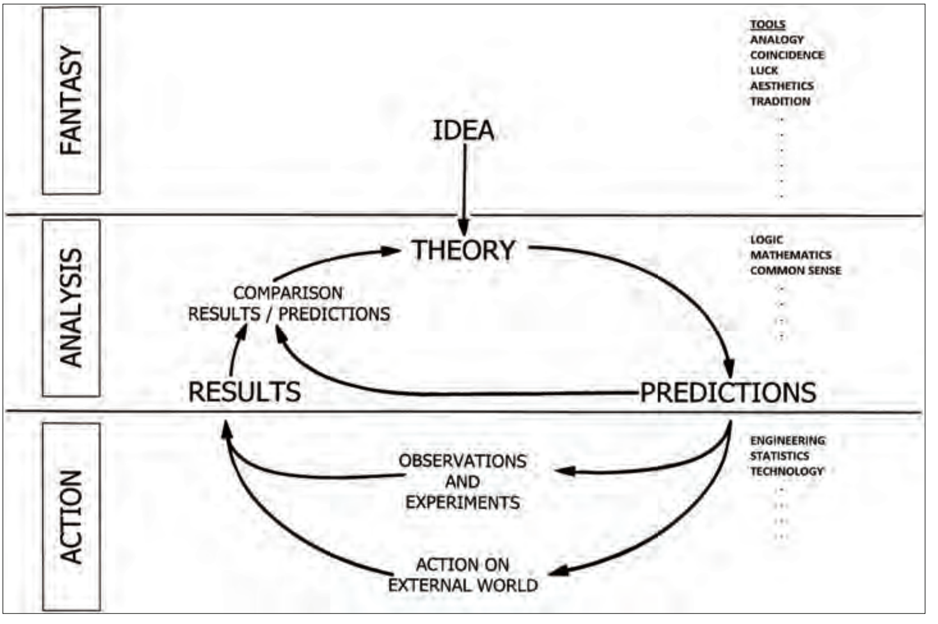

Figure 1: The scientific method. The predictions deduced from a given theory are compared with the results of appropriate experiments and/or observations and/or manipulations of the external world. This is assumed to yield a gradual refinement of the theory. The process is subdivided into three phases. The main intellectual and practical tools utilised in the three phases are also indicated. See text for details.

As a general rule, in the scientific routine, these phases largely overlap and reverberate onto each other; as such they can not be clearly separated. However, it seems to me that upon close scrutiny, they can be easily identified in the conceptual development of many, if not all, scientific processes. A particularly fruitful example is the historical evolution of human powered flight, wherein the three phases “Fantasy”, “Analysis”, “Action”, spread as they are over millennia, can be easily identified. The sections that follow will therefore be dedicated to a brief recapitulation of the history of human powered flight.

Fantasy

Postquam manus ultimas coeptis
imposita est, geminas opifex libravit in alas
ipse suum corpus, motaque pependit in aura.[1]

Daedalus was the famous Greek architect who built the Labyrinth where Minos, King of Crete, sequestered his son, the Minotaur, who had the body of a man and the head of a bull. To avenge the death of another son, Androgeus killed by the Athenians, Minos demanded that seven Athenian youth and seven maidens should be sent every ninth year to be devoured by the Minotaur. Theseus volunteered to be among the nine youths to be sent to Crete, where he entered the Labyrinth and killed the Minotaur, thus freeing the Athenians form the horrible tribute. Theseus succeeded in finding the way out of the Labyrinth thanks to Ariadne who fell in love with him a gave him a spool of thread to guide him through the mazes of the Labyrinth. In turn, this trick had been suggested to Ariadne by Daedalus. Minos discovered the whole plot and sequestered Daedalus and his son Icarus in the Labyrinth.

In spite of being the architect of the Labyrinth, Daedalus was not able to find the way out. If not by land, then by air: Daedalus constructed four large wings with feathers and wax and glued them to Icarus' and his shoulders. They are up, in the air. Thrilled by success, Icarus flies high, too close to the Sun, the heat of which melts the wax. Icarus falls into the Egean Sea, whereas a tearful Daedalus, reaches Sicily where King Cocalus welcomes and protects him.

So far, the myth is the obvious product of fantasy. This, however, is somehow realistic: the wings constructed by Daedalus are based on a model provided by Mother Nature; as such the model can be experimentally tested. More than two thousand years will have to elapse before formal proof could be reached that to fly using his own muscle power, man should abandon the idea of imitating Nature. Even so, Daedalus' fantasy is the kernel of a scientific enterprise which will eventually succeed. Thus, the fundamental requirement of scientific Fantasy, in the sense utilised in this article, is that the products thereof be experimentally testable. As such, scientific Fantasy is conceptually different from artistic or poetic fantasy which does not have any requirements in terms of experimental verification.

1 "After having given the last touch to his work, the craftsman lifted his own body on twin wings, and suspended it into the moving air." Ovid (Publius Ovidius Naso 43B.C.–18A.D.), Metamorphoses VIII: 200–202.

Analysis

Sicuti terrestria animalia super terram,
sic aves per aere volando incedunt.
Talis motus efficitur mirabili artificio,
et organis mechanicis,
quorum theoriam esplicare conabimur.[2]

The first descriptions of the macroscopic anatomy of birds are due to Aristotle (384-322 B.C.) and to his disciples. After very nearly two millennia without substantial innovations, Leonardo da Vinci (1452-1519) dedicates a non negligible fraction of his monumental opus to study animal and human flight. Leonardo is not content with knowledge, he strives for transferring it to practice: to have man fly like a bird. His drawings show his genius, but his practical attempts met with failure.

One hundred and fifty years after Leonardo's death, the physiologist Giovanni Alfonso Borelli (1608-1679) devotes a fraction of his book "De Motu Animalium" (which can be considered the forerunner of the modern textbooks on biomechanics) to the flight of birds and humans. Galileo had previously shown that the mass of geometrically similar animals increases with the cube of a given linear dimension (since their body density is essentially equal), whereas their surface increases with the square of the same linear dimension. Extending this type of analysis to birds, Borelli shows that a given surface of the wing of a bird must sustain a weight which increases with the dimensions of the animal. From this line of reasoning, Borelli draws two conclusions: a) there must exist an upper limit of body mass above which no bird, conceived according to the rules of Mother Nature, can possibly fly, and b) the muscles of the upper girdle and limbs of humans are too weak to allow them to fly like birds. Conclusion b shows why Daedalus' idea, if applied literally, was doomed to failure. Indeed, to fly with his own muscular power, man has followed a different route, which will be described below.

About three hundred and fifty years after Borelli, his ideas were given a quantitative from, thanks to the work of the British physiologist Douglas Wilkie (1922-1998). Wilkie showed that, for a given set of geometrically similar birds of equal body density, the metabolic power requirement to fly horizontally at the minimum (constant) speed necessary for sustaining the animal in the air (Pf), increases with the mass (M) of the animal as described by:

2 "As the beasts of the earth move on the land, so do the Birds wing their flight through the air. This motion of flight is accomplished with marvellous skill and by means of organic mechanism in such fashion as we shall here endeavour to set out". G. Alfonso Borelli. De Motu Animalium -Caput XXII. Romae ex Typographia Angeli Bernabò, MDCLXXX. English translation by T.O'B. Habbard, J.H. Ledeboer, in "Founders of Experimental Physiology - Biographies and Translations". Ed. by John W. Boylan. J.F. Lehmanns Verlag, Munich, 1971, p. 23

$$Pf = ß\, M^{1.167} \qquad 1)$$

where ß is a constant which depends on the shape of the animal, on the air density, the acceleration of gravity and the efficiency of transformation of metabolic into mechanical power (Wilkie, 1959). It is worth noting that Equation 1 applies also to geometrical similar airplanes, in which case Pf represents the power of the engine and ß assumes, obviously enough, a different value. Equation 1 shows that the minimum metabolic power for constant speed horizontal flight at the lowest possible speed increases more than the mass of the animal: e.g., for an increase of M of four times, Pf increases five times.

At variance with Pf, the metabolic power that the animals can actually generate (E) increases less than the mass of the animal:

$$E = a\, M^{0.79} \qquad 2)$$

where *a* is a constant which depends on the duration of the exercise (Taylor et al., 1980). For E in watts and M in kg, *a* is about 4 for resting metabolism, 24 for the metabolic power sustainable over a 6 hour period, and 40 for the maximal aerobic power, which can be sustained for about 10 minutes. Equation 2 shows that the increase of E associated with a fourfold increase of mass is only threefold, as compared to the fivefold increase of Pf mentioned above.

Equations 1 and 2 taken together show the conundrum in which Mother Nature has put herself when producing flying animals of greater and greater body mass: with increasing body mass, the minimum power required for flight increases more that the power generated by the animal. In quantitative terms, these two equations allow us to calculate the maximal body mass for which horizontal flight is a physiological possibility, as a function of the two constants ß and *a*. Indeed, for flight to be possible the minimum metabolic power required must be equal to that generated by the animal (Pf = E). Hence, from equations 1 and 2:

$$ß\, M^{1.167} = a\, M^{0.79} \qquad 3)$$

or, taking the logarithms:

$$\log ß + 1.167 \log M = \log a + 0.79 \log M \qquad 3')$$

and rearranging:

$$\log M = (\log a - \log ß)/0.38 \qquad 4)$$

Figure 2: The great ottard (Otis Tarda).

For natural flight, ß amounts to about 8.3 (for Pf in watts and M in kg). Thus, inserting into Equation 4 the two values of *a* applying for metabolic power sustainable for 6 hours and 10 minutes, M turns out to be 14 and 65 kg, respectively.

Thanks to this line of thinking, essentially due to Wilkie, it is therefore possible to assign numerical values to the qualitative predictions of Borelli. Indeed, the maximal possible body mass for a bird capable of sustained flight can not exceed 14 kg. Incidentally, this is close to the mass of the great ottard, a renowned long distance flyer (Figure 2). This also shows that migrating birds, the body mass of which is much less than the critical mass of 15 kg, can overcome the enormous distances required by their ecological needs without increasing their metabolic power to a great extent. Indeed, rearranging equation 3':

$$\log a = \log ß + \log M \ (1.167 - 0.79)$$

Since ß = 8.3, assuming e.g. M = 0.1 kg, *a* turns out to be 3.5, i.e. close to that for resting metabolism. This value applies to the minimal speed compatible with horizontal flight, thus showing that the migrating bird does not need to raise his metabolism to a great extent to achieve the desired migration speed.

The body mass calculated above for a duration of 10 minutes is close to that of a small size human adult. This shows that, even if humans were constructed like a standard bird, their flight capabilities would be essentially nil, since for any realistic situation they should rely on anaerobic metabolism, a fact that would greatly reduce the actual flight duration, not to mention take off and turns, in which case, even at the minimal speed the power requirement increases substantially. Once again, these considerations support and extend quantitatively the original qualitative predictions of Borelli.

Action

Because of Icarus and what befell him the idea
of manpowered flight started off with bad press.
What was really no more than a minor structural failure
has been wrongly taken as proof
that the whole thing was impossible in principle (Wilkie, 1982).

The first attempts to produce flight machines moved by human muscle power are due to Leonardo da Vinci. In spite of his ingenuity as witnessed by his magnificent drawings, his attempts met with failure. Leaving aside the father of gliding flight, Otto Lilienthal (1848-1896) who made over 2000 glides in safety and was killed on August 9, 1896 when his glider was caught by a sudden gust of wind, the first successful man-powered flights were accomplished in 1935 - 36 by a German (Hassler-Villiger) and an Italian (Bossi-Bonomi) machine which flew 700 and 920 metres. The power generated by the engine and pilot was not enough for take-off which was made possible by a catapult. World War II put a tragic end to these attempts of peaceful aviation which were resumed in the 1950s, thanks to the generosity of an Englishman, Mr. H. Kremer, who established a 5000 pound prize for the first man-powered vehicle to fly a figure eight around two pitons half a mile (800 metres) apart. In spite of numerous attempts by English and Japanese engineers and scientists who achieved straight flights over 1000 metres, wherein also take-off was generated by the engine-pilot, the figure eight flight remained off-limits because of the increased power required for the two turns, and the prize climbed to 10,000 and then 50,000 pounds.

The situation changed in the mid 1970s when an America team lead by Paul MacCready constructed a machine characterised by an "old fashion" design similar to that allowing the Wright brothers to accomplish the first mechanical powered flight in December 1903. The characteristics of this machine (The Gossamer Condor) was that of generating a lift sufficient to maintain it and the engine-pilot in the air, already at a very low speed (about 12 km/h), thus reducing to a minimum the power necessary to overcome the air drag which increases with the cube of the speed. This, coupled with an extremely light weight (32 kg) and a very large wing surface area (97.2 m^2) allowed

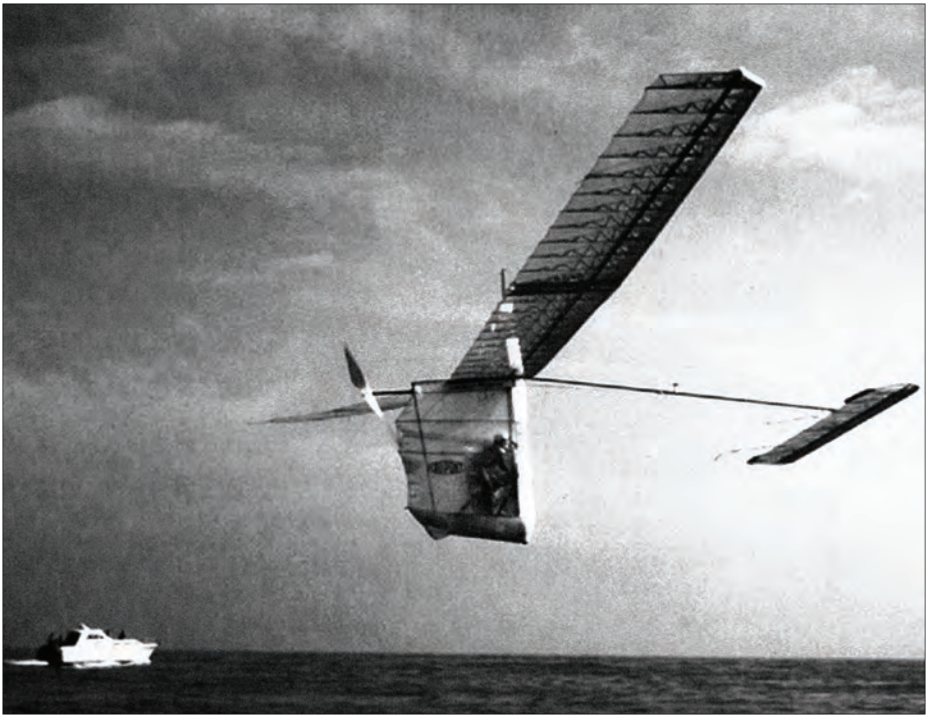

Figure 3: Brian Allen flying over the British Channel on June 12, 1979.

the team to win the Kremer figure eight prize. On June 12, 1979, a similar machine (The Gossamer Albatross, Figure 3) powered and steered by Brian Allen crossed the English channel from Folkestone to Cap Gis-Nez, near Calais (35.6 km), at an average speed of 12.6 km/h, in spite of relatively strong opposing winds, thus winning a new prize of 100,000 pounds that Mr. Kremer had established in the meantime for the first man-powered machine to achieve this deed (Grosser, 1991).

The ideas of Paul MacCready and his team obtained additional recognition on April 23, 1988, when the Greek cyclist K. Kanellopoulos succeeded in flying over the arm of sea between Crete and the island of Santorini (120 km) at an average speed of 30.3 km/h, thus showing that Daedalus was not so wrong after all[3].

3 For a more detailed discussion of these matters see Prampero (di) P.E. “Il volo a propulsione umana” in “Dagli abissi allo spazio. Ambienti e Limiti umani” Ed. by G. Ferretti, C. Capelli, Edi Ermes, Milano 2008, pp. 151–159.

THE SCIENTIFIC METHOD

Fatti non foste a viver come bruti,
ma per seguir virtude e conoscenza.[4]

In the previous paragraphs, I have attempted to show that the development of any given scientific idea can be subdivided into three phases: "Fantasy" to conceive a theory (T), "Analysis" to express T in formal language; "Action" to utilise T in practice. Each phase would deserve a far deeper discussion than was possible in this article. Nevertheless, I would like to point out briefly the main characteristics of each phase.

Fantasy. From where a scientist or a group of scientists begets a theory (T) is a matter of fascinating debate: fortuitous coincidences, chance, analogies, dreams (as in the famous case of the chemist F.A. Kekule von Stradonitz (1829–1896) who allegedly conceived in a dream the cyclic nature of the aromatic compounds of carbon, such as benzene (Holton, 1973, 1978, 1979). Be this as it may, the so conceived T must be somehow realistic. Indeed, to be of any scientific value, its products must be experimentally testable even if often, at least initially, only by means of the so called "Gedank Experimente" (thought experiments). As mentioned earlier, this is the main difference between scientific and artistic fantasy, this last being free from any experimental constraint. However, common to both is the aesthetic appeal: scientists and artists alike are inevitably partial towards "beautiful" theories. Foremost among the canons of scientific beauty is simplicity, as synthesised by Occam's Razor "Entia non sunt moltiplicanda praeter necessitatem"[5].

Analysis. This is the phase in which T is expressed in formal, often mathematical terms. It is a crucial step which allows the scientist to derive from T a finite set of testable predictions that can be verified or disproven by experiment and/or observation, the results of which can be utilised to gradually refine T. Another fundamental role of this phase is that of expressing T in "public language", thus making it as well as its assumptions, predictions, constraints, limits, available in principle to the scientific community. Public language is one of the crucial differences between science and other types of knowledge such as religious or mystical beliefs which are free from the stringent necessity of expressing their Ts in formal language. On a more mundane note it seems appropriate to mention here Lord Rutherford's (1871–1937, Nobel Prize 1908 for Chemistry) famous dictum "Truth comes easier from error than from confusion", wherein he very effectively stressed the fact that an erroneous scientific theory expressed in formal language is more useful in scientific terms than a vast collection of unorganised data. In-

4 "you were not made to live like brutes, but to follow virtue and knowledge." Dante Alighieri - La Divina Commedia - Inferno, canto XXVI 119–120.

5 William of Occam (c. 1280–1349). "Beings ought not to be multiplied except out of necessity."

deed, in the former case, the theory can be proven wrong and thus be a stimulus towards a new one, whereas a vast array of data or observations without a possible theoretical common ground is less likely to lead to organised science.

Action. This is the phase in which the conceptual products of a scientific theory are utilised in practice to shape the external world. It is the phase to which the great majority of people will refer to when asked about the meaning of the term science: the phase worshipped for its triumphs or blamed for its feared dark sides. Both extremes, however, miss the beauty of this most human endeavour which encompasses the richest fruits of Western thought: 1) The Greek quest for theorising and knowledge (Fantasy); 2) The Roman drive towards organisation and law (Analysis); 3) The desire to mould the world according to our needs, gaining ever growing momentum during the Renaissance and Modern times (Action).

The process described above and summarised in Figure 1 may suggest that with time and effort scientific theories gradually progress towards a state of perfection asymptotically approximating Truth. Upon closer reflection, however, this is far from evident. Indeed, as described so far, the process does not explain what happens when, as is often the case, a given T is not confirmed by experiments and/or observation. Thus, the simplified view of the process summarised in figure 1 may well apply under conditions of "normal science" but fails to do so in the troublesome periods of "scientific revolutions". These considerations were brought to the foreground of the debate on the history and philosophy of science be Thomas Kuhn in his remarkable book "The Structure of Scientific Revolutions" (Kuhn, 1970). More recently other authors have taken the extreme view that the correspondence between experiments and observation, on the one side, and predictions of the theory on the other, plays only a minor or negligible role in the acceptance of a given T by the scientific community. According to these authors, the crucial factor in the acceptance of a given theory must be looked for in other aspects of science, such as social conventions or fashion to the extreme position of Feyerabend "anything goes" (Feyerabend, 1975). The majority of active scientists will probably refute these positions, since they know very well how important the agreement between fact and theory is. However, they are also very well aware of the relevance of other factors, such as scientific fashion, political interests, the availability of research funding, etc. in directing the main research lines of the scientific community (Feyerabend, 1981). The extreme example of this state of affairs is the (un)famous scientific disaster of Lysenko's genetics in URSS under Stalin's dictatorship.

In an attempt to reconcile the role of hard facts (i.e. the agreement between predictions and experimental observations) with that of other factors, social, political, aesthetic, etc. in determining the degree of acceptance of a given T, I will rely upon the Catastrophe Theory of René Thom, as described by A. Woodcock and M. Davis (1982). The simplest elementary catastrophe can be viewed as a plane convoluted in a tri-dimensional space. The vertical axis of this space, defined "potential" depends on two

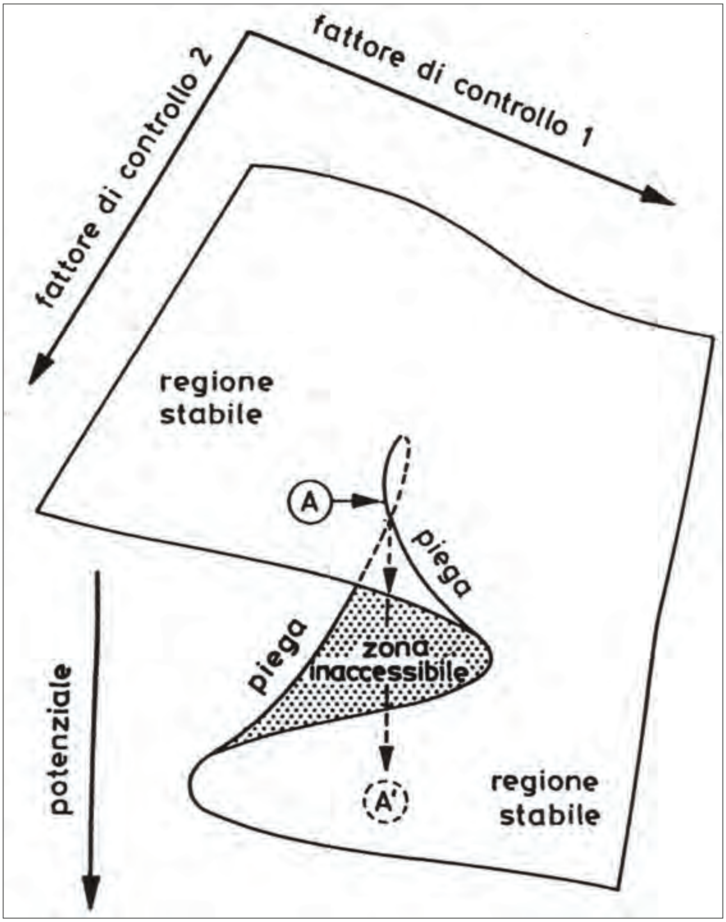

Figure 4a: Graphic representation of the simplest catastrophe: the cusp. The "Potential" (Potenziale) of a given phenomenon is assumed to depend on two control factors (Fattore di controllo). When the phenomenon is close to the cusp (piega), small changes of one or both control factors can lead to great "catastrophic" changes of potential. The dotted line joining A and A' indicates such a change. The dotted area denotes an inaccessible zone (zona inaccessibile). See text for details.

factors, as schematically indicated in Figure 4a. In the upper part of the figure the potential is relatively stable, since the plane is very nearly flat (regione stabile), so that, even large changes of one or both factors, do not lead to any substantial changes. However, when approaching the cusp, small changes of one or both factors can lead to a dramatic, "catastrophic" change of potential. After this catastrophe, a new flat region is attained.

If the potential is identified with the degree of acceptance of T and the two other axes with factors presumed to foster the degree of acceptance of T, the simplest elementary catastrophe of Figure 2a can be applied to the philosophy of science. To this aim, I will choose two factors: 1) the agreement between facts and predictions and 2) the aesthetic appeal of T, as expressed by its "simplicity" (Figure 4b). In the period of normal science there will probably exist a leading theory (Tl) the degree of acceptance (grado di accettazione) of which is fairly large thanks to the relatively good (alto) "explicative power" and "simplicity". As such, Tl will fare in the lower right part of

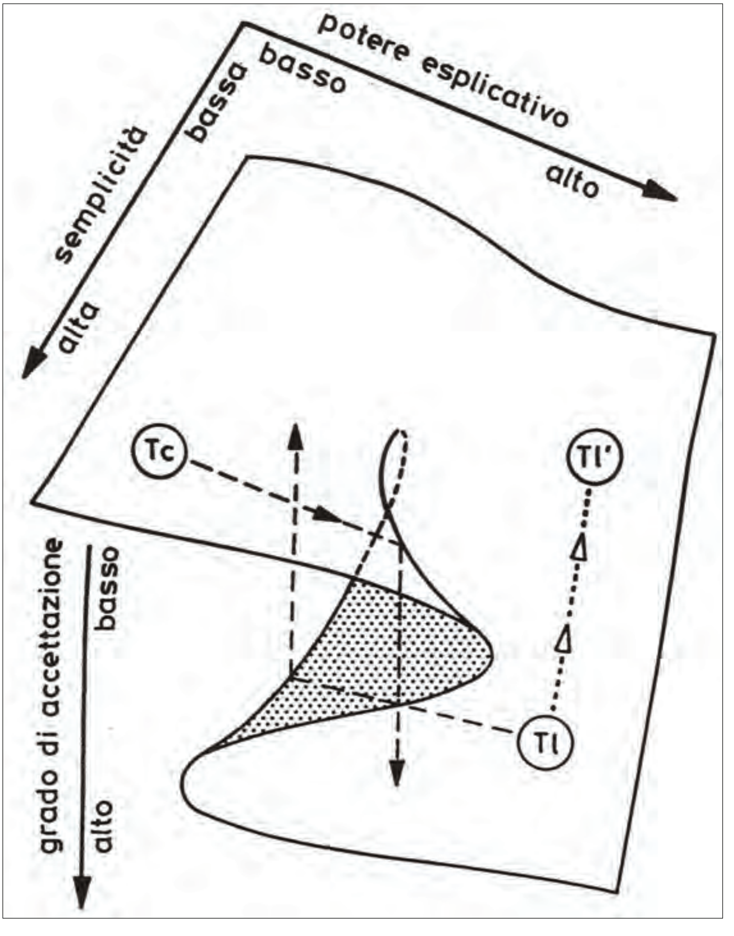

Figure 4b: The degree of acceptance of a given theory by the scientific community is here assumed to depend on two control factors: "simplicity" (semplicità) and "explicatory power" (potere esplicativo). See text for details.

the plane of Figure 4b. In the revolutionary periods (as defined by Thomas Kuhn) new facts emerge that are not easily reconcilable with Tl which therefore moves to the left towards the zone of low (basso) explicative power, thus approaching the cusp. If this is attained, a catastrophic change of the degree of acceptance of Tl will occur, bringing it in the upper left part of the plane. To avoid the decrease of explicative power, Tl can be modified by "ad hoc" constructs which, however, will detract from its simplicity. Hence the so modified Tl (Tl') will move towards the upper right part of the plane towards the zone of low (bassa) simplicity. In either case, the decrease of explicatory power or of simplicity will stimulate the scientific community to produce new theories or to refine alternative existing ones. Thanks to the emergence of new facts, these new competing theories (Tc) will be brought towards the cusp of the plane, thus moving from the upper left to the lower right part of it. If this is the case, Tc will become the new leading theory.

It goes without saying that instead of two control factors (explicatory power and simplicity) as was the case here, three or more can be selected. In this case, the topological representation of the catastrophe becomes more complicated, being described by an n-dimensional structure, convoluted in an (n+1)-dimensional space, where n is the number of factors assumed to control the degree of acceptance of T.

Truth

There are more things
in Heaven and Earth,
Horatio, than are dreamt of
in your philosophy. [6]

The aim of what follows is to discuss briefly the meaning of scientific Truth within the conceptual framework summarised in the preceding sections. To this aim, I will assume that a "Theory of Everything" (TE) has been achieved and condensed in an appropriate formal system.

A formal system is defined as a set of axioms, a set of operating rules and a set of symbols (an alphabet). A theorem is hereby defined as a string of symbols which can be arrived at in a finite number of steps from the axioms, operating on the alphabet, by means of the canonical operating rules. Thus, theorems are "True" since they are consistent with axioms. It also follows that within any given theory "Truth" can be defined as the sum total of the appropriate theorems.

As shown in 1931 by Kurt Gödel (1906-1978), in a sufficiently powerful formal system, there exists strings of symbols that are demonstrably true but that can not be arrived at in a finite number of steps. As such, they are not theorems. Thus the set of true

6 William Shakespeare. Hamlet I, V: 166-167.

string that can be expressed in a sufficiently powerful formal system is larger than the set of theorems and comprehends it (Nagel & Newman, 1958; Hofstadter & Douglas, 1979).

This line of reasoning shows that the theorems of TE, derived from its axioms, on the bases of its canonical rules will constitute only a subset of all true strings. The conclusion that TE is incomplete in the Gödelian sense seems therefore inescapable.

CONCLUSIONS

The preceding discussion was based on the correspondence theory of truth. Indeed, it was implicitly assumed that a bi-univocal correspondence does exist between our mental image of the world and the world itself. It was also assumed that the scientific language describing our mental image of the world is public and that, as such, it is shared by the scientific community at large.

If we adopted the more conservative view that science is a "language game" in the Wittgensteinian sense, then any correspondence between the scientific description of the world and the world per se, is bound to become a meaningless expression. If this is so, we are also inevitably bound to conclude with the final gnomic sentence of Wittgenstein Tractatus Logico-Philosophicus:

"Wovon man nicht, sprechen can, darüber muß man schweigen."[7]

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