Reasoning, Metaphor and Science

edited by

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Maria Grazia Rossi

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1. Stars embedded in the sky like nails: when nature becomes more understandable[1]

Stars are embedded in the sky like nails, the wind is as fast as birds, the cosmos revolves as a mill wheel and the sun spins as a felt cap around our head: during the VI-V centuries b.C., when the nature's exploration began and a rational image of the world was developing, Anaximenes of Miletus already resorted to using something like metaphors and similarities. A subtle sensation of nearness of heaven to men, or the strong faith in human rationality, must have convinced the Ionian thinker to describe the nature of the farthest sky as comprehensible as things on the Earth (the stars are implanted in the sky like nails. Diels & Kranz 1951: 93, testimonial 13A14), to explain what is invisible in itself but understandable by means of the same mechanisms of the terrestrial facts (the wind is as fast as are the birds. Diels & Kranz 1951: 94, testimonial 13A19), to show that unreachable things act as man-made things (the cosmos revolves like a mill wheel and

[1] This work is the outcome of a collaborative effort. However, Flavia Marcacci is responsible for the section 1 and 2, Maria Grazia Rossi is responsible for the section 3. Section 4 is the result of the joint effort of both authors.

Flavia Marcacci and Maria Grazia Rossi,
"Reasoning by Metaphors in Science, Philosophy and Practice"
in Flavia Marcacci and Maria Grazia Rossi, *Reasoning, metaphor and science*, pp. 7-22.

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the sun spins like a cap. Diels & Kranz 1951: 93 and 92, respectively testimonials 13A12 and 13A7). An extended and functioning technical dictionary describing nature did not exist at that time. Philosophical and specialized terms and concepts were starting out and common language was the most available source for describing and approaching reality through human words. Anaximenes could not be conscious to use metaphors, as we consider Isocrates to be really the first author to term them this way (see Giombini in this book). However, he actually employed metaphors in his natural philosophy. Melissus created the first dictionary for the ontology, as his fragments display (Diels & Kranz 1951: 259-275), and he replaced natural metaphors with more detailed and rational descriptions.

Nature is an exceptional stage to witness the most important chances for an encounter between science and metaphor. The desire to understand nature has always been the reason to venture metaphorical images for grasping something that is otherwise incomprehensible at first sight. The idea of nature itself has been woven into a rich metaphorology. A place of honour is up to Raymond of Sabunde (Ramon Sibiuda, c. 1385-1436), who extensively and explicitly spoke of nature like a book (Raymond of Sabunde 1501; De Puig 1993; Conti 2004)[2], like a place wherein the Creator's traces are identifiable. Hans Blumenberg largely explored this idea, and he resorted to the metaphor to inspect roots, turning points and changes of Western philosophical thought (Blumenberg 1981: especially chapter 1). According to Blumenberg, "truth" is a metaphor of paramount importance: Aristotle weaved nature and truth to such an extent that truth and nature have the same power to show themselves, and the nature's essence matches its truth. The classical thought considers nature as a truth's dress, just one of several dresses from ancient and medieval wardrobe used by philosophers and theologians to speak about truth in metaphorical terms, in additional to those of light, force, energy. Thus, for instance Ramon Llull designated the truth as a "dignity" of God, and according to Milton "God himself is truth". The modern age discovered the dichotomy between subject and object, and the relationship between God and the truth became mediated by knowledge. Hence, knowledge, not contemplation, becomes what to look for in order to be happy. In this knowledge, the subject plays a decisive role, although swinging and exposed to doubt and uncertainty. Therefore, science, the

[2] The book became very famous because it was translated into French by Michel de Montaigne in 1569. Another way to quote the Raymond of Sabunde's book is *Scientia libri creaturarum siue libri naturae et scientia de homine* and it has many editions.

"new science", becomes bearer and ensign of a new way of looking at the world.

Of course, the metaphor of the book of nature has exercised an irreplaceable conditioning for the emergence of new scientific perspectives. Suffice it to think of Galileo, who related the metaphor of the book of nature with the mathematical cipher enabling to decode it: this constituted a central assumption in his thinking. Along the path of science, the metaphor has played several roles. Remarkably, it has had a heuristic and cognitive role in several moments of the history of science. One example is the concept of infinity, which was variously elaborated in mathematicians and philosophers' minds. When such a concept became a cosmological hypothesis, it compelled astronomers to verify how really big the cosmos was (see Marcacci-Zaffino in this volume). Similarly, thinking the infinitely small and making it suitable to describe curvilinear movements required a certain degree of abstraction (see Bussotti-Pisano in this volume). Thus, metaphors have facilitated the approach to new concepts, like stretched strings to be grasped in order to get a first hang and later begin defining them. Finally, they have helped us to find the "right words".

2. Windows and parents, demons and angels: the pervasiveness of the metaphor

When a discipline or a research theme takes shape, its technical and scientific dictionary does the same as well. During such a process, words can be acquired from the common dictionary, then emptied of their denotative meaning and filled with a new sense. Words such as *reproduction*, *chaos*, *catastrophe*, *singularity* have a certain meaning in common language and a technical meaning in the scientific language of biology, mathematics and computer science. In the process of their invention, terms can also be completely new and validated with greater or lesser force: there are technical neologisms like *adiponectin*, a protein encoded by the ADIPOQ gene, or *blogosphere* and *infosphere*, whose use is widespread in different environments and communicational frameworks (see also Tramontano & Bondi in this volume); then there are also terms that have been imposed with great success, widely used outside their specific domain of reference, as *creativity* coined by A. N. Whitehead (1861-1947) in his *Process and Reality* (1978). There are also terms in relation to which we are now unable to establish what kind of development they will have, such as *hyper-modernity*, the meaning of which is not always concordant[3].

Metaphor has nowadays a significant and pervasive role in media studies and digital communication. A unique definition of "media" does not exist yet, even if we are overrun by them. We can reason on them by different points of view, e.g. media such as instruments, culture, social phenomena, environment. Their reality is really concrete and the metaphor becomes an access tool to the reality of media and of information, and the language of computer science is completely laced with metaphors, that interconnect computational and traditional domains: algorithm designers and information architects manipulate data and name them *parent*, *ancestor*, *child* and a common user opens *windows*, presses a *button* or reads a *menu* (Colburn, Shute 2008). New words and new ontologies constantly emerge in the computational environments and determine new practical requirements (see Giunti in this volume). The same interpersonal relationships are being studied in the context of *Computer-mediated communication (CMC) systems* because their interaction with culture has to be understood (Walther 2011). Digital environment performs the relationships between people and groups in an un-reproducible way off line. Therefore, youngers' media environments are nowadays peculiarly under metaphorical investigation: the self-expression, that is being offered to others, might sound slippery, as if it were emerging from a "foggy mirror" (Ellison, Heino, Gibbs 2006). The way we communicate influences the perception of history, so nowadays we live inside a *hyper-history* after few phases[4]: the oral phase, the Gutenberg phase when books were not yet accessible, and eventually the press-phase that makes information more and more accessible. The information was subsequently dematerialized and the human mind, which had been conceived for the past past 50 years by means of the *computational metaphor*, was integrated by the *collective intelligence* (Levy 1994; De Kerckhove 1998). New computational objects as well – personal digital assistants (PDAs), cellphones, laptops – are becoming even closer companions for their users, "even as the ubiquity of these objects began to dull our sensitivity to their effects" (Turkle 2005: 3). The arrival on the scene of the *Internet of the things* (Ashtone 2015) has facilitated the formulation of the metaphor of the net as "the nervous system of our society", which can transmit both good and bad information. This is the

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[3] E.g. *hypermodernity* in literary criticism (Donnarumma 2014) or in philosophy of information (Floridi 2015).

[4] See footnote 3. Also Levy (1998: 31-32).

present. Maybe the future will be filled with other kind of *Digital nervous systems*, namely the super-advanced, electronic offices.

The metaphor causes a shift of meaning and allows “a description of an object or event, real or imagined, using concepts that cannot be applied to the object or event in a conventional way” (Indurkhya 1992: 18). An interaction between conventional and metaphorical meanings of the objects in question remains, but such a connection can change meanings themselves. First, a metaphor moves the literal meaning towards the metaphorical one (the stars stuck like nails), but, secondly, it is also able to evoke new meanings (the sun spins like a cap, therefore, it moves along the celestial dome that is like a hemisphere, following a trajectory of which we need to produce a geometrical representation). Third, the metaphor can change the way to see things and raises new questions: if the stars are stuck in the sky like nails, is their own movement due to their inherent nature, or are they dragged by the sky wherein they are placed? If metaphors help to understand things, then they have an important cognitive role in scientific activity as well (see the contributions of Di Bernardo and Moretti in this volume). After Thomas Kuhn proposed to start dealing with the “dynamics” of the sciences – which means how science evolves and how scientific theories evolve during the time – linguistics, semioticians and epistemologists began to employ the metaphor and its creative role in science. Richard Boyd and Thomas S. Kuhn, particularly, took care of a section of a conference on the relation between metaphor and thought in 1977 at the University of Illinois (Ortony 1993). Between them, a key issue was the continuity or discontinuity of the “metaphoric redescription”[5] of the world: Boyd accepted the metaphoricity in the scientific language, whereas Kuhn supported his view that the meaning of the terms differs radically from a theory to another (Kuhn 1989). Beyond the details of that debate, any suspicion against the metaphors, inherited from Neopositivism, began weakening when the cognitive role of the metaphor was cleared. And thus, whoever studied science started to study metaphors as well (Gagliasso & Frezza 2010). Two possible approaches to this study were either the comprehension of the genesis and the formation in their historical background, or the inquiry into the creative and heuristic thought’s functioning and metaphorical embodiment.

In other words, we can say that an “internal” and “external” use of the metaphor are there. In the first case, the “internal” one, metaphor assists and

[5] Hesse (1966: 171-177). The concept is essentially based on the “interaction view of the metaphor” by M. Black (1962).

urges the formation of new ideas in the inside of science. In the “external” case, from the inside of science to its “outside”, metaphor is useful to communicate scientific ideas; metaphor helps us to express intuitively concepts and contents, so science can be explained and told to the public at large. Sometimes, the comparison is addressed towards the most known piece of knowledge (“the Moon is attracted to the Earth *just like an apple is*”), sometimes the comparison is addressed towards the least known piece of knowledge in order to underline the necessary relevance and the requirement to increase our knowledge (“How can a metal body fall like a feather falls?”). In the first case, the scientific concept is introduced by recalling a well-known effect, in the second case two effects are put in relation and the challenge is demonstrating that is not just a bizarre metaphor.

From the evil genius of Descartes, from Maxwell’s demon to the celestial intelligences of medieval astronomers and meteorologists’ butterflies, science has always been supported by these nice presences that are able to guide our ideas. The metaphors often have been such as facilitators, able to pave the way to the final formalization of the scientific concepts and to make the scientific discovery more comprehensible: it is not easy to understand singularities in mathematics and physics, but of course, it is much more intriguing by thinking of a *black hole* or a *big bang* (Curiel & Bokulik 2017).

3. Communicating with metaphors: theoretical and practical issues

Alongside this major fundamental research line on the use of metaphors within science, the above mentioned researches dealing with the external use of metaphors have relevant impact to understand metaphors as effective tools for communication. This paragraph sheds light on such an external use of metaphor by stressing the relationship among metaphor, education and scientific dissemination. Indeed, a closer reflection on the external use of metaphors provides us with an opportunity to highlight once again the effectiveness of metaphors as powerful (and controversial) reasoning device within communicative contexts (Rossi 2016).

There are two main issues that should be taken into account here. On the one hand, the analysis of metaphors as reasoning device is a way to think about the nature and functioning of metaphors themselves; namely, this analysis deals with important philosophical issues within the contemporary theories of metaphor (Ervas & Gola 2016; see Ervas & Gola in this volume). On the other hand, such an analysis allows to underline the practical relevance of metaphors as tools potentially useful for the purposes of education and dissemination of scientific knowledge (see Indurkhya in this volume).

Regarding the first point, it has often been pointed out that metaphors are reasoning devices because they frame an issue in a certain way, from a specific point of view. This close connection between figurative framing and reasoning device has been recently underlined by Burgers and collaborators (2016). Their idea of metaphor as reasoning device is built on the notion of framing proposed by Entman (1993) within the traditional framing theory. Entman (1993: 53) wrote:

> Framing essentially involves selection and salience. To frame is to select some aspects of a perceived reality and make them more salient in a communicating text, in such a way as to promote a particular problem definition, causal interpretation, moral evaluation, and/or treatment recommendation for the item described.

Starting from this definition of framing, Burgers and collaborators (2016) distinguish different levels of analysis: linguistic level, conceptual level and communicative level. By focusing their attention on the relationship between the conceptual level and the communicative level of analysis, they consider the important role of metaphor in reasoning and communication: within this framework, metaphor framing is understood as one of the forms of perspectivization - at the conceptual level of analysis - and perspective change - at the communicative level of analysis (see also Steen 2008). It is pretty clear that by using a metaphor we can frame an issue by adopting a specific point of view, selecting precise properties to map out the systematic correspondence between source and target domain, thus suggesting a given interpretation and proposing the reliability of a certain belief and/or behavior.

The metaphorical framing effect has often been discussed in terms of metaphorical persuasive effect (for a review see Sopory & Dillard 2002). Due to the often implicit and unconscious ways in which metaphors affect our reasoning, and thus our thoughts and our decisions, that persuasive effect has been often interpreted as negative or irrational. This theoretical framework is further supported by the experimental researches conducted in recent decades, which have shown the strong role of the metaphors' framing effect (for the field of political reasoning, see Lakoff 2008; for the field of policy reasoning, see Thibodeau & Boroditsky 2011, 2013, 2016; for the field of healthcare, see Hauser & Schwarz 2015, Ervas et al. 2016). As

Ervas, Gola, Rossi (2014, 2015, 2016; see also Rossi 2016) have pointed out in previous articles, in most cases the persuasive influence of metaphors in reasoning has been interpreted as a form of manipulation. This negative view about the role of metaphors in reasoning is closely linked to their unconscious (and thus manipulative) influences. This leads to the following initial conclusion: metaphors framing may be used to change people's minds and influence their judgments (e.g., by manipulating or subconsciously restructuring the way in which people decide to vote; see also Allegra in this book). Whether it is possible determine which features affect the quality of a metaphor in order to make a clear distinction between their positive and negative effects on reasoning remains to be seen (e.g. Damerall, Kellogg 2016; Giora 2003). Therefore, it might be vital to conduct more research in this direction.

However, this is just one side of the coin: a lot of philosophical, psychological and pedagogical works insist on the strong educational power of metaphors (e.g. Ortony 1975; Low 2008; Hesse 1966; Naik et al. 2011). Regarding this second point, namely, the issue related the use of metaphors for the purposes of education and dissemination of scientific knowledge, the unconscious dimension counts once again. In addition to the unconscious effect of metaphors framing, the unconscious dimension is also related to the question of the unconscious use of metaphors. Even if humans are often unaware about the fact they are using metaphors, oral and written texts are pervaded by them. Indeed, metaphors represent from 10% to 20% of natural discourse (Steen et al. 2010). An unconscious use of metaphors might become troublesome when a proper understanding represents the core of an oral or written communication, as in all cases of communication within a declared educational context. It is pretty clear that people make use of metaphors to better explain complex topics; but it remains to be understood which metaphors can be considered as effective communication tools and why.

For example, an appropriate use of metaphors as educational tools become necessary in the context of health communication. The citizen's understanding affected by the use of metaphors within public health campaigns and the patient understanding affected by the use of metaphors within the patient-provider interactions are particularly relevant in the same way. Citizens' and patients' understanding can be positively or negatively influenced by an appropriate or inappropriate use of metaphors in both contexts. Also in this regard, many open problems remain for future research. For example, just to mention one point in addition, it is very important to identify metaphors used in the different areas of healthcare and to determine in theory and by experimentation their actual effectiveness (cfr. Rossi 2016). Finally, it is very important to encourage an informed use of metaphors to those who design public health campaigns educating citizens and to healthcare providers educating patients.

4. Contents of this volume

This book is composed in two parts: the contributions in first part look into the nature of metaphors and their role in the description of human rationality; the second part inquires the heuristic use of metaphors in science, by drawing on both few historical case-studies and theoretical discussion.

Antonio Allegra explores the power of metaphor in the posthuman storytelling, especially in the narratives that move between science and conjecture and where not inquiring the true meaning of such literary inventions is allowed. Obviously, the storytelling power would not gain from explaining the distance between scientific and imaginative aspects, but in any case this power may have an interesting social impact. Especially the metaphor of the immortality and the one of happiness are explored through a series of literary phenomena. The conclusion is the recognition firstly of at least an ambivalence, like the one between paradisiac or apocalyptic conclusion, and secondly, the ideological hidden agenda aimed glorifying or forcefully denouncing the possibilities or the risks of the future. In these narratives, an intellectual analysis is able to distinguish what is plausible and how to work or not for it, without adhering to a dogma every time.

The contribution of **Bipin Indurkhya** investigates the relationship between scientific models and reality by examining the role of three different tools (thoughts experiments, simulations and field experiments) in scientific process and methodology. After discussing the epistemic status of these tools, the author applies a gestalt-projection model and proposes an interactive view of the scientific experimentation. Considering thoughts experiments, simulations and field experiments as mediated interactions, the author argues that any mediated interaction “is constrained by the validity of the mediating model or conceptual framework”. In this context, he recognizes an important heuristic role to metaphors: especially within thought experiments, metaphors can be considered heuristic instruments able to generate new ideas and hypotheses, and hence instruments to increase human epistemic knowledge in a creative way.

Francesca Tramontano and **Damiano Bondi** argue the reason and in which sense metaphors have a "poietic" power, that expands our theoretical and scientific knowledge. Moving from the epistemological turning point during last century, that considered metaphor no longer as only a linguistic and rhetorical problem, but also as a form of thinking useful to organize our perception and make conceptualizations, the authors consider the skill of scientific metaphor to have a sort of autonomy in producing sense. "Substitutive/plastifying" and "revealing" metaphors are used in science, to make descriptions or revealing a mystery. Metaphors as a semantic power, both in philosophy and in science, even though this power shall be a danger and a risk. Anyway, metaphors are un-renounceable for contemporary science, included technological/digital tools, and are a permanent sign of the man-phenomenon.

Stefania Giombini proposes a historiographical reconstruction of the history of metaphor, by analyzing texts from Presocratic literature. She reveals as in Parmenides and Empedocles, although the opposite approach, metaphor is used to explain the core of their philosophies. Anyway using metaphor does not allow them to elaborate a theory of metaphor. Not even Isocrates specifies what a metaphor means, but he defines it as a figure of speech. A relevant author for a history of metaphor in Presocratic philosophy is Antiphon, who knew metaphor as a figure. Finally, the most important Sophist Gorgias creatively invented and used many rhetorical figures including metaphor, maybe in a more original way than Plato. Effectively, Aristotle will use Sophists' results. Giombini argues that the Sophistic Movement played a fundamental role for the birth of metaphors in the fifth century.

Francesca Ervas and **Elisabetta Gola** analyze the case of metaphor translation in order to discuss more recent metaphor theories that have re-evaluated the role of imagination in the modulation of the literal meaning. Considering three different degrees of translation (untranslatability, full translatability and partial translatability), they argue that a subtle knowledge of the lexis is necessary and plays a central role within the process of metaphor translation. More specifically, the authors show that both metaphor and polysemy present a continuum of translation possibilities and thus different strategies could be used for dealing with such cases. Taking into consideration the distinction between lexicalized and live metaphors, they find that translation failures are definitively easier to find for creative metaphors. But simultaneously, due to the close relationship between lexical knowledge and imagination, the authors argue that live metaphors can also become an experimental laboratory for new creation in the target language during the translation process.

In the second part of the volume the relationship between the science and the explicative role of metaphor is inquired, with a special attention to some historical cases.

Flavia Marcacci and **Valentina Zaffino** pay attention to the historical passage from a closed geocentric world-system to an infinite one. The similarity is the figure of speech that reveals its explicative power, especially in the case of Giordano Bruno who uses it to introduce the idea of an infinite cosmos. The astronomers tried hard to understand how widely they could extend the (depth of the) universe on the basis of the observational data available at that time, with opportune instruments and without any metaphorical reasoning: Giovanni Battista Riccioli, the Jesuit astronomer who proposed the last semi-geocentric model of world before Newton by using the telescope, compares different methods and results from many astronomers and once again concludes with a closed world.

Based on their previous Newtonian researches, the core of **Raffaele Pisano** and **Paolo Bussotti**'s paper is the role played by infinitesimal quantities in Newton's Principia. It is their new historical analysis of the Newton's text. Here they focus on *lineola* and related propositions of the Book I. The infinitesimal quantities might be fictions, like saying fictitious and metaphorical entities used in physics and factually connected with the infinitesimal geometry. From a scientific-linguistic point of view, the infinitesimal entities seem to be used in a metaphorical sense. As a matter of fact, they are described with the words "which is as small as possible and of a given length". However, the *lineola*, namely the quantity whose length is given and that Newton employs in his demonstration, does not correspond exactly to this definition, but the same definition may refer to a *lineola*, though not literally existing. The authors discuss, from an historical–epistemological standpoint, the geometrical conceptualization of the infinitesimal quantities within Newton's physics–mathematics.

Sabrina Moretti considers the role of metaphors and analogies in the field of social simulation models. By discussing the plausibility of the computational models from a methodological point of view, the author consider two classes of models (models based on cellular automata and models based on the contagion spreading metaphor) in order to argue that both metaphors and analogical representations determine an ideal-typical situation and so provide a method useful to build computer simulation in sociology and social psychology. Actually, the heuristic value of the aforementioned representations can be used «to discover new scenarios and to propose new cognitive challenges».

Marco Giunti provides a detailed analysis of the concept of physical realization of a computational system. In particular, the author aims at answering the main question about what is the gap between the system implementation and its most concrete formal representation. In this regard, Giunti places the notion of mapping at the heart of the analysis and argues as follows: «computational systems are more similar to *empirically correct dynamical models* than to dynamical systems tout court. Thus, the solution of the realization problem is to be sought among the *modeling* relations between *dynamical systems* and *phenomena*, and not among the *emulation* relations between purely mathematical dynamical systems». The author pursues this goal and proposes a formal machinery describing the realization, the representation, and a mapping between them.

Mirko Di Bernardo deepens the heuristic role of metaphor inside the Life Science, particularly in the construction of the Models of the Living and in the theory of the Biological Self-organization. Particularly the metaphor of the "great dance" has an interesting role in inspiring various scientific explanation problems: it helps the human mind to discover ideal or material relations between objects. For instance, discovering DNA is particularly emblematic because it disclosed self-regulating mechanisms that undermine a deterministic paradigm.

Especially in those cases where the study of the functional and structural complexity of organisms has played a role against any reductionist approach to biology, the metaphor of the great dance underlined how the scientific research reveals the intrinsic intelligibility of the reality, also when processes are not yet well explained.

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Part 1

The Nature of Metaphors and Their Role in Human Rationality

Μεταφορά.
The Figure of Speech before Aristotle

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1. Introduction: from etymology to rhetoric

The aim of this paper is to explore the origins of metaphor, i.e. when it emerges as a structured and defined figure of speech.[1] Our primary concern about the ancient history of metaphor is of historiographical nature. When does the metaphor get its name and meaning? Who contributed to its development?

In order to understand the issue, we can approach it through etymology. The word "metaphor" comes from the verb "μεταφέρειν - metapherein", i.e. "to carry across", to move an object from one point to another. In a rhetorical sense it means to talk about one thing in terms that apply to another: a word literally "moves" to a new unprecedented context (so that the move is not in space but in meaning). It is possible to say that, through the metaphor, something can be explicated by another term coming from another conceptual context.

On the other hand, it is clear, for everybody, that it was Aristotle who fixed the concept of metaphor, its meaning, its form and content. He dedicates a large investigation on this issue: we owe Aristotle so much for his systematical discussion on metaphor in many parts of his works,

[1] Some outstanding works about the ancient theory of metaphor are: Cassin (1995); Cazzullo (1987); Giannakis (2014); Guastini (2004); Guidorizzi (1984); O' Rourke (2006); Stanford (1936).

Stefania Giombini, "Μεταφορά. The Figure of Speech before Aristotle."
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particularly in *Rhetoric* and *Poetic*.[2] As a matter of fact, Aristotle built our current idea of metaphor, although, as Guastini argued, the rhetoric after Aristotle, especially the latin one of Cicero and Quintilian, doesn't use the term metaphor in the same sense as the Stagirite.[3] Today we are fully aware that the metaphor is not a figure of speech whose sole purpose is the ornamentation of style and aesthetics for structuring a text. The metaphor is more: it plays a well-defined role in a text where it is clearly able to produce an increase in knowledge.[4] The metaphor produces clarity and pleasure (*Rhet*. III 1495 to 8-10) and so it is a medium for knowledge. A well done metaphor shows the similarity between things and events; and the ability to perceive this similarity is only for the skilled.

Therefore, if we are in search of the birth of metaphor, we need to look for it before Aristotle, and this means that we should put aside the Stagirite's speculation, even though we are going to use him as a source.

2. Before Isocrates: Parmenides and Empedocles

Hence, we think it is possible to find the metaphor before Aristotle's intervention; at the time, therefore, when philosophy and rhetoric were united in the investigation of thinkers who were dedicated to large-scale speculation. Of course, we are hereby referring to metaphor as a theoretical elaboration of this figure of speech. It is more than obvious considering that no writing lacked of metaphors: just think about the sophisticated style of Homer's works and of the ancient poetry.[5] Anyway, we can't find any meta-analysis of metaphor and its nature, nor any theoretical approach to it. So, the presence of metaphor in poetical production just means that poets used this rhetorical tool, without an intention to think about it and to produce theories in point.

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[2] *Poet*. 22, 1459a5-9; 1457b21 ss.; *Rhet*. Γ 2, 1404b-1505b; Γ 4, 1406b-1407a; Γ 10-11, 1410b-1413b.

[3] Cicero and Quintilian override the typical cognitive dimension of metaphor by considering it only for its aesthetic dimension. Cf. Guastini (2004: pp. 1-2).

[4] Just for an overview: Cassin (1995), particularly the section dedicated to "Rhetoric and Fiction".

[5] The same Aristotle selected excerpts as sources in order to show their use. Cf. Arist., *Rhet*. III, 11, 1411b: καὶ ὡς κέχρηται πολλαχοῦ Ὅμηρος, τὸ τὰ ἄψυχα ἔμψυχα ποιεῖν διὰ τῆς μεταφορᾶς ["And as Homer often, by making use of metaphor, speaks of inanimate things as if they were animate", tr. Freese (1926)]. Cf. Snell (1936: cap. XI. *Similitudine, paragone, metafora, analogia; il passaggio dalla concezione mitica al pensiero logico*, pp. 269-312).

A useful element to limit the chronological extent within which metaphor is structured can be given by an excerpt from Isocrates. In the *Evagoras* (9-9), we can find the term "metaphor" in its rhetorical sense:

> [...] καὶ γὰρ πλησιάζοντας τοὺς θεοὺς τοῖς ἀνθρώποις οἷόν τ᾽ αὐτοῖς ποιῆσαι καὶ διαλεγομένους καὶ συναγωνιζομένους οἷς ἂν βουληθῶσι, καὶ περὶ τούτων δηλῶσαι μὴ μόνον τοῖς τεταγμένοις ὀνόμασιν, ἀλλὰ τὰ μὲν ξένοις, τὰ δὲ καινοῖς, τὰ δὲ μεταφοραῖς, καὶ μηδὲν παραλιπεῖν, ἀλλὰ πᾶσι τοῖς εἴδεσι διαποικῖλαι τὴν ποίησιν:
>
> […] They [*the poets*] can write of gods interacting with humans, conversing and fighting alongside whomsoever they wish, and they can portray this not only with conventional language but also with borrowings, new terms, and metaphors, not neglecting anything but embellishing their compositions with every figure (*eidos*).[6]

In this excerpt, the metaphor is identified as a figure of speech: it is introduced by Isocrates in a list of new forms of writing which are different from the conventional language, indeed. In this passage of *Evagoras*, Isocrates doesn't specify what a metaphor means, or its nature or its composition, but he just defines it as a figure, an attested tool of common use at his time.

The source is indicative but not explanatory: it is a proof that metaphor, at the time of Isocrates, was an attested poetic figure, a common form of expression in poetry, but no more information comes from this passage.

This step from *Evagoras*, therefore, shows us that, between the fifth and the fourth century, metaphor was already recognized as a figure of speech. Isocrates had the rhetorical training he received from Gorgias and Prodicus, thus it is easy to think that some of his rhetoric expertise came precisely from the teachings of these two first generation sophists. If we set this boundary, the birth of metaphor as a figure of speech necessarily takes place between the ancient poetry production and Isocrates' one.

It is possible to find two references to metaphor: one in Parmenides the monist and one in Empedocles the pluralist.

For what concerns Parmenides, the source is Proclus:

> [DK 28 A 18] PROCL. *in Parm.* I665, 17 αὐτὸς ὁ Π. ἐν τῆι ποιήσει˙ καίτοι δι᾽ αὐτὸ δήπου τὸ ποιητικὸν εἶδος χρῆσθαι μεταφοραῖς ὀνομάτων καὶ σχήμασι καὶ τροπαῖς ὀφείλων ὅμως τὸ ἀκαλλώπιστον καὶ ἰσχνὸν καὶ καθαρὸν εἶδος τῆς ἀπαγγελίας ἠσπάσατο.
>
> Parmenides himself in his poem: and yet although obliged, because of the poetic form itself, to use metaphorical terms, figures, and terms of phrase, he

[6] Mirhady-Too (2000: vol. II, 142).

> nevertheless embraced the most unbecoming, dry, and austere form of expression.[7]

Proclus informs us on Parmenides' rhetorical and stylistic choices: Parmenides includes the metaphor, because of the need to use some poetic forms, as he produced a veritable poem. About the content, Proclus is quite right: Parmenides used the metaphor; just think of the use of the sphere as image of the being, or the use of night and day to show the transition from false beliefs to the truth. Therefore, although the information Proclus gives us is challenging, still it is limited by the historical point of view. In fact, the term "metaphor" – μεταφορά – is used by Proclus to reflect on Parmenides' rhetoric and narrative mode, but it is not directly used by Parmenides. Hence, it is quite impossible to connect the same Parmenides with metaphor, because, maybe, the concept of metaphor was just in Proclus' mind, not in that of Parmenides. What we know, therefore, is that Parmenides actually used the metaphor, as it can be seen from his poem, but we do not know if he produced a reflection on metaphor and its nature. It can not totally exclude that the need to use metaphors could have lead Parmenides to develop a personal conceptual elaboration of the metaphor as figure of speech. However, it seems rather strongly as possible, given the specificity of its production, that Parmenides did not produce this kind of reflection: no fragment or testimony shows us that hypothesis.

Going on to Empedocles, we have a testimony and a fragment available. The testimony is by Diogenes Laertius:

> D.L. VIII 57[8]- [A1 Inwood]: Ἀριστοτέλης δὲ ἐν τῶι Σοφιστῆι φησι πρῶτον Ἐμπεδοκλέα ῥητορικὴν εὑρεῖν, Ζήνωνα δὲ διαλεκτικήν. ἐν δὲ τῶι Περὶ ποιητῶν φησιν ὅτι καὶ Ὁμηρικὸς ὁ Ἐμπεδοκλῆς καὶ δεινὸς περὶ τὴν φράσιν γέγονεν, μεταφορητικός τε ὢν καὶ τοῖς ἄλλοις τοῖς περὶ ποιητικὴν ἐπιτεύγμασι χρώμενος˙
>
> Aristotle says in his *Sophist*[9] that Empedocles first discovered rhetoric and Zeno dialectic. In his *On Poets* he says that Empedocles was both 'Homeric' and impressive in diction, being given to the use of metaphor and successfully employing the other tricks of the poetic art.[10]

In this passage of the *Lives of Eminent Philosophers*, Diogenes Laertius shows Empedocles as a specialist in the use of rhetorical instruments. Actually, Aristotle (in Laertius' version) introduces Empedocles as the

[7] Gallop (1984: 109).
[8] Part of DK31A1.
[9] An Aristotelian dialogue. This, by Diogenes Laertius, is the only reference about it.
[10] Inwood (2011: 151).

inventor of rhetoric,[11] but this is really difficult to prove. For sure, the attribution of the fatherhood of rhetoric is an honour award, as for example the definition of Zeno as father of dialectics.[12] It is nonetheless important to understand that Empedocles was definitely a partaker in the birth of ancient rhetoric as autonomous knowledge: Empedocles stood out for its ability to build sophisticated and well-made texts in line with all the rules of rhetoric, including the metaphor. It seems, then, that he was Gorgias' master. Either way, we want to emphasize that the source mentions the metaphor along with the whole set of rhetorical techniques. This means that the metaphor has got a particular role within the technical art of persuasion: a privileged position in a still developing context.

While from a *Scholium on* Euripides, 31 B 66. SCHOL. EURIP. *Phoen*. 18:

> [I 336. 15] [...]: Ἐ. ὁ φυσικὸς ἀλληγορῶν φησι'σχιστοὺς λειμῶνας Ἀφροδίτης'.
>
> [CTXT 55 – Inwood]: [...] Empedocles the natural philosopher says allegorically: the divided meadows of Aphrodite.[13]

Empedocles is hereby identified as able to construct allegories; Euripides as the one who uses more technical terms and appropriate metaphors. The scholium is "poor" because the "allegoric text" of Empedocles is, indeed, a metaphor: in fact, Empedocles uses terms coming from another semantic field and that do not concern at all the one the author is meant to refer to instead. Thus, what we deduce from these sources is that the philosopher Empedocles knew the metaphor and was able to build this figure of speech, indeed. The topic can be cleared up by reading the fragments of Empedocles: for example, fr. DK31B23, conveyed by Simplicius, in which, in order to explain how the same elements stem from different things, Empedocles uses the metaphor of the painters who produce multiple images through the colors. We know that Empedocles used metaphors also from Aristotle. In the *Meteorology* (357A24), the Stagirite tells us that Empedocles used poetic metaphors, in the unsuitable context of

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[11] Also in: D.L. IX, 25; DK29A1; DK29A2; Arist. fr. Rose 65; DK31A5; DK31A19. For Protagoras as one of the first inventors: DK80A40; for the role of Tisias, Thrasymachus and Theodorus: DK85A2; for Gorgias as advocate of rhetoric: DK82A1 = Philostr., *v. soph.* I, 9, 1.

[12] About this possibility, cf. Giombini – Marcacci (2010).

[13] Inwood (2011: 125).

a scientific issue;[14] Aristotle, moreover, wrote about Empedocles in the *Poetics* (1457b 10-26), quoting one case of metaphor by analogy.

Empedocles, like Parmenides, did not elaborate a theory of metaphor: yet we know that he was able to produce texts in which there were metaphors; and also, he was the first, or one of the first ones, to be interested in rhetoric, and he likely gave his contribution to its birth as a form of art. For sure, we can't recall him as a thinker who was able to produce a meta-analysis of metaphor: he, probably, used the metaphor without a reflection on it. And for sure this is not enough for deeming him to be the real father of rhetoric.

3. The Sophists

Here we must restrict again the field of our research. If before our first reference was ancient poetry, now it is necessary to face these thinkers, the physiologists; so our chronology can apparently settle on the fifth century. Thus, we need to move within the Sophistry. Let's start with some interesting minor authors, i.e. Theodorus, Theramenes, Polos. According to Cicero[15], we know that not only Thrasymachus[16] and Gorgias used rhetorical figures, but also Theodorus of Byzantium did. Anna Cazzullo writes[17] that Theodoros, Theramenes and Polos definitely treated somehow the metaphor as figure of speech; in particular Theodorus[18] was quoted by Plato as *logodaidalos* and was recalled two times in the Aristotle's *Rhetoric.* Cazzullo tells us that Theramenes wrote (reputedly; the *Suida* accounts for it) a *Peri eikon* and a *Peri skematon* and, though still uncertainly from my own point of view, Isocrates was his pupil; Polos, finally, wrote about rhetorical figures[19]. This suggestion given by Cazzullo is important, though not conclusive, because there is no evidence of these three *sophoi* actually having a specific interest in the metaphor. On the other hand, it is highly likely that these sophists produced some reflection on the issue of metaphor,

[14] Only a passage quoted in DK31B55.

[15] Cic. *Orat*. 12, 39 (=DK82A30).

[16] Cf. DK85A1 (*Suid*.); DK85A (Dionys. *Isae*. 20).

[17] Cazzullo (1987, 64): «Teodoro, Teramene e Polo, a esempio, hanno sicuramente avuto a che fare con la questione della figura e dunque con la metafora. Teodoro, *logodaidalos* a detta di Platone, è infatti nominato due volte nella *Retorica* aristotelica là dove sono impartite le norme su come "trarre" la metafora [*Rhet.* III 11,1412 e ss.]».

[18] About Theodoros: Cic. *Orat*. 12, 39 (DK82A30).

[19] Cf. Plato, *Phaedr*. 266d ss; pupil of Gorgias: *Suid*. 82DKA2; same style of Gorgias: Diod. XII, 53, 1 ss (DK82A4); see also Aristotle, *Rhet*. B 23 1400b19.

especially for what concerns Theodoros. In fact, the name of Theodoros is involved and present in a part of the analysis Aristotle dedicated to metaphor: in 1412a his name occurs when the Stagirite says that a metaphor stems from and is expressed by well-designed riddles. Hereby *Rhet.* III 11 (1412a):

> καὶ τὰ εὖ ᾐνιγμένα διὰ τὸ αὐτὸ ἡδέα (μάθησις γάρ ἐστι καὶ μεταφορά), καὶ (ὃ λέγει Θεόδωρος) τὸκαινὰ λέγειν […]

> And clever riddles are agreeable for the same reason; for something is learnt, and the expression is also metaphorical. And what Theodorus calls "novel expressions" […][20]

Hence, if this discourse is valid there are at least three sophists who could be deemed to be 'experts' in linguistical and rhetorical issues and, as it seems, in the metaphor as one of the figures they studied.

Aristotle later identifies these new things (*novel expressions*) in paradoxical quotes that should not be opposed to a current opinion, but should rather be similar to words that are coined specifically to surprise and to parody. Yet it is clear that Theodorus appears just when Aristotle enumerates all the possibilities to generate metaphors and in the same pages many authors are mentioned, even from different periods. So, if on the one hand the recall to Theodorus is evident, on the other hand there is no particularly sharp information.

If we put these minor authors aside, the next ones are Antiphon and Gorgias.

There is very interesting information concerning Antiphon the Sophist (also known as Antiphon the Rhamnusian)[21] in Harpocration, [22] in his *Lexicon of the Ten Orators*:

> 87 B 70 [115 B., 93 S.]. HARPOCR. [II 366. 20App.] εὐηνιώτατα· Ἀ. ἐν τῶι Περὶ ὁμονοίας. εὐήνιος ὁ πρᾶος καὶ μέτριος καὶ μὴ ταραχώδης. ἡ μεταφορὰ ἀπὸ τῶν ἵππων.

> [91] Most obedient to the rein: Antiphon in *On Concord*. 'Obedient to the rein' means tame, moderate, not unruly. Metaphor from horsemanship. [23]

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[20] Freese (1926: 3.11.6).

[21] Almost all the scholarly literature agrees on identifying Antiphon the Ramnusian and Antiphon the Sophist. See Narcy (1989), Gagarin (2002) and Giombini (2010).

[22] Harpocration refers to Antiphon the Rhamnusian.

[23] Graham (2010: 825).

And:

87 B 69 [114 B., 92 S.]. HARPOCR. βαλβίς˙ Ἀ. Περὶ ὁμονοίας˙ ἡ ἀρχή. ETYM.GEN. βαλβίς...καὶ βαλβῖσιν ἀντὶ τοῦ ταῖς ἀρχαῖς.

[Graham 90] [βαλβῖσιν: Ἀ. Περὶ ὁμονοίας ἀντὶ τοῦ ταῖς ἀρχαῖς] Starting point: Antiphon *On Concord* for ‘beginning’[24].

The first text (the second in the *Lexicon*’s alphabetical order) is a primary source for our investigation: Harpocration explains a metaphor by Antiphon in his *On Concord* (of which we have fragments) and the most interesting aspect is that, in a little quotation, the author not only includes just the explanation of the metaphor, but he also feels the urge to specify that what he’s talking about is a metaphor. The metaphorical relation is structured between the human behaviour and the world of horse-riding: a person ‘obedient to the rein’ is a person who is moderate and can be led by another. Moreover, we have at the same time an example of metaphor and the identification between the example and the same appellation of ‘metaphor’. Thus, this first testimony seems a very interesting source to reconstruct a story of metaphor before Isocrates. Actually, this source is more symptomatic than the same Isocrates.

In the second text, Harpocration doesn’t use the term ‘metaphor’, but he reports an example of metaphor, always in Antiphon’s *On Concord*. Here there isn’t any specification -that it is a kind of metaphor- but just the quotation: the beginning is expressed as a starting point.

Harpocration shows very well that Antiphon knew the metaphor as a figure, as a rhetorical alternative and his accounts bring Antiphon to be considered as a relevant author for our research. So, it would be proper to investigate more sources about him, albeit distinguishing our first source, with a direct reference to the word ‘metaphor’, from the others that are quotations, hence kinds of metaphor.

In DK87B7:

[174 B., 178 S.] POLL. II 57. Ἀ. δὲ καὶ τὸ ὀψόμενον εἶπε καὶ τῆι ὄψει οἷον τοῖς ὀφθαλμοῖς καὶ ὀπτὴρ [d. Rhamn., d. caed. Her. 22] καὶ ἄοπτα.

A. Also said what will see and with sight, meaning “with the eyes” and eyewitness and unviewed.[25]

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[24] *Ib.*

[25] Graham (2010: 797).

And in DK87B52:

> [106 B., 84 S.]. Harpocr. ἀναθέσθαι: Ἀ. Περὶ ὁμονοίας˙ 'ἀναθέσθαι δὲ ὥσπερ πεττὸν τὸν βίον οὐκ ἔστιν' ἀντὶ τοῦ ἄνωθεν βιῶναι μετανοήσαντας ἐπὶ τῶι προτέρωι βίωι. εἴρηται δὲ ἐκ μεταφορᾶς τῶν πεττευομένων.
>
> Revoke: A. *On Concord*: it is not possible to revoke one's life like a move in a board game, for 'relive, repenting on one's former life.' Said by reference to moves in draughts.[26]

In this last source, Harpocration points out that Antiphon used metaphors but also similes (see the use of 'like'), indeed. And further on, many examples about Antiphon's ability with words are given and his tendency to use some words instead of others which are conceptually similar is highlited in different contexts: I am referring to B71 (by Harpocration); B74 (also by Harpocration); B77 (by Plutarchus).

In DK87B60, then, there is a metaphor where education is compared to the action of the semen in the body: the metaphor is built around pregnancy, i.e. around being pregnant with something. This same metaphor seems to be even in *Lex Medicinae* (2-3), treaty of *Corpus Hippocraticum*.[27]

For what concerns Gorgias, it is known that he was one of the most important Sophists and there is no doubt that he was an acknowledged specialist in the art of rhetoric. We know that he wrote a manual of rhetoric,[28] and he was one of the most involved sophists in the issue of *techne rhetorike*[29]. If we carefully read the sources on and by Gorgias, we can find some interesting notes.

According to *Suida* we know that Gorgias was the first to introduce the use of many figures of speech[30] and also of metaphor:

> DK82A2 – *Suid. s.v.* Gorgias […] οὗτος πρῶτος τῶι ῥητορικῶι εἴδει τῆς παιδείας δύναμίν τε φραστικὴν καὶ τέχνην ἔδωκε, τροπαῖς τε καὶ μεταφοραῖς καὶ ἀλληγορίαις καὶ ὑπαλλαγαῖς καὶ [II 272. 30] καταχρήσεσι καὶ ὑπερβάσεσι καὶ ἀναδιπλώσεσι καὶ ἐπαναλήψεσι καὶ ἀποστροφαῖς καὶ παρισώσεσιν ἐχρήσατο.

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[26] *Ibid.*, 821.

[27] Cf. Leitao (2012: 134).

[28] D.L. VIII 58. Following Diogenes Laertius, authors who wrote a manual of rhetoric were (following the order proposed by the same D.L. in his work): Theophrastus (V 48), Aristo The Stoic (VII 164), Demetrios of Alexandria the sophist (V 84), Heracleides of Cyme (V 94), Bion of Syracuse (IV 58), Aeschines (II 64), Parmenides (not the philosopher of Elea) (IX 23), Aristotle (a siceliote rhetor) (V 35). But also: Archelaus (not the philosopher) (DK 60 A1) and Thrasymachus (DK85B7a).

[29] DK82A1.

[30] Cf. Calboli (1986: 1000).

> He was the first to give to the rhetorical genre the verbal power and art of deliberate culture and employed tropes and metaphors and figurative language and hypallage and catachresis and hyperbaton and doublings of words and repetitions and apostrophes and clauses of equal length.[31]

Gorgias is presented as the one who built many of the techniques and figures of rhetorical art. He also used - or took into account, at least - metaphors and other devices.[32] Gorgias gave a new strength to rhetoric which, according to Pausanias,[33] had fallen into obsolescence before the Sophist from Leontini.

Aristotle[34] introduces him as an expert in rhetoric and, in a famous passage of *Rhetoric*, quotes a meaningful metaphor by Gorgias.

Rhet. Γ 3, 1406b14 (=DK82A23):

> τὸ δὲ Γοργίου εἰς τὴν χελιδόνα, ἐπεὶ κατ’ αὐτοῦ πετομένη ἀφῆκε τὸ περίττωμα, ἄριστα τῶν τραγικῶν˙ εἶπε γὰρ ’αἰσχρόν γ’ ὦ Φιλομήλα’. ὄρνιθι μὲν γάρ, εἰ ἐποίησεν, οὐκ αἰσχρόν, παρθένωι δὲ αἰσχρόν. εὖ οὖν [II 277. 20] ἐλοιδόρησεν εἰπὼν ὃ ἦν, ἀλλ’ οὐχ ὃ ἔστιν.

> The remark of Gorgias to the swallow, when it flew over him and let go its droppings, is in the best tragic style. He said, “Shame on you, Philomela.” If a bird did it there was no disgrace, but it was shameful for a girl. His reproach was clever, therefore, since he called the bird what it was rather than what it is.[35]

This formulation of the metaphor is emblematic in the use of this figure in this sophist. In fact, Gorgias uses the myth of Philomela[36] to create a connection with a real fact (a swallow let go its droppings on Gorgias). Actually, this is a particular metaphor in which two distant domains are connected: by just knowing the myth, it is possible to understand the metaphor. Moreover, it is possible to take this metaphor for a metonymy (the difference between these figures of speech it is not always so obvious and easy to identify; and it changes on the basis of the chosen definition of

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[31] Kent Sprague (2001: 32).

[32] See also: DK82A4 = Diodor. XII 53, 4; Cicer. *orat*. 52, 175 (=DK82A32).

[33] Paus. VI 17, 8 = DK82A7.

[34] For the relation between Aristotle and Gorgias, see Battegazzore (1987); Natali (1999); Giombini (2011).

[35] Kent Sprague (2001: 39).

[36] The myth says that Philomela, a young girl who was raped and mutilated by Tereus, the husband of her sister Procne, obtains her revenge from the gods and is transformed into a nightingale. In some versions it is not Philomela to be transformed but her sister.

metaphor)[37]. For Aristotle, this is an inappropriate metaphor, but still a metaphor in its full sense.

Aristotle dedicated more notes of the *Rhetoric* to Gorgias. In *Rhet*. Γ 3, 1406b5, while Aristole is treating the frigidity of style, he introduces its fourth cause: the metaphor. Aristotle gives the example of Gorgias and writes:

> καὶ ἔτι τέταρτον τὸ ψυχρὸν ἐν ταῖς μεταφοραῖς γίνεται: εἰσὶν γὰρ καὶ μεταφοραὶ ἀπρεπεῖς, αἱ μὲν διὰ τὸ γελοῖον (χρῶνται γὰρ καὶ οἱ κωμῳδοποιοὶ μεταφοραῖς), αἱ δὲ διὰ τὸ σεμνὸν ἄγαν καὶ τραγικόν: ἀσαφεῖς δέ, ἂν πόρρωθεν, οἷον Γοργίας "χλωρὰ καὶ ἄναιμα τὰ πράγματα", "σὺ δὲ ταῦτα αἰσχρῶς μὲν ἔσπειρας κακῶς δὲ ἐθέρισας": ποιητικῶς γὰρ ἄγαν.

> The fourth kind of frigidity occurs in metaphors; for there are inappropriate metaphors, some because they are laughable (comic poets, too, use metaphor), some because too lofty and tragic. And they are unclear if far-fetched, for example, Gorgias' phrase about "pale and bloodless doings," or "you have sown shamefully and have reaped badly." These are too poetic. [38]

The ability of Gorgias to create metaphors, similarities and metonymies is also attested in other contexts: for example, in the fragmentary *Epitaphios* where to mean 'vultures' he used 'living tombs'[39]; but, in general, all his work is full of these figures of speech and it would be impossible to list them hereby[40].

It can be argued, therefore, that Gorgias used metaphors and many more figures of speech and he can be included into the sophists who participated substantially in the development of rhetoric and the growth of its analysis.

In the end, we can find a trace of metaphor in the *Rhetoric to Alexander* (1434b33) where there is the term μεταφέρων in the sense of 'translated word'; in Demosthenes, in *Against Leptines* 20.113 where it gains the sense of 'giving a twist to the argument', and in 20.126 with the sense of

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[37] For the difference between metaphor and metonymy cf. Arduini- Damiani (2010). Also Croft (1993: part. 348): according to Croft, metaphor establishes a relation between two different domains, which are not part of same domain matrix; on the contrary metonymy estabilishes a relation inside the same domain matrix. Metonymy comes from the greek verb "metonomazein" (i.e. call by a new name): it is possible to find this verb in Herodotus (1,94; 4,155 name change, 4,189 name change; 5,69 to rename; 8,44 in the sense of changing the name to acquire another) and in Thucydides (I, 122, 4), who, in a speech of the Corintii, speaking about the fragility of Athens, uses the verb μετονομάζω (μετωνόμασται) in the sense of name change. Cf. Cazzullo (1987: 65).

[38] Freese (1926: 3.3.4).

[39] DK82B5a.

[40] Cf. e.g. Calboli (1986).

'transferring the name'; and in Aeschines, too, the verb can be found in different meanings, though not in the rhetorical sense (1.166; 3.193; 3.220).

The development of concept and structure of the linguistic metaphor undoubtedly took shape within the Sophistry: all sources show that there had been a debate about metaphor as a figure, from Empedocles (Gorgias' master and maybe the father of rhetoric as *techne*) to various sophists or akin thinkers. The metaphor substantially stems from the sophists' speculation and conceptual elaboration. They included it in a larger context of construction of the rhetorical art. And, probably (though not certainly), they produced a reflection, and a meta-analysis about the nature of metaphor in their manuals on rhetoric. Even if it did not happen, anyway, they had been nonetheless the founding fathers of this rhetorical elaboration: they systematized the nature and role of this figure of speech.

4. Plato and Aristotle

After the Sophists, an actual insight on the metaphor was only given by Aristotle. He found in rhetoric one of his early speculations, for Plato's will. When Aristotle was young, in the platonic academy the master asked him to set up a course of rhetoric, in order to gather the students who otherwise would have gone to the school of Isocrates. This way, Aristotle developed his own doctrine starting from the already existing contributions to the Sophistry. Thus, it should not be surprising that before the Rhetoric two more works could already be ascribed to him: they are a *Compendium* of rhetorical arts and the *Gryllus*. The *Compendium* has a fundamental value for us as it was a collection of the previous rhetorical arts (*technai rhetorikai*), rhetorical manuals from the area of Sophistry, of which there is no trace left. Those manuals were written by Corax, Tisias, Theodorus, Thrasymachus, Gorgias, Polos, Licymnius and their use is in line with the educational and professional context in which the same Sophistry integrated. These guides possibly contained both theoretical speculations on sophistry and exempla that could be able to explain satisfactorily. And in these works the figures of speech for which the Sophists stood out also found their place: just think of the *gorgieia schemata*. Hence, for Aristotle Sophistry is the direct reference for what concerns rhetoric and its techniques. From the earlier sophistical works, and then through the Platonic elaboration, the Stagirite had enough data to start producing his own work.

The role of Plato in this transmission of knowledge is nonetheless particular. Plato must have known the work of the sophists, indeed, but he only developed a moral evaluation on rhetoric. Especially when it comes to metaphor, Plato doesn't develop such figure of speech in a rhetorical sense. In his works, the term metaphor appears in limited amounts: or better, the verb *metapherein* is clearly used in his literal sense; i.e. to move something from a point to another, to switch from a concept to another: for example in the *Protagoras* 339a (in the passive form: μετενηνεγμένον δ' εἰς ποίησιν […] but in connexion with poetry […]); and a step in the *Critias* (113a) meaning "to translate into another language". Here is the text:

> […] Σόλων, ἅτ' ἐπινοῶν εἰς τὴν αὑτοῦ ποίησιν καταχρήσασθαι τῷ λόγῳ, διαπυνθανόμενος τὴν τῶν ὀνομάτων δύναμιν, ηὗρεν τούς τε Αἰγυπτίους τοὺς πρώτους ἐκείνους αὐτὰ γραψαμένους εἰς τὴν αὑτῶν φωνὴν μετενηνοχότας, αὐτός τε αὖ πάλιν ἑκάστου τὴνδιάνοιαν ὀνόματος
>
> […] Since Solon was planning to make use of the story for his own poetry, he had found, on investigating the meaning of the names, that those Egyptians who had first written them down had translated them into their own tongue.[41]

As outlined above, nonetheless, Plato doesn't produce a theory of metaphor; he was instead not interested in this issue, and most of all he does not mention the metaphor in its rhetorical sense.[42] This is a substantial piece of evidence. In fact, Plato, despite writing about the issues of language (e.g. in the *Cratylus*) was very interested in rhetoric (in many dialogues, from the *Protagoras* to the *Gorgias*, *Euthydemus*, and so on) - but in order to criticize it, refused Sophistry as a valid cultural and 'philosophical' movement. He also refused the outcomes of the speculation of Sophistry, by criticizing the rhetoric in general and, accordingly, the specific theme of metaphor in particular. For this reason, it is noteworthy that he left metaphor out of his speculations. In fact, it is possible that metaphor was very typical in the Sophistry and for this reason he removed that issue from his speculation.

On the other hand, Aristotle makes full use of the results of the Sophists' rhetoric and develops them in a personal way, giving substantial shapes and structures to the ultimate construction of the themes of ancient rhetoric.

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[41] Lamb (1925).

[42] Cazzullo (1987: 65).

5. Conclusion

Restricting the chronological and speculative context of the birth of metaphor, although there is no direct evidence, it seems more than plausible to think that the metaphor had to get its specifications and its own definition within the Sophistic Movement, in the fifth century. The idea also seems corroborated by the analysis provided by Domaradzki[43] on the allegoresis, i.e. the ability to read into the allegories, that were already used in the sixth century. He found in the fifth century sophists, namely in Protagoras and Prodicus, those who "definitely created premises for allegorical interpretation of poetry"[44], adding a further connection when he argues that "the Sophists did allegorically interpret the archaic poetry so as to demonstrate that poets such as Homer or Hesiod in one way or another anticipated their teachings"[45]. Ascribing to the sophists the development of this practice of rhetoric supports the idea that the art of rhetoric (*techne rhetorike*) in its complexity was created and developed within the Sophistry.

Sophistry, in fact, made the structuring of the rhetorical art one of its most clearly recognizable tasks: these authors, very heterogeneous in production, interests and ties with philosophical thought, provided a dense framework of rhetorical art, and it is almost impossible to think that there was not an elaboration of metaphor as one of the key figures of speech within such a structure.

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[43] Domaradzki (2015).
[44] Domaradzki (2015: 257).
[45] *Ibid.*

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From a Ghost to a Sketch:
Translating Metaphors in Context

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1. Theorizing metaphors

Since the beginning of the history of linguistics and philosophical thought, metaphor has been considered a powerful device in communication. In Rhetoric, metaphor played a special role among other rhetorical figures. Quintilian (*Inst. Orat.*, VIII, 6 [4]), for example, described metaphor as a trope *frequentissimus* and *longe pulcherrimus* and stated that "[in] metaphor […] a noun or verb is transferred from the place to which it properly belongs to another where there is no literal term or the transferred is better than the literal". Aristotle (1987) was aware that metaphors represented a non-eliminable way to communicate and think. In *Poetics* (322 B.C.) he wrote: "The greatest thing by far is to be a master of metaphor. It is the one thing that cannot be learned from others; it is also a sign of genius, since a good metaphor implies an eye for resemblance". Aristotle himself (1973) identified an important property of metaphors: their capacity to put scenes before our eyes.

> It is also good to use metaphorical words; but the metaphors must not be far-fetched, or they will be difficult to grasp, nor obvious, or they will have no effect. The words, too, ought to set the scene before our eyes; for events ought to

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> be seen in progress rather than in prospect. So we must aim at these three points: Antithesis, Metaphor, and Actuality (*Rethorics*, III, 10, 1410 b).

In this regard, we can claim that from the very beginning, philosophers and rhetoricians grasped all the basic properties of metaphor in their theories. These same ingredients have been developed and shared by the multidisciplinary community of scholars who deal with non literal meanings and metaphors today: centrality of the process of metaphor use, reference to the senses, connection between learning effectiveness and a pleasant attitude and environment, role of intuition that points out the not so obvious relationships. All these issues call into question the mental mechanisms that are not merely circumscribed to the usage of language, but also extend to the logical-cognitive, sensory, and emotional processes involved in communication. These processes are related to communication, both comprehension and aesthetic 'taste'.

Afterwards, while theoretical perspectives on metaphor did not discard some of the properties identified by Aristotle, but scholars emphasized certain singular properties, thus losing the overall picture. The cognitive power of metaphors and its relationship with the physical nature of the body is underlined in the work of Giambattista Vico. According to him, metaphor has primary importance in thought and is connected to the conception of *ingenium*, that is to say the capacity to catch ideal similarities, to unify different things and to create correlations. Vico wrote that, among all the tropes, metaphor is the "most necessary and frequent" (Vico 1744: tr. 116). Vico's 'embodied' perspective nevertheless lost the scientific and learning role of metaphors. In the age of Enlightenment, indeed, scientific research is based on the Cartesian approach, in which a rationalist and geometric method left the non-deductive reasoning outside the realm of scientific knowledge.

In this process, obviously, the Aristotelian idea that metaphor was a proper conceptual instrument for knowledge acquisition was lost. During the period of Enlightenment the gap between formal methods (*langues des calcules*) and other forms of knowledge got strengthened. This gap has increased in our century by logical neo-positivism, in which the gap between scientific knowledge and linguistic natural reasoning is probably the highest. Newman (2002: 1), indeed, describes a direct bridge between Aristotle and contemporary theory of metaphor:

> In Rhetoric, Aristotle identifies 'bringing-before-the-eyes' as a capacity that is crucial to metaphors because it allows rhetoricians to actualize actions immediately before audiences, leading those audiences to insight. Because this

description suggests that metaphors activate cognitive mechanisms on the part of their listeners, 'bringing-before-the-eyes' has been considered a key element within Aristotle's theory and the nexus of that approach to metaphor and contemporary conceptual ones.

Max Black in the Sixties took decisive steps back from neo-empiricist method and demonstrated that metaphor is a form of conceptual model capable of generating new knowledge and even generating scientific progress (Black 1954, 1960, 1977). Furthermore, Black, not only deepened the understanding of the operations implied by the logical-conceptual transposition of meaning, but also identified different types of metaphor accounts. There is the case in which we have a literal sentence L that we can express metaphorically (*substitution view of metaphor*):

> On this view, the meaning of M, in its metaphorical occurrence, is just the literal meaning of L. The metaphorical use of an expression consists, on this view, of the use of that expression in other than its proper or normal sense, in some context that allows the improper or abnormal sense to be detected and appropriately transformed (Black 1954: 279).

A special case of the substitution view is the *comparison view*, which holds that the metaphorical statement might be replaced by an equivalent literal comparison.

> If a writer holds that a metaphor consists in the presentation of the underlying analogy or similarity, he will be taking what I shall call a comparison view of metaphor. When Schopenhauer called a geometrical proof a mousetrap, he was, according to such a view, saying (though not explicitly): "A geometrical proof is like a mousetrap, since both offer a delusive reward, entice their victims by degrees, lead to disagreeable surprise, etc." This is a view of metaphor as a condensed or elliptical simile (Black 1954: 283).

Black introduces instead the *interaction view*, according to which a metaphorical statement has two distinct subjects (a principal one and a subsidiary one), which are systems of things. The system of associated implications of the subsidiary subject is applied to the principal one that extends its meaning. The result is a new set of meanings, in which there is a shift in the words of the sentence.

> The metaphor selects, emphasizes, suppresses, and organizes features of the principal subject by implying statements about it that normally apply to the subsidiary subject. [...] This use of a 'subsidiary subject' to foster insight into a 'principal subject' is a distinctive intellectual operation (though one familiar enough through our experiences of learning anything whatever), demanding

> simultaneous awareness of both subjects but not reducible to any comparison between the two (Black 1954: 291-193).

After Black's work, no one could say that metaphor is a marginal phenomenon and an obstacle to understanding the truth. The focus is now on the relationship between objectivity and the natural language component in theoretical construction.

In building common sense and scientific concepts, metaphors play a relevant role especially in the step of discovery and/or creation of 'new' representations of world aspects. One of the mechanisms involved in this process is the capacity to find similarities and create conceptual categories. Many scholars, among which Amos Tversky (1977), George Miller (1979), Andrew Ortony (1979a, 1979b), Earl Mac Cormac (1985) focus their research on the cognitive functions in place in the process of categorization and comprehension. Another approach regarding the ways through which metaphor intervenes in modelling our world representation is the conceptual metaphor theory, formulated by George Lakoff and Mark Johnson (1980). Lakoff & Johnson's perspective has represented a conceptual revolution in the field of metaphor theories, mainly because they changed the focus of metaphor theories from language to thought:

> In contemporary metaphors theories, there is a passage from an approach to metaphor as a mainly linguistic issue to an approach centered on its conceptual nature. This passage causes a transfer of the metaphorical locus from words to concepts that metaphors – directly or indirectly – express and structure (Cacciari 1991: 2).

In Lakoff and Johnson's theory (1980), through a metaphor we can extend our knowledge to grasp new concepts, mapping the conceptual structure from the source domain (usually concrete or at least better-known) to a target domain. The linguistic expressions are a display of this projection. Metaphors appear in language, but are rooted in conceptual schemas, which are metaphorical in nature.

> […] complex metaphors arise from primary metaphors that are directly grounded in the everyday experience that links our sensory-motor experience to the domain of our subjective judgments (Lakoff & Johnson 1980: 515).

The only literal relationship in this view is the grounding of image-schemata that are directly connected to 'literal' activities. Conceptual metaphors are indeed based on image schemata, i.e. recurring models of bodily experiences, which structure (in a non-propositional format) relevant information coming from sensory-motor activities. Even if this view has forever changed the field of metaphor studies, and no one can ignore the relevance of metaphor in thought, reasoning, action, and – of course – communication (Gola & Ervas 2013, 2016; Ervas *et al.* 2017), nevertheless it has been criticized for its conceptual reductionism. It has been objected that metaphorical expressions would not be a surface reflection of a deeper conceptual structure that determines the metaphorical nature of the expression. Proofs in this direction come from cultural and translation studies that highlight that metaphors are not so universal as they would be if they were so strictly rooted in universal concepts (such as the PATH metaphor). Often, metaphoric expressions are strongly determined by the language and culture of the linguistic community to which speakers belong, rather than by the conceptual structure (Delaney 2004; Deignan 2005; Kövecses 2005).

More recent metaphor theories propose a unified theory of the aesthetic and cognitive aspects of metaphor, re-evaluating the role of imagination in the modulation of the literal meaning (Carston 2010; Indurkhya 2016). Carston (2002), in particular, maintains that lexicalized metaphors can be understood through the lexical concept, created *ad hoc*, starting from literal meanings. This pragmatic process takes the encoded concept and generates an ad hoc concept in the proposition the speaker intends to communicate, i.e. a proposition corresponding to the intuitive truth-conditions. They assign the intuitive truth-conditions to the explicit proposition, respecting speakers' semantic intuitions: understanding a statement means knowing the *concrete* circumstances of its truth. In the case of live metaphors, images are instead activated and further developed by imagination when a change of perspective is required, either by focusing on a detail or by dynamically restructuring a sequence (Carston 2010). In this paper we aim to discuss the possibilities and limits of this theory in the case of metaphor translation, taking into account, in particular, the main translation strategies proposed in the relevant literature (Newmark 1988; Larson 1984; Tirkkonen-Condit 2001). We will analyze some examples to show how in the translation process we find a *continuum* of cases, that range from metaphors based on consolidated and intercultural conceptual systems to images strictly connected to the literal meaning of the source language.

2. Metaphor and polysemy in translation

The translation of metaphor has always been a source of discussion and considerable disagreement, due to its multifaceted nature and the high level of creativity involved. Translation scholars have formulated different hypotheses on metaphor translatability that can be classified into three main groups: 1) metaphors are untranslatable, 2) metaphors are fully translatable, and 3) metaphors are partially translatable and thus are not completely equivalent to the target language. The advocates of the first hypothesis (Nida 1964; Vinay & Darbelnet 1995; Dagut 1976, 1987) argue that metaphors evoke cultural and context dependent images in the source language whose nuances of meaning have no equivalents in the target culture. Other scholars embracing the second hypothesis do not think metaphor as a special case for translation and argue that it can be translated as well as any other linguistic phenomenon (Kloepfer 1981; Reiss 2004; Mason 1982). The defenders of the third hypothesis (Van den Broeck 1981; Toury 1985, 1995; Newmark 1988) believe that metaphors always present a degree of translatability according to their specific features. In our view, as we will demonstrate, there are different degrees of translatable metaphors: some fully, some partially, while some completely untranslatable. The degree of translation depends on the literal meaning and the correspondent translator's lexical choice as well as the availability of similar conceptual schema and/or images in the target culture. In the following, we will briefly show certain examples in which lexical semantics play a central role in the resolution of problems that typically emerge in translation. This is particularly crucial in the case of metaphor translation.

In some cases, and especially in the case of lexicalized metaphors, which are often grounded on widespread conceptual patterns (Kövecses 2005), metaphors are fully translatable. We can find, indeed, terms as *decollo* (in Italian), which can be translated as take-off (in English) thus preserving both the literal (airplane *take-off*) and the metaphorical senses (activity/enterprise/event take-off). Other cases of lexicalized metaphors can be found in table 2.1.

Source language	SL word	Target Language	TL word
Italian	ondata (referred to sea) ondata di gente (referred to people)	English	*wave* *wave*
Italian	quadretto (literal: picture) quadretto (metaphor: family)	English	*picture* *picture*

Table 2.1. Examples of 'fully translatable' lexicalized metaphors

Other lexicalized metaphors, on the contrary, require to be translated selecting one of the possible meanings. When we have lexicalized metaphors, sometimes, the translator is forced to change the image that the literal meaning suggests, because of the lexicon of the target language. For example, the Italian term *abbozzo*, that literally means sketch or outline, is translated into English as ghost in the lexicalized metaphor 'abbozzo di un sorriso' (*ghost of a smile*). A sketch or a ghost are completely different concepts that evoke different images: the translator has to find out, in the target language, an image that though different but can capture the correct meaning. Other examples are listed in table 2.2.

Source language	**SL word**	**Target Language**	**TL word**
Italian	aggancio (literal) aggancio (metaphorical)	English	*link* *(political) contact*
Italian	forte (literal) forte (metaphorical)	English	*strong* *loud*
Italian	paletto (literal) paletto (metaphorical)	English	*stake/pole/peg* *strict limit*
Italian	capitolo (literal) capitolo (metaphorical)	English	*chapter* *driving force*

Table 2.2 Examples of 'partially translatable' lexicalized metaphors

In translation, lexicalized metaphors behave similarly to polysemy, probably because they share very similar concepts or conceptual frameworks in both source and target languages. Many cases of polysemy, for example, may be translated using a corresponding polysemy in the target language, because both words are ambiguous in a similar way in the source and the target language. For example the Italian word *ala*, which might mean both a wing of a bird or a building, can be correctly translated into English as wing and into French as *aile* (Federici *et al*. 2012). Another case is the Italian term *corsia*, which can refer to a swimming pool or to a street and can be translated into English with the word *lane* in both cases. Other cases are listed in table 2.3.

In other cases of polysemy, there is no single word that translates both meanings into the target language. The translator should then select one of the terms that disambiguate the polysemy of source language. This is the case with the Italian word *appello*, which means '*exam*' but also 'help'. In the first case, in English it can be translated as exam, but in the second it should be translated as *call*. Other cases are listed in table 2.4.

In the cases discussed above the whole range of lexical semantic information allows to solve the translation problems related to ambiguity and polysemy. That is not always the case. Sometimes the translator does not find sufficient information in the source text to be able to find the right word for the target text (Bazzanella 2011). In such cases translation fails. For example, the Spanish word *pata* means both 'paw' and 'leg' (of an animal). If in the source text we do not find enough information about the context in which *pata* has been used, we would not be able to correctly translate it. Analogously the same thing happens with the English word fish, when we wish to translate it into Spanish, where the live fish is called *pez and pescado* the fish caught to be sold and eaten; and with the Italian word *nipote* where to understand its meaning, we need to know the degree of relationship among the involved people. Without this information, we will not be able to decide, for example, if in French whether it is *nièce* (niece/nephew) or *petite-fille* (grand-daughter). Sometimes this detailed information is missing in the source text, and the translation can easily fail, even if we paraphrase the text in the same language.

Source language	**SL word**	**Target Language**	**TL word**
Italian	appendice (book) appendice (body part)	English	appendix (book) appendix (body part)
Italian	espresso (coffee) espresso (train)	French	express (coffee) express (train)
Italian	corsia (of a swimming pool) corsia (of a street)	English	lane (of a swimming pool) lane (of a street)

Table 2.3 Examples of 'fully translatable' polysemous words

Source language	**SL word**	**Target Language**	**TL word**
Italian	ferri (to knit) ferri (to operate)	English	*knitting needles* *surgical instruments*
Italian	barra (metal object) barra (graphic sign)	English	*bar* *slash*
Italian	borsa (wearing accessorize) borsa (economy)	English	bag (accessorize) stock exchange (economy)

Table 2.4 Examples of 'partially translatable' polysemous words

3. Translating novel metaphors

We can now provide some answers to the following questions: given that metaphors seem strongly related to lexical knowledge, in particular to source language lexical knowledge, is it actually possible to translate metaphors? From this perspective, is there a specificity in metaphor translation? Translation process does highlight that lexical knowledge plays a relevant role in both comprehension and the cognitive processes. A translation process presupposes the understanding of the varied aspects characterizing a text (Miller & Monti 2014). Besides the conceptual aspects, it is necessary to disambiguate morphological and syntactic levels, the logical form, the coherence among semantic restrictions and preferences of words. To establish equivalence between a source and a target text a translator should also understand other semantic and pragmatic aspects (for example conversational implicatures, metaphors, ironic contexts, etc.), that are not easily detectable. According to Max Black (1954: 293), when we translate a metaphor, we always fail in a sense, because

> the relevant weakness of the literal paraphrases not that it may be tiresomely prolix or boringly explicit - or deficient in qualities of style; it fails to be a translation because it fails to give the insight that the metaphor did.

Nevertheless, we have seen that there are different cases of translation in which a metaphor can be maintained in the target text. The process of metaphor translation, as well as translation of polysemous word, seems to be faced by adopting different strategies:

1) keeping the same image and translating the metaphor using the same words in the target language (translation): that is the case of 'ondata di gente' translated into English as 'wave of people';

2) changing the image and finding in the target language a metaphor that can have an analogous meaning (substitution): that is the case of 'abbozzo di un sorriso' translated into English as 'ghost of a smile';

3) dissolving the metaphor into a simile or a paraphrase (paraphrase). That is often the case of live metaphors, which are inextricably linked to both lexical features of literal meaning and cultural-contextual cues. In the case of lexicalized or dead metaphor, understanding metaphors is a process very similar to understanding polysemy, as we have seen. Comprehension of both polysemy and metaphor, indeed, implies the creation of an *ad hoc* concept (Carston 2002). Different strategy has to be applied when we translate new and live metaphors. In this case lexical knowledge is not

enough to produce a translation in the target language. We need to use images and not only words. But, how do lexical components interact with images in metaphor translation?

In *Dire quasi la stessa cosa* (2003), Umberto Eco quoted, as an example of a live metaphor translation, the roof in Paul Valéry's poem *Le cimitière marin*, where the doves stroll as boats on the surface of the sea. Eco points out that the live metaphor of the roof as the sea works because in Paris the roofs are coloured blue-slate that releases metallic glares under the sun, but the metaphor is not easily translatable in another context where the roofs are imagined as red-coloured. In such a case cultural-contextual cues could be the reason for failure in translation. In other cases, lexical features of metaphor could cause a failure in translation and the translator has to resort to alternative strategies such as paraphrases, similes or a completely new and creative piece of work. An example being the spider as a metaphor of a man captures a fly, or in other words a woman, in his cobweb. The metaphor is used by Paola Capriolo in her story *Lettere a Luisa* included in the book *La grande Eulalia* (1988). The metaphor is quite complex because it depicts a possessive and haunting relationship between the protagonist and his quarry Luisa. The translation risks losing the exact image of human relationships evoked by the metaphor of the spider/fly. For instance, the feminine Italian term *mosca* (fly) is translated into French with the feminine term *mouche*, but also the masculine Italian term *ragno* (spider) is translated with a feminine term: *araignée*. Therefore the figurative relationship between a man and a woman is lost. The same problem is found in the translation into German, where both the term *ragno* and *mosca* are feminine, respectively *die Spinne* and *die Fliege* (Capriolo 2002). Another example is Eugenio Montale's translation into Italian of Emily Dickinson's *The storm*, where the 'Emerald Ghost' is the metaphor of wind which shares the green color with the metaphor of a snake as a shiver provoked by the movement of the grass on the earth. Both the metaphors contain a net of semantic associations, as well as phonetic features, not easily translatable into Italian, because of its being more polysyllabic than English. Montale decided to lose part of the semantic content to maintain the same rhythm and similar phonetic features of the original to create a new poetic image in the target culture.

In Robyn Carston's view, in the case of novel or literary metaphors, such as those described above, an alternative 'imaginative' route has to be hypothesized (Carston 2010; Carston & Wearing 2011). Metaphoric interpretation would maintain the literal meaning of the metaphorically used language, which undergoes a more global pragmatic process resulting in a range of communicated affective and imagistic effects. By doing so, Carston allocates greater importance to the evocative power of images in metaphor understanding and reassesses Donald Davidson's view (1978), in which metaphors have "no other meaning than the literal one." The 'ulterior purpose' of a metaphor is indeed to produce an imagistic effect: "metaphor can, like a picture or a bump on the head, make us appreciate some fact but not by standing for, or expressing, the fact" (Davidson 1978: 46). For Davidson, in using a metaphor, the speaker is not conveying any other message other than the literal one, and the further imagistic effect of the metaphor is exactly due to its literal meaning. As Carston (2010: 319) explains:

> images are not communicated but are activated or evoked when certain lexical concepts are accessed and may be further imaginatively developed (by, for instance, shifting mental focus or perspective, zooming in on detail, or forming a connected dynamic sequence) as the conceptual content of the utterance is recovered.

This hypothesis has been confirmed by experimental studies, which showed that in the process of metaphor interpretation, the corresponding literal meaning is not suppressed in a straightforward manner (Glucksberg, Newsome & Goldvarg 2001; Gernsbacher *et al.* 2001; Rubio Fernandez 2005, 2007) but rather remains to evoke further imagistic effects. This 'second route' to understanding metaphors does not exclude the *ad hoc* concepts mechanisms, i.e. a more conceptual way to metaphor understanding. However, the literal meaning endures in evoking an image with more important effects with respect to the first route. In the same vein, Stern noted: "No account of metaphor will be adequate without explaining the fact that something about the meaning of the literal vehicle remains active in metaphorical interpretation" (Stern 2006: 250).

4. The specificity of metaphor translation

Contrary to Carston's view, the interaction between lexis and imagination was not considered in the cognitive-semantic perspective *à la* Lakoff. Among the diverse criticisms made against cognitive semantics, there are indeed those according to which metaphor does not have much to do with the conceptual dimension of language comprehension, as with its imaginative dimension. According to the 'cognitivist' approach to mental imagery, images can be explained as clusters of concepts, thoughts, propositions, that is to say 'conceptual schemas' rather than actual images. Others instead maintained that images were a code completely different from language. Indeed, the contemporary theories on mental imagery present two opposite perspectives. On the one hand, proponents of the 'unique code' believe that the only symbolic structure that allows humans to think, reason and talk would be kind of propositional-symbolic. On the other hand, pictorialists instead defend the idea that mental images have spatial and figural properties, which cannot be preserved through linguistic-propositional structures. This is the reason why philosophers, such as Davidson (1978: 359), maintained that cognitivist approach, in which

> associated with a metaphor is a definite cognitive content that its author wishes to convey and that the interpreter must grasp if he is to get the message [...] is false as a full account of metaphor, whether or not we call the purported cognitive content a meaning.

Images have spatial and physical properties not completely transferable in propositional structures and linguistic sentences. Nevertheless this does not mean that images are literal copies of our visual experience (as shown in Ferretti 1998). The framework of our paper follows from this perspective: mental images are considered different from both equivalent propositional description and visual experience. They are not 'pictures' of what we see nor the effect of the perceptual activity of seeing. This peculiar 'intermediate' nature of mental images, allow them to play a creative role in cognitive processes: "Images are especially useful when we are in front of unusual or new situations, because they increase the amount of information that we can use to understand them" (Ferretti 1998: 14). Mental images are more powerful of implicit information encoded in linguistic structure, thanks to the possibility of representing information simultaneously, as it happens in visual systems (Ferretti 1998: 14-15). This is the case of live metaphors, which not only implicitly convey a piece of information, but also evoke a mental image strictly linked to the lexical features of the relative literal meaning as well as to the specific characteristics of the cultural context.

Newmark (1988) demonstrated that it is easy to translate dead or lexicalized metaphors literally than live metaphors, even though translation depends on the typology of a text in which the metaphor is used. Dead metaphors has to be indeed revitalized in expressive/emotional texts, where imagination plays a crucial role, so that the translation will consist in finding an equivalent image and not a literal word transposition (Ervas 2008, 2011). Furthermore, recent corpus based studies (Federici *et al.* 2012) show that metaphor translation depends greatly on lexical knowledge richness and not only on the typology of the text. This is particularly clear in the case of live metaphors translation, as we saw in the example discussed in the previous paragraph. These examples highlight some specificities of metaphor translation useful to shed light on both general problems in translation and specific features of metaphor when compared to polysemy or other figures of speech. In translation theories we find at least two general perspectives: the 'interlinguistic' approaches which resort to an intermediate representation, which is a-linguistic and common to both source and target languages ('interlanguage', Hutchins 1986) and the 'lexical-linguistic' approaches which search for alignment and transformation rules of words in other words (Nagao 1984; Brown 1999; Turcato *et al.* 1999). Neither of the two is sufficient to explore and solve the translation process of a metaphoric expression, if metaphor has been invented in the discourse (Benveniste 1964, 1966) for the first time, on the basis of usage of words and literal concepts, as in the case of live metaphors.

Lexical knowledge is the required for a good translation of non-literal idiomatic or conventionalized expressions (Ruimy & Gola 2006). Even translation of live metaphors depend to a great extent on the richness and precision of lexical knowledge. It would not be possible to understand an expression such as "Internet has been a tsunami for publishing industry", without knowing the lexical meaning of the word 'tsunami'. However we could wonder whether there is a specificity of metaphor translation when compared to cases of polysemy. In our opinion there is. In polysemy and lexicalized metaphors – which are consolidated in lexical uses and underlying conceptual schema – there are indeed some correspondences in different languages which are in their turn consolidated by linguistic routine or previous translations. This is the case of the first translation strategy, where exactly the same image can be maintained in the target language. In such a case, there is no need for an effort in terms of innovation and imagination. In other cases, the same image cannot be used because it would not make sense in the target language, but transcultural equivalents are already there to fill the gap. This is the case of the second translation strategy, where for instance *ghost of a smile* is translated into Italian as *sketch of a smile* (*abbozzo di un sorriso*). They are both lexicalized metaphors respectively in English and Italian, and even though they use a different semantic field and thus evoke different images, they fulfill readers' or interlocutors' expectations. Even though a *ghost* and a *sketch* do not share many properties apart from the fact of being the fade image of something, they have a similar pragmatic effect in different linguistic and cultural contexts.

There is therefore a continuum of translation cases, which ranges from full to partial translatability. As the third translation strategy shows, live metaphors are easily prone to untranslatability or translation failures, as in the cases of Valéry's roof or Capriolo's spider, where the translator has to resort to paraphrasing or other *escamotages*. However, live metaphors are also the laboratory for new creation in the target language – as in the case of Dickinson's Emerald Ghost in Montale's translation. Here the specific aspect of live metaphors translation seems to be exactly the relationship between lexical knowledge and imagination. Lexis and imagination are indeed related and essential for metaphor comprehension in our language, as well as in others.

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Thought Experiments, Models, and the Heuristic Power of Metaphors in Science

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1. Introduction

We are concerned here with the nature of scientific process and methodlogy; and in particular with the role of models and metaphors therein. We consider three tools of scientific methodology, namely thought experiments, simulations, and field experiments, and examine to what extent they provide us with an epistemic access to reality. We argue that an open-ended interaction with the environment is necessary for generating any epistemic information, and only field experiments can provide that. However, we distinguish cognitive value from epistemic value, and argue that even though thought experiments may not provide us with epistemic information, they may have a significant cognitive value for an agent by providing them alternative ways to construe a situation or phenomenon. We articulate a gestalt-projection view of cognition to explain how any interaction with the environment is necessarily mediated by the models and metaphors of the cognitive agent. Taking this point of view, we argue that a change of models and metaphors can generate new ideas and hypotheses, including creative insights, which provide new ways to interact with the environment, thereby increasing our epistemic access to reality.

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2. Epistemic status of thought experiments

We begin by considering thought experiments, which perhaps make the weakest epistemic claims. Nonetheless, thought experiments are recognized to play a key role in the history and philosophy of science. In philosophy there are numerous examples where a groundbreaking insight was generated by a thought experiment. Gettier (1963) destroyed the age-old notion that knowledge is equivalent to justified true belief with a simple thought experiment. Kripke (1980) reinstated the direct reference theory by means of some well-articulated thought experiments and questioned the idea that a name stands for a set of descriptions.

In science also, it is sometimes argued that a thought experiment can settle an issue without any physical experiment (Brown 1986, 1991, 2000; Moui *et al.* 2006; Sorenson 1992). The most celebrated case may well be that of Galileo (1638), when he argued with a thought experiment that Aristotle's premise that heavier bodies fall faster than lighter bodies is contradictory. Legend has it that he demonstrated this by dropping a cannon ball and a musket ball from the leaning tower of Pisa, though this account is disputed. What is more relevant for the discussion here is that Galileo argued that the Aristotelean premise is contradictory, leading us to *logically* accept the conclusion that all bodies fall at the same rate regardless of their weight. Indeed, this is considered to be a well-accepted argument in scientific community and is often cited as a prime example of how natural laws can be logically deduced in an armchair without necessarily resorting to active experimentation (Brown 2000; Guthery 2008; Sorenson 1992): it tops the list of *Best thought experiments* compiled by Lorge (2007).

We start this discussion with a critical examination of Galileo's argument. As the conclusion of this thought experiment, namely that all bodies fall at the same rate, regardless of their weight, is correct, most people do not examine the structure of the argument critically. Nonetheless, Casper (1977), Norton (1996), Gendler (1998), Atkinson (2003), Atkinson & Peijnenburg (2004), and Norton & Roberts (2012) have analyzed Galileo's argument in detail to reveal many serious structural flaws in it. We add to this discussion by showing why one cannot logically deduce that all bodies fall at the same rate. Based on this discussion, and supplemented by a few other examples, we comment on a general epistemic limitation of thought experiments: namely, that they reveal flaws of our models and explanatory systems, but do not necessarily imply whether a situation can or cannot exist in reality.

2.1. A critique of Galileo's thought experiment

Here is one version of Galileo's thought experiment (Van Helden 1995), the objective of which is to refute Aristotle's premise that heavier objects fall faster than lighter objects.

> Imagine two objects, one light and one heavier than the other one, are connected to each other by a string. Drop this system of objects from the top of a tower. If we assume heavier objects do indeed fall faster than lighter ones (and conversely, lighter objects fall slower), the string will soon pull taut as the lighter object retards the fall of the heavier object. But the system considered as a whole is heavier than the heavy object alone, and therefore should fall faster. This contradiction leads one to conclude the assumption is false.

There have been slightly different ways of presenting it. For example, sometimes it is pointed out that when the string gets taut, is the lighter object pulling the heavier object thereby slowing it down, or is the heavier object pulling the lighter object thereby speeding it up? These two ways of considering the situation lead to opposite conclusions, and hence a contradiction. Notice that the contradiction implies that it is a *logical necessity* that all objects fall at the same rate, and it is not a matter of empirical determination.

We would like to argue here that there is no logical necessity about the law of falling bodies. First of all, in the light of Newtonian mechanics, let us see why bodies of different mass fall at the same rate. If Earth's mass is M, then the force acting on a body of mass m is (Mm / R^2), where R is the Earth's radius (neglecting the height above the Earth's surface from where the body is released). However, given a force, acceleration is inversely proportional to mass, so the acceleration of the body is (Mm / mR^2) = ($M / R2$). This is a constant with respect of m, hence the mass of the body has no effect on its acceleration and, therefore, on the speed with which it falls. However, there is *no logical necessity* about this. If the nature were configured by slightly different laws, then it is quite conceivable that bodies of different mass could fall at different speeds. In other words, we cannot conclude from the thought experiment that the acceleration of a falling body is (M / R^2), and is independent of m. Thus, this thought experiment belongs to Gettier's (1963) class of arguments, where the conclusion is correct but the argument (or the justification) is not.

One simple way to illustrate that bodies of different mass could fall at different speeds is to consider fall in a viscous medium like honey. If two bodies of different mass (and consequently of different sizes) are dropped in a vat of honey, they will fall at different rates, which can be empirically determined. However, Galileo's argument would lead us to conclude that they must fall at the same rate, because there is nothing in the logical structure of the argument to account for viscous drag (See Atkinson & Peijnenburg (2004) for an analysis of this situation). So the contradiction that is arrived at by applying Galileo's argument to falling bodies in a viscous medium merely shows the limitation of our explanations, but does not constrain reality to be this way or that way.

If we examine the original dialogue written by Galileo, he did consider other parameters like the density of the falling objects, and the density of the medium (air or water). He explicitly claims that his arguments show "that a heavier body does not move more rapidly than a lighter one *provided both bodies are of the same material*" (Galileo 1638: tr. 107, emphasis added). However, we can do the same thought experiment by tying two bodies of different materials and argue that bodies of different materials move at the same rate. Of course, the conclusion is correct, but the point is that Galileo seemed to be intuitively aware that there might be other factors that determine the rate at which objects fall, though he did not realize that because density of the object does not play any role in the argument structure, it easily generalizes across objects of different densities. Conversely, if it is conceivable that two bodies of different material tied together can fall at a rate that is consistent with their distinct individual rates of fall, then the same formula can be applied to two bodies of different mass but the same material. All these situations can be experimentally tried out, but the mere idea of tying two bodies together, and considering how they might fall does not logically force us to accept that each must fall at the same rate.

To emphasize again, the conclusion of Galileo's thought experiment is correct, and it is only the argument structure that we are questioning. Galileo appeals to not only logic, but also our experiences in order to be persuasive:

> [I]f you tie the hemp to the stone and allow them to fall freely from some height, do you believe that the hemp will press down upon the stone and thus accelerate its motion or do you think the motion will be retarded by a partial upward pressure? One always feels the pressure upon his shoulders when he prevents the motion of a load resting on him; but if one descends just as rapidly as the load would fall how can it gravitate or press upon him? Do you not see that this would be the same as trying to strike a man with a lance when he is running away from you with a speed which is equal to, or even greater, than that with which you are following him? (Galileo, 1638: tr. 108).

Notice here that the analogy with pursuing a fleeing soldier appeals to our experience, and, moreover, it is not a free-fall situation for both the fleeing soldier and the pursuing soldier are propelling themselves with force. The main point of bringing this analogy is to argue that if two bodies are moving at the same rate, then one does not have to push or pull the other. However, 'pushing' and 'pulling' are metaphorical, model-based constructs that help our understanding of the situation (Lakoff & Johnson 1980). But if we cannot come up with a plausible explanation for a situation, it reveals the limitation of our conceptual model and understanding, and does not necessarily imply that the situation cannot exist. (To be fair, we should consider Galileo's thought experiments in the historical context in which they were put forth, considering the scientific methodology of that time. One such analysis is presented in Camilleri (2015). But in this paper we are examining Galileo's arguments in the modern context to help us understand the role and limitations of thought experiments).

2.2. Limitations of thought experiments

The analysis of Galileo's thought experiment presented above illustrates that a thought experiment essentially sets up a situation in terms of existing concepts, and reasons about it using the accepted models. If a contradiction is revealed, it could well be because of the flaw or inadequacy of the accepted models. A contradiction through a thought experiment does not necessarily mean that the situation or the phenomenon does not exist or is not possible.

A classic example of how our inability to provide an explanation for a phenomenon does not rule out the phenomenon itself is provided by the well-known Zeno's paradox (Brown, 2011: 252-58). In one of Zeno's thought experiments, it is argued how Achilles, who allows a head start of, say, 100 meters to the tortoise, will never be able to catch up with the tortoise no matter how fast he runs. The argument is structured as follows. In order to catch up with the tortoise, Achilles has to first cover 100 meters to get to the starting point of the tortoise. However, during this time, the tortoise would have covered some further distance and would be at another point. So now Achilles has to reach this other point, which will take some finite time. But during this time, the tortoise would move a bit further and would be at yet another point. As this process can be repeated ad infinitum, with the tortoise always ahead of Achilles, it follows that Achilles can never catch up with the tortoise.

Much has been written about this paradox (Lynds 2003; Morris 1997; Salmon 1970). In a simple way, with our current mathematical knowledge, we can say that what the argument does is to point out that there are infinite steps required before Achilles can catch up with the tortoise, so that we never finish them. But each step is of a smaller duration than the previous one, and now we know that the resulting infinite series has a finite sum. So even though this particular way of explaining or modelling the problem portrayed by Zeno leads to infinite steps, it does not necessarily follow that the process in reality would never end. In other words, the paradox is only seen in terms of the model or the explanation of the phenomenon, but does not invalidate the phenomenon itself.

To reinforce this point further, consider Schrödinger's (1935) famous cat paradox. He used the thought experiment of a cat trapped in a cage with a decaying atom, which is in a probabilistic state according to the quantum theory, and a mechanism to release poison if the atom decay is detected. Though at the quantum level, the decay of the atom can be a probabilistic event — it decays with some probability and does not decay with the remaining probability — at the macro level, either the decay is detected and the cat dies, or it is not detected and the cat lives, but it cannot be both. In other words, the cat cannot be alive with some probability and not alive with the remaining probability. However, this apparent paradox or contradiction does not invalidate any of the numerous experimental findings of quantum mechanics. One does not say (and neither did Schrödinger): Aha, I constructed this neat contradiction in the quantum theory, therefore quantum phenomena cannot exist. On the contrary, a scientist respects the experimental findings and continues in the quest for a suitable model and an explanation. For example, the multiverse theory (Deutsch 1997; Hawking & Mlodinow 2010) provides one such model and explanation for Schrödinger's paradox.

To sum up, we see that thought experiments reveal gaps, flaws or inconsistencies in our models and explanatory systems. But these gaps, flaws and inconsistencies, because they are embedded in our conceptual systems, do not necessarily rule out or invalidate a real-world situation or phenomenon. (See also Häggqvist 2007, 2009; Zeimbekis 2011). It is also in this sense that Norton (2004a; 2004b) has claimed that thought experiments are essentially arguments: they amount to inferences based on the assumptions underlying the accepted theories and models.

3. Epistemic status of (computer) simulations

We now turn to an examination of the role of simulations in generating epistemic knowledge. In recent years, as computer technology has become more and more powerful, computational models have proliferated various physical and social sciences. These models are implemented as computer simulations, which can be run as 'experiments'. Among the philosophers of science, there has been much discussion on the epistemic value of results obtained via simulations, and how they differ from the results of field experiments (Barberousse *et al.* 2009; Frigg & Reiss 2009; Giere 2009; Morrison 2009; Simpson 2006; Winsberg 2009). For example, Barberousse *et al.* (2009) argue that "computer simulations, although they are basically computations and do not involve any measurement interactions, nevertheless do generate new data about empirical systems, just as field experiments do" (Barberousse *et al.*, 2009: 573). Gierre, on the other hand, claims that

> calling computer experiments, 'experiments', thus suggests that running a simulation somehow provides a basis for evaluating the representational adequacy of the simulation models involved when it does not. This is dangerous in that it can mislead consumers of simulation results (and maybe even some practitioners) into thinking that their simulation models are epistemologically better founded than they in fact are (Gierre 2009: 62).

Let us elaborate on how simulations typically work. Generally, a simulation of a physical, natural, or social phenomenon assumes a formal or mathematical model of the phenomenon. In the model, certain observable parameters of the phenomenon are identified and represented, and relationships (causal and otherwise) between these parameters are posited or hypothesized. These relationships are then programmed on a computer; or implemented in a physical system such as a wind tunnel. Given some initial states of the parameters, when the program is executed, or the physical system is activated, subsequent states of the phenomenon are outputted, or can be observed, as per the posited relationships.

Now the crucial question is whether these outputs or observations are to be considered as *experimental data* or as *predictions*. To appreciate the difference, let us consider the example of road traffic simulation. The city administration is considering how to set the timings of traffic lights at certain intersections. They collected some empirical data on traffic density (by sampling), and based on it, they created a traffic simulator. Cars appear randomly in the simulator with a density that matches the empirical sample. They test two settings of traffic lights in this simulator, and find that one of them results in traffic jams at rush hours. Is this an empirical observation, or is it a prediction?

To contrast this situation with a field test, suppose the city administration decides to do a trial run to compare the two settings. On Tuesday, they implement one setting and collect data on the traffic flow. On Thursday, they implement the other setting and observe the traffic density. What is the difference between these observations, and the ones derived from the simulator as described above?

Notice that in the case of the simulator, once the parameters of the traffic-generator module are set, it works according to the mathematical principles, or the theory of probability density functions. So the pattern of traffic it generates is like an inference based on the parameter values and the underlying theory. Therefore, the result we get as to the effectiveness of the traffic-light timings is also a prediction based on the assumptions about the traffic density pattern.

To appreciate how this is different from a field test, notice that in a field test a number of external factors can have an influence on the observations. Suppose Thursday happened to be a holiday, so the traffic pattern turned out to be different. One can argue that this can be built into the simulator. But then what if there happened to be a traffic accident on Tuesday, which greatly affected the traffic pattern. The city administration may then decide to discard this data as an anomaly, and collect data on another day the following week. The point is that a field test is like an open system, where the environment can affect the observations in a myriad of ways, revealing parameters that were not considered at all in the design of the experiment or the survey. But a simulation is a closed system, where anything that is observed derives directly (and completely) from the assumptions and the theoretical or mathematical framework underlying the simulator. Having some random-number generator in the simulator does not make it open-ended because any random variables are also part of the theoretical framework. (See also Beisbart & Norton 2012 for more detailed arguments along similar lines using the example of Monte Carlo simulations).

These arguments can also be extended to physical (non-computer) simulations. Consider, for instance, wind tunnels. These are based on verified and tested theories of fluid dynamics. Let us say you are making some modifications to the design of a drone you bought recently. You can use a wind tunnel to get empirical data on how your design will perform. However, the validity of the generated data crucially depends on the validity of the theories on which the simulator is based and the correctness of any underlying assumptions. What the wind tunnel generates is a prediction that must be empirically tested. As engineers well know, a design that has been comprehensively tested on a simulator still needs to be field-tested to be deemed workable. (See also Stojanov 1994).

Thus, a simulation is essential an *implementation* of a theory. Sometimes, the goal of the simulation is to verify the correctness of the theory or the model that is being simulated. In all such cases, the predictions derived from the simulation are matched against the empirical observations. If a mismatch is detected, then the model or the theory underlying the simulation is considered to be incorrect (after verifying that there were no implementation errors) and in need of revision. In all such situations, a simulation generates no epistemic value in itself, for the epistemic value is in matching the prediction against empirical observation. Therefore, there is nothing special about simulations, for this is how normal science proceeds. (See also Frigg & Reiss 2009). What simulations do is to make it possible to generate theory-based or model-based predictions that are very difficult, if not impossible, to generate otherwise. So, in this way, simulations are essentially tools for testing implications of a theory in order to verify or falsify it.

A somewhat different, and perhaps more pervasive, use of simulations occurs when a physical device, mechanism or a computer program is created according to certain principle, and the simulation is actuated to find out the effect of the principle. A simple example illustrates this use of simulation. A gear train with a reduction ratio of 1:7 is constructed to implement the operation of 'multiply- by-7'. In this mechanism, if the speed of the slower gear is interpreted as N, then the speed of the faster gear would correspond to 7*N. Such simulations seem to generate an empirical value: if you did not know what 43*7 is, you could run the simulation and find out.

The traffic simulator example presented above can also be used in this fashion. So, for instance, by running the simulator, one can discover that a certain timing pattern of traffic signals results in backed-up roads, thereby causing increased traffic in adjacent residential roads. This seems to be an empirical observation. However, this 'observation' derives from the assumptions of traffic density, and how individual drivers act when confronted with congested roads. If the situation were to be implemented in reality, a number of other factors, not represented in the simulation, can affect the outcome: it might be raining heavily, causing some streets to flood; there may be a big wedding reception at some place, causing a lot of traffic to head in that direction; and so on.

In all such uses of simulations, parameters of the physical phenomenon or the theory are represented as physical quantities (or variables in a computer program) and actions or transformations correspond to the physical processes (or operations on the variables of the program). After the simulation is run, we observe the state of the parameters (physical quantities or variables) in the simulator, and interpret them as the state of the physical phenomenon (or theoretical variables) being simulated. These observations, however, carry epistemic value only as long as the underlying assumptions of the theory, and the correspondences between the physical phenomenon and the simulator processes are valid. In this regard, a simulation is not any different from a thought experiment.

Generally speaking, the difference between these two uses of simulations is that in the first situation, the natural phenomenon being modelled is not fully understood, and so the goal is to improve the model so as to be able to fit the phenomenon more accurately. Extensive experimentation coupled with making minor or major adjustments in the theory/model are typically used to accomplish this objective. In the second situation, on the other hand, the physical phenomena that are made to correspond to theoretical parameters are well understood, so we accept the results of the simulation as if they were empirical observations. Typically, in these situations, the theories are rather complex and it is difficult to figure out the consequences of theoretical operations, hence simulations are used to assist with this task. (See also the discussion in Indurkhya 2003. These two uses of simulations correspond to environment-driven models and theory-driven models in there).

4. Field experiments

We already made some remarks above as to how field experiments are open systems, whereas thought experiments and simulations are closed systems. Let us elaborate on this some more here. Consider the case of falling bodies. If Galileo were to actually drop two bodies of different weights from the leaning tower of Pisa, as the legend has it, a number of different things might have happened. Perhaps a strange magnetic field or mysterious air drafts affect one of the bodies and not the other. If the bodies were connected by a string, perhaps some not-yet-known force is generated when the string becomes taut resulting in an explosion. There are a horde of imaginable and unimaginable possibilities. When any of these possibilities are actually observed, the scientists have to come up with a better theory or model to explain its occurrence. That the actual observation is deemed impossible from our existing theory or model is no excuse to deny the phenomenon — though one can certainly be cautious and would want to reconfirm the observation if it seems to go against the accepted theories.

We can offer two case histories to illustrate this point. One is the prehistory of heavier-than-air flight (Hart 1985). Before Wright brothers' successful demonstration of heavier-than-air flight in 1903, several attempts were made with internally consistent theories, based on observations of the flights of the birds and numerous experiments, but they failed utterly to take off. As any scientist or engineer well knows, real world has a mind of its own and does not care for the internal consistency or compelling logic of our theories, or for the dedication and hard work which we may have invested in them. It should also be added here that in this pre-Kitty Hawk period, several arguments were advanced to prove that heavier-than-air flight was logically impossible — one such argument is often attributed to the celebrated physicist and engineer Lord Kelvin. Such examples illustrate that scientific knowledge and engineering development is not constrained or confined by the logical implications of our current knowledge and theoretical frameworks.

Another set of examples to illustrate this point is provided by the history of various attempts at designing perpetual motion machines (Ord-Hume 2006). Even though the very idea of a perpetual motion machine goes against the second law of thermodynamics, a well-established and comprehensively-tested cornerstone of our existing knowledge of physics, it has not prevented many bright and talented scientists and engineers from trying to design and build such a machine, and in the process have discovered other useful principles of physics.

To sum up this discussion, when we interact directly with the environment, as in a field experiment, the reality can react in unforeseen ways because it is not bound by the limits of our conceptual knowledge, or by our theories and models. The true epistemic value of an experiment lies in contemplating such observations and results, and incorporating them into our theories and models. (See also Giere 2009).

5. Models, reality and model-dependent realism

We can now take a step back and incorporate epistemic roles of all three methodologies — thought experiments, simulations and field experiments — into an integrated framework of scientific process. We start with the view, which is now generally accepted in the philosophy of science, that a scientific theory is a model of the real-world, and in that sense it is an approximation that captures some aspect of the real-world (Kuhn 1962; Rentetzi 2005). So, in this view, Newton's theory of gravity, Einstein's general theory of relativity, theory of plate tectonics, the polygon model of surface used in deformation analysis, etc. are all considered as models of reality.

Next we use the gestalt-projection framework (Indurkhya 2006) to explain the interaction between theories and the environment. The framework was developed to explain the action-perception cycle and the role of metaphors therein, but it can also account for how experiments mediate interaction with the environment and generate epistemic information. We illustrate this in Figures 5.1 and 5.2, where the theory-experiment terminology is superimposed on the original gestalt-environment interaction schematic.

In Figures 5.1 and 5.2, theories are like gestalts, which are structured network of concepts that interrelate a set of parameters into organized wholes. A theory carves out, or parameterizes, certain aspects of the environment, in terms of which an experiment can be conceived. (See also Peschard 2011). Conducting an experiment is equivalent to taking an action in the environment. In yielding the result of an experiment, the environment asserts its autonomy, and therein lies the realism or objectivity. As the results of an experiment can be quite surprising and unexpected, it provides new information to the scientist (cognitive agent), and therein lies the epistemic value of an experiment.

Notice that this view implies a *model-dependent objectivity* or realism. When an experiment is performed or an action is taken in the environment, the ontology of the action and the parameters of the experiment are based on the model, which is determined by the scientist or the cognitive agent, but the result of the action or experiment depends on the autonomous environment. One can say that it is in reacting to the action or experiment that the environment reveals its mind-independent nature, albeit in terms of the parameters that are dependent on the model and the cognitive agent. (See also Hawking & Mlodinow 2010, Chap. 3).

In this framework, thought experiments correspond to within-model reasoning; essentially a simulation within a framework of model-based assumptions. It may be largely conceptual but may also involve perceptual components and imagistic simulation (Barsalou 1999). Nonetheless, it remains completely within the theoretical framework. In this respect, the conclusion derived from a thought experiment may be valid as long as the theoretical framework remains valid. But because we cannot determine the validity of a theoretical framework a priori, the conclusion of a thought experiment are only tentative, and need to be verified. How far a theory correctly and accurately represents the real-world is something that requires extensive experimentation and verification by the scientific community. Though logical contradictions are to be avoided in any theory, for it severely undermines the explanatory power of the theory, a contradiction within a theory does not invalidate a real-world phenomenon, as we have demonstrated above with some examples. On the other hand, though internal consistency is a necessary prerequisite for any theory, consistency alone does not validate a theory.

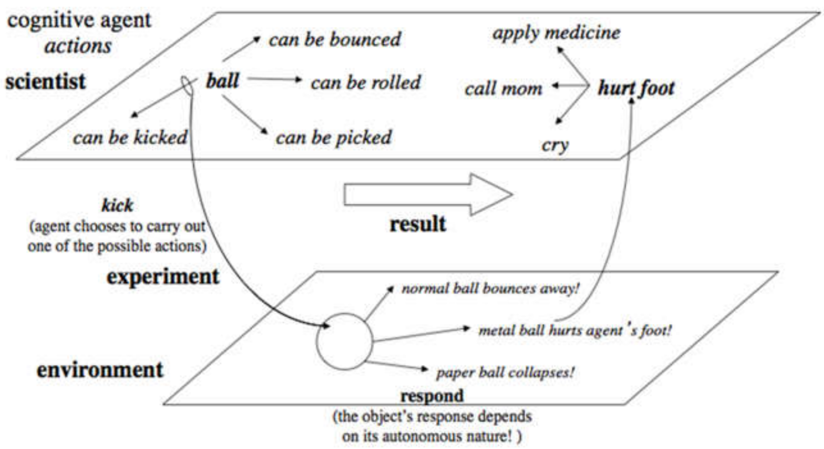

Fig. 5.1 Action perception cycle as seen from the cognitive agent's point of view (without requiring God's eye view.) Adapted from Indurkhya (2006)

Similar arguments can be applied to simulations, even though they are realized in the environment. A simulation by itself is not the object of interaction, but it is a proxy for generating inferences based on a theoretical framework.

To sum up, a conclusion derived solely from a thought experiment or a simulation is valid as long as it stays within the well-charted and well-understood realm of scientific knowledge so that no epistemic justification is needed. However, if it ventures out of this familiar territory into the unknown, then its epistemic status becomes dubious. It may or may not be correct. The existing conceptual framework, on which the argument from the thought experiment is based, may give it an aura of justification. But, in the end, it is the reality that calls the shots, and, in this respect, thought experiments are no substitutes for field experiments performed in the real world.

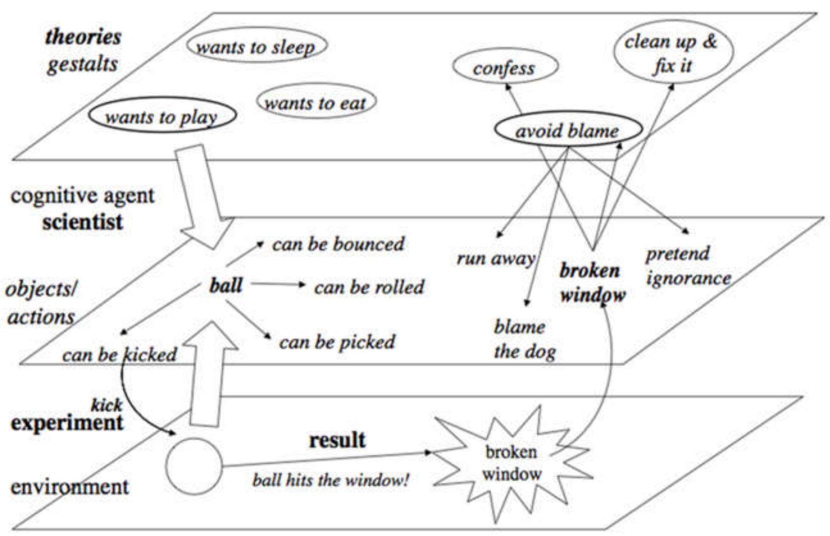

Fig. 5.2 Gestalt projection model (adapted from Indurkhya 2006)

6. Cognitive value of thought experiments (and simulations)

In all our discussion so far, we have been focusing on the epistemic value, by which we mean new information about the environment. However, there is another dimension to the role of thought experiments and simulations, which concerns cognitive value. (There are also several cognitive aspects of Galileo's thought experiments that we did not discuss here; see for instance Palmieri 2003). Perhaps the best way to understand the distinction between these two dimension is to consider a mathematical theorem like the Pythagorus Theorem.

The Pythagorus Theorem states a relationship between the sides of a right-angled triangle. The proof of the theorem establishes that this relationship is grounded in the definition of a right-angled triangle and operations like squaring and summing. So one could claim that the information about this relationship is implicit in the concept of a right-angled triangle, and the discovery of this relationship (proof of the theorem) does not have any epistemic value.

However, we could also look at it from a cognitive point of view, and see that the discovery of this relationship clearly reveals something new to the cognitive agent, and thereby has some cognitive value. In coming up with the proof of a theorem, the cognitive agent learns a new relationship among existing mathematical objects. In a similar way, thought experiments and simulations can carry cognitive value by revealing new connections, new associations and new relationships among existing concepts, which may have a deep significance for the cognitive agent. (See also Irvine 1991).

We would like to discuss here three aspects of this cognitive value of thought experiments. The first one concerns their educational role. Thought experiments can be very helpful in classroom teaching, as they explore the conceptual framework in different situations (Gilbert 2000; Stephens & Clement 2010). It should perhaps be pointed out that most of the thought experiments discussed in the literature are such that the conclusions are known to be correct independently of the underlying thought experiment. So the thought experiment provides a post-hoc justification or explanation for the conclusion that is already accepted by the scientific community. However, there is cognitive value in this as the thought experiment helps us to see how a situation or a phenomenon can be understood through different models or explanatory systems. Research has shown that people tend to understand a phenomenon and reason about it more effectively if it is presented as a concrete situation or a realistic story, and in this respect thought experiment can be very valuable.

Another cognitive aspect of thought experiments is their rhetorical role in persuading the reader of a certain point of view. In scientific discourse, it is not just the correctness of the conclusion that matters, but also the model or the argument used to justify it. An illustrative example is provided by the debate concerning the nature of vacuum when Robert Boyle experimented with his air-pump (Shapin & Schaffer 1985/2011). This concerned the nature of Torricellian space: the space that appears at the top of the mercury column when a glass tube filled with mercury is inverted into a tub filled with mercury. Boyle put the Torricelli's apparatus in his pump, and when he sucked out the air (which was disputed by Hobbes), the mercury level dropped. The explanation that there was a vacuum, or lack of air, at the top of the mercury column was hotly disputed by many celebrated scientists and philosophers of that time. Linus, for instance, argued that because one could see through the Torricellian space, it could not be vacuum, for he considered vacuum to be something through which no visible species could travel. Another argument he advanced was based on the observation that if you conduct Torricelli's experiment by taking a tube that is open at both ends, using your finger to close one end, and then inverting the tube in a tub of mercury, then you can feel a suction force on your finger. If the air is pushing the mercury column up, as Boyle claimed, one should feel an upward pressure, Linus argued. He posited an invisible, thread-like substance he called *funiculus* to explain the experimental observations. Thought experiments play a major role providing a rhetorical basis for such arguments. (See also Fahnestock 1999, 2011; Moss 1993; Moss & Wallace 2003).

A third way in which thought experiments can have a significant cognitive impact has to do with their role as a gestalt-switching device, which we discuss in the following section.

7. Thought experiments and the heuristic force of metaphor

Thought experiments can be very useful to consider a situation from a different perspective, stimulate discussion, and suggest experiments. Searle's (1980) famous Chinese room thought experiment has sparked much lively discussion about the nature of understanding, intentionality and consciousness, which is still continuing. We can consider the well-known example of a fly flying to and fro between two trains that are racing towards each other. The problem is to figure out the distance travelled by the fly until the trains crash. This problem can be solved by obtaining the sum of a convergent infinite series; or simply by figuring out the time it would take for the trains to crash and multiplying it with the speed of the fly. Similarly, there is the problem of covering a mutilated checkerboard, of which two opposing corners have been removed, by 2x1 tiles. If you think of the checkerboard as a plain white grid, you might spend much time trying different ways to cover it until giving up in frustration. However, if you think of the checkerboard in the usual alternate-black-and-white-squares pattern, you will quickly realize that this cannot be done, and will come up with an argument or 'proof' why this cannot be done. In all such examples, thought experiments that make us see the situation in alternate ways can be very effective in solving the problem.

This role of thought experiments is closely linked to how metaphors (or gestalts) provide us with a perspective on the problem (or a part of reality), as explained above in Section 5. As whatever perspective we take dominates how we perceive the situation, and what possible actions (experiments) we consider, sometimes a change of metaphor can be instrumental in solving a problem, or sprouting a new theoretical framework.

Indeed, the crucial role of metaphor in science has long been acknowledged (Black 1962; Boyd 1979; Hesse 1966, 1974, 1980; Hoffman 1980; Indurkhya 1992, 2007; Jones 1982; Kuhn 1979; Rothbart 1984; Turbayne 1962). The metaphorical nature of any scientific theory means that the theory creates its own ontological representation of the reality, and a cognitive agent believing in a theory experiences the reality in terms of the concepts and structure of that theory. This is in keeping with the gestalt-projection framework outlined above, but let us elaborate it a bit further to distinguish it from what I refer to as the traditional view. Consider gravity. In the traditional view of science, gravity is a part of reality, *independently of any theory*. In this view, we say that Newton *discovered* gravity: for it was always there, but Newton found it and incorporated in a theoretical framework. In the metaphor view, however, gravity is a concept that is meaningful only within the framework of Newtonian theory. It may be meaningful in some other theories as well, but it is certainly not universal and theory-independent. For instance, in the framework of Einstein's general relativity, we do not have any concept of gravity, but only space-time curvature. The experience of falling bodies is explained through gravity in Newtonian framework, and through space-time curvature in the Einstein's framework.

Thus, in this view, every theory imposes its own ontology on reality and structures it in a certain way. However, whether that structure is actually respected by the reality is an empirical matter and is subject to objective verification. A theory may be partially correct; meaning that some space-time chunk of the reality may respect its structure. Epistemically speaking, we cannot know if a theory is completely correct because we simply do no have access to all of the space-time chunks so we cannot verify it. (This is essentially the problem of induction; see Indurkhya 1990). As Popper (1963) has shown, we can only refute a theory but cannot really prove it.

But this view also implies that because our access to reality is only through our models and metaphors, our knowledge of reality is invariably partial. So a key question is how can we increase our access to reality and expand our epistemic access.

One answer to this question is provided by Colin Turbayne (1962), who argued that viewing reality through different metaphors, or different models, increases our knowledge of reality, because taken together both the metaphors provide more information about the reality than either one alone. Lest this may seem somewhat abstract, consider that the particle theory and the wave theory of light taken together provide a more complete picture of the nature of light, and can account for more experimental data than either theory alone. (See also Hawking & Mlodinow 2010). Needless to say, when we say two metaphors (or theories), we do not mean any arbitrary theories, but theories that have been extensively tested and verified.

A corollary to this view is that in applying one metaphor (or model) to interpret data of another domain can sometimes lead to creative insights. Carnot's use of fluid-flow model to interpret data of heat flow; Darwin's use of tree imagery to interpret the data on how varieties of species come about; and Wegener's use of the movement of icebergs to understand the data about the shapes of continental coastlines are three examples to illustrate this phenomenon. (See Indurkhya 2007 for more details.)

There are also many interesting examples of how the use of a novel metaphor can be instrumental in creative problem solving. One such episode is recounted by Schön (1963: 74-76), where a product-development team came up with an innovative design for a synthetic-fibre paintbrush (in the 1940s). The key insight came when a member of the team suggested the paintbrush might be viewed as a pump. Though initially this idea seemed 'crazy', after it was assimilated, a new ontology for painting, and the role of paintbrush and its bristles therein, emerged. This new ontology was the key to figuring out how to design a synthetic-fibre paintbrush that performs comparable to a natural-fibre paintbrush. (See also Indurkhya 2007: 21-22).

In this regard, thought experiments provide a crucial mechanism for construing one thing in terms of another, or for interpreting the data of one domain using the representation scheme (gestalt) of another domain. Notice that the act of metaphorical interpretation does not involve active experimentation, but is essentially a thought experiment. In construing paintbrush as a pump, the product-development team was basically doing a mental simulation.

This example also reinforces the limits of thought experiments. The insight that was generated by considering paintbrush as a pump was that to obtain a smooth painted surface, it is necessary to have the fibres bend gradually away from the surface, as opposed to bending sharply. This insight needed to be experimentally verified. There were other suggestions as well, for instance that fibres should have split ends, like natural fibres do, but they did not result in an improved performance. Thus, it is the experimental verification that generated the epistemic value, but it was the thought experiment that led to the idea. (See also Gendler 2004, 2007).

It is interesting to note here an observation made by Peijnenburg & Atkinson (2003, 2007). They pointed out that physical sciences, because they are generally awash in facts and data, are more in need of organizing structures or gestalts. In other words, when there is a lot of data available, the problem facing a scientist is to organize and structure it in different ways. In this regard, thought experiments and metaphors can be very valuable. These organizations and reorganizations can yield insights into the nature of reality (which would need to be empirically verified) that would not otherwise be possible.

8. Conclusions

To sum up, we have argued that the only way a scientist (or cognitive agent) can generate epistemic value is by directly interacting with the domain of enquiry. Any mediated interaction, as in thought experiments or in simulations, is constrained by the validity of the mediating model or conceptual framework; for example, assumptions implicit in the thought experiments or the theoretical model that is the basis of the simulation. In other words, an inference based on a thought experiment or a simulation is valid as long as the underlying assumptions or framework is valid.

We applied the gestalt-projection model to show how the model (theory) – environment interactions are mediated by experiments. In this framework, we articulated an account of model-based objectivity or model-based realism in such a way that even though each perspective on reality experienced by a cognitive agent crucially depends on the conceptual models of the agent, within each model, reality asserts itself by revealing its structure with respect to that model in an autonomous way. To put is simply, a scientist can carve out the reality in somewhat arbitrary ways, and can decide which parameters are relevant and which ones are not, but when an experiment is performed, it is the autonomous reality that determines which parameters are inter-related and what measurements result.

Finally, we argued that any perspective on reality is essentially metaphorical, and metaphors provide a cognitive mechanism to interact with the environment. Therefore, using multiple metaphors can generate more information, sometimes also creative insights, thereby leading to more refined theories and models.

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The Poietic Power of Metaphors

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«No doubt metaphors are dangerous -
and perhaps especially so in philosophy.
But a prohibition against their use would be a wilful
and harmful restriction upon our powers of inquiry»
(Black 1955: 294)

The current scientific and epistemological debate surrounding the living being shows an increasing use of metaphors as a means of theoretical elaboration. Compared with the classical linear modeling approaches, the metaphorical explanatory models seem to show a greater intelligibility of the self-organizing process, proper to biological systems[1].

In this paper we would try to argue for the explanatory power of metaphors as a tool of knowledge (scientific knowledge in particular). We aim to discuss and assess that metaphors are not mere means to simplify or outright promote theories too sensational for media outlets to pass up; their power of inquiry is basically "poietic", as it expands our theoretical approach, and is even able to open new perspectives, mostly unexpected.

[1] For the sole purpose of a general framework of the issue concerning the relevance of metaphorical thinking for scientific knowledge, cfr. Edelman (1995).

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1. Two theories of metaphor: Lucian Blaga and Max Black

In the last Century, we observed the transition from the ‘classical’ theory, in which metaphors were considered a linguistic phenomenon belonging to the Rhetoric, to the cognitive/conceptual theory – thanks to the contribution of G. Lakoff, M. Johnson and M. Turner – which underlines that metaphors are a form of thinking able to organize our perception and make several conceptualisations. While the classical theory has considered metaphors ‘objectively’ as linguistic and rhetoric tools, on the other hand, the cognitive theory emphasizes the ‘subjective’ side and the essential need of metaphors for human reasoning; in particular, as we will see, for the explanation of new phenomena..

The difficulty of fully applying the cognitive theory to scientific metaphors is that science aims at objectivity: while scientists are conscious of scientific limitation (as the use of metaphorical language itself reveals, among other elements)[2], they tend to transcend them. Therefore, we have chosen to hark back to a couple of philosophers who represent an intermediate stage between the classical and the cognitive theory: in this way we hope to highlight that, particularly in science and beyond any subjective connotation, metaphors show a sort of autonomy in producing sense, being characterised by a constant autopoietic function of continuous self-transcendence.

It is rather unexpected to find a deep correlation between two theories of metaphor coming from two philosophers who appear to be completely different, apart from the time they lived – the first half of the 20th century: Lucian Blaga (1895-1961) and Max Black (1909-1988). The first is the national poet of Romania, and a productive philosopher of the culture influenced by the thought of E. Cassirer and O. Spengler; in 1981, the famous Romanian thinker Mircea Eliade wrote that if Blaga’s works have been translated by Romanian, in French, German or English, during the

[2] Thanks to the contribution of the science and development of physics in the twentieth century, the epistemological ideal of achieving full objectivity of scientific knowledge has proven to be in no wise scientific, but rather mythological. The frantic search for “purity”, in fact, is quite compatible with the religious inspiration of a gnostic spiritualist, but clashes not a little with the task of a scholar of material realities. Science is the work of scientists, and thus of men, and thus of beings deprived of the possibility of completely coming out of themselves and looking at things “from God’s point of view”. Borrowing the title of a famous book by Thomas Nagel, we do not possess the gift of the *view from nowhere*: we always look at things “from somewhere”, from a specific point of view, immersed in specific social and cultural contexts. Cf. Nagel (1986)

Thirties or the Forties, «today he would have found a place in the history of philosophy»[3].

The second, Max Black, is a famous British-American philosopher and mathematician. He studied at Cambridge, with Russell and Wittgenstein, and later became professor of philosophy in the USA (at the University of Illinois at Urbana-Champaign and at the Cornell University). Therefore, by underlying how the two perspectives represent two linked and mutually enriching positions on the problem of metaphor, this comparison aims to look at this sort of autonomy in producing sense as a timeless autopoietic process throughout sciences and ages.

1.1. Blaga's "revealing metaphors"

The third book of Blaga's *Trilogy of Culture*, published in 1944, is entitled *The Genesis of Metaphor and the Meaning of Culture*. In this essay Blaga provides a distinction between what he (metaphorically) called the «plastifying metaphors» and the «revealing metaphors». The first represents a symbolic and concrete 'summary' of a description: «the words suffer of a kind of anemia, such that, in order to rebuilt by language the concreteness of a fact, we would need an infinite sequence of essential and specific terms. The plastifying metaphor has the power to make all this parade of words unnecessary». (Blaga 1944: tr. 340). Therefore, this example of metaphor doesn't enrich any fact, but reduces – and 'paints' – this description. The "revealing metaphors", instead, «try in some way to *reveal* a mystery by means derived from the concrete world, from the sensible experience, and from the imaginary world»[4] (Blaga 1944: tr. 344). This means that we can discover something new and unknown before, by combining elements derived from what we already know in both the concrete and imaginary world. Therefore, the revealing metaphor has an "ontological purpose" (Blaga 1944: tr. 358).

We could expect, here, a simplistic identification between scientific knowledge and mythical knowledge, as William F. Clocksin recently wrote: the classic representationalist model of knowledge being nothing more than a form of myth (Clocksin 1995: 190-199). But Blaga makes the opposite move. First of all, he argues that "myth" is something specific, therefore not

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[3] M. Eliade, interview with M. Handoca, "Viața românească", n. 2, February 1982.

[4] We can't dwell, here, upon the metaphysical and anthropological role of the "mystery" in Blaga's system. For more insight, cf. G. Baffo, *Gnosi senza redenzione: la filosofia della cultura di Lucian Blaga*, in Blaga 1944: it. tr. VII-LXV; Nemoianu 1989: 153-173.

everything in the human world can be easily called “mythological”; secondly, he says that also the scientific knowledge is specific but different from the mythological knowledge. Even if a scientific hypothesis has been proven false by an experimental verification, or superseded by a new theory, nevertheless it remains a scientific hypothesis, and does not become a myth – this is the case of the Ptolemaic System of the Universe, or the Phlogiston Theory. This means that there are some other intrinsic differences between the two ways of thinking. Blaga indicates at least one of them: «the myth *assimilates* the concrete appearances, the scientific visions tend to *replace* them» (Blaga 1944: tr. 365) For example, the concrete appearance of fire is “something which consumes what is approached from outside”. Now, the mythical thought assimilates this fact and builds on it a sophisticated vision, remixing together other elements coming from the human experience: the fire “eats” what he meets, except from water, which becomes its enemy; fire brings death, therefore he is a sort of demon; and so on. The scientific thought of 18th Century, instead, suspends the concrete appearance of fire (“something which consumes what is approached from outside”), and “replace it with another image, according to which each body contains, in its normal state, a certain quantity of fire (Phlogiston); the combustion, therefore, is the process of elimination of Phlogiston from the bodies” (Blaga 1944: tr. 366). The same occurs with other concrete elements of experience: “[science] replaces the sound with the vision of vibrations; the light with the vision of infinitesimal corpuscles, or with the abstract image of undulatory perturbations in a magnetic field” (Blaga 1944: tr. 367).

This inner difference between myth and science clearly emerges within the metaphorical language. With a vivid “plastifying” metaphor, Blaga says that “the mythological spirit is the orgiastic slave of analogy, while the scientific spirit is its careful sovereign” (Blaga 1944: tr. 363), and then he explains what he means: for the mythological spirit, “a minimum of analogy” derived from the experience permits an immediate leap to a “maximum of analogy” in the process of abstract elaboration, with the proliferation of uncontrolled and all-engaging metaphors, often far from the first insight. In science, instead, there are several criterions to menage and limit metaphor (i.e. the experimental test, or the doubt upon the concrete appearances), and this makes science more free and conscious in disposing of it. For example, Blaga says, science can use an analogical language for what in experience is totally un-analogical, like the newtonian association between the state of the moon in relation to the earth, and the fall of an apple from a tree: “‘staying in a place” is diametrically opposite to “moving”, but science establishes an analogy between the two situations, conceiving 'staying in a place' as 'movement zero'" (Blaga 1944: tr. 363). According to Balga, science can also make the contrary, taking a phenomenological analogy and transforming it into a not-analogy: everyone look at whale as a fish, but science tell us that whale is not a fish, but a mammal – like the lion. "These modalities to escape from the logic of analogy are completely extraneous to the mythical spirit. And it is by these ways, which depend on the will to separate itself from the immediate suggestions of analogy, that science proves its sovereignty upon analogy itself" (Blaga 1944: tr. p. 364).

The problem with Blaga's system is to establish a clear distinction between "plastifying" and "revealing" metaphors. Actually, the examples provided by Blaga himself are not so persuasive. He considers as an example of "plastifying metaphor" the comparison between "the swallows on the telegraph wire" and "the notes on the stave", and as an example of "revealing metaphor" the poetic vision of the death as "the bride of the world" (Blaga 1944: tr. 344). Now, at first sight it would seem obvious that, if a mystery has to be revealed, death would be a better candidate than the swallows on a wire. Nevertheless, the habits of the swallows are a "mystery" - as well as death - that science aims to explain. And the metaphor of the "notes on the stave" tries to interpret the position of the swallows on the wire, in search for the "law" that lies behind their regularity. Blaga himself recognises that "even scientific theories and hypothesis want to be revelations of mystery" (Blaga 1944: tr. 361).

Ultimately, we can say that each metaphor can be "plastifying" or "revealing", depending on the specific discipline. Or, in a more extreme way: each metaphor is also a "revealing metaphor", with a precise "ontological purpose".

Therefore, the two metaphors for Blaga are actually two different theories of the cognitive role of metaphor. Max Black called them the "substitution view" and the "interaction view" of metaphor. We will analyze them in the following paragraphs.

1.2. Black's "interactive metaphors"

First of all, Black asserts clearly that "calling a sentence an instance of metaphor means saying something about its meaning, not about its orthography, its phonetic pattern, or its grammatical form. To use a well-known distinction, 'metaphor' must be classified as a term belonging to 'semantics', and not to 'syntax' – or to any physical inquiry about language"

(Black 1954: 276). But what is exactly the “semantic power” of metaphor? Why do we use it or even need it to describe phenomena?

Black starts from what he calls the “substitution view” of metaphor, meaning that the metaphorical expression (let us call “M”) is a substitute for some other literal expression (“L”), «which would have expressed the same meaning»: «the focus of a metaphor, the word or expression having a distinctively metaphorical use within a literal frame, is used to communicate a meaning that might have been expressed literally. The author substitutes M for L; it is the reader’s task to invert the substitution, by using the literal meaning of M as a clue to the intended literal meaning of L. Understanding a metaphor is like deciphering a code or unravelling a riddle [...] So viewed, metaphor is a species of catachresis, which I shall define as the use of a word in some new sense in order to remedy a gap in the vocabulary» (Black 1954: 279-280).

The parallelism between Black’s “substitutive metaphor” and Blaga’s “plastifying metaphor” is evident and, in addition, both consider the catachresis as an extreme way to use or understand a metaphor: for Black catachresis is «a striking case of the transformation of meaning that is constantly occurring in any living language» (Black 1954: 280n); for Blaga, in a derogatory sense, it is a riddle in which metaphor is consciously used to darken rather than enlighten the mystery – «with catachresis appears a sort of artificial mystery, or, to better say, a surrogate of mystery», he writes. (Blaga 1944: tr. 352).

The substitution view of metaphor, if not completely wrong, seems at least very partial. By using a metaphor, we do not just shorten or simplify a description: we establish a new link between two distinct objects of experience. With the term “establish” we mean the complex dialectic between “discovering” a correlation, and “creating” it: who establishes a metaphor often “feels” the analogy as something offered to his faculty of comprehension; on the contrary, for an external viewer, the analogy is “created” by that person, and nevertheless it “works”, awakening new patterns of cognition. This correlation between discovery and creation breaks down the stiff categorical framework and shows how the metaphors’ essential element is not just providing answers but, more interestingly, provoking questions, and promoting new and enriched perspectives. Those perspectives represents our own way to “explore” - more than “solve” - new phenomena.

In Black’s words: “often we say, ‘X is M’, evoking some imputed connexion between M and an imputed L (or, rather, to an indefinite system, L1, L2, L3, ...) in cases where, prior to the construction of the metaphor, we should have been hard put to it to find any literal resemblance between M and L. It would be more illuminating in some of these cases to say that the metaphor creates the similarity than to say that it formulates some similarity antecedently existing" (Black 1954: 285).

Therefore we need a philosophical theory of metaphor which overtakes the mere substitution/plastifying vision: this is what Black calls the "interaction view of metaphor", not so far from Blaga's "revealing metaphor". In the interaction view, we consider that "the new context – which Black calls the 'frame' of a metaphor – imposes extension of meaning upon the focal word"; for example, if I use the metaphor of the wolf to describe a man, then this metaphor "suppresses some details, emphasises others – in short, organizes our views of man [...] We can say that the principal subject is 'seen through' the metaphorical expression – or , if we prefer, that the principal subject is 'projected upon' the field of the subsidiary subject" (Black 1954: 288).

In the same line of thought, the Italian philosopher G. L. Brena calls metaphor "a figure of verbal language: it is a *verbal icon*. […] Metaphor is the assumption of the image *in itself* (in its iconic preverbal sense) within the verbal chain" (Brena 1984: 223).

2. Some features of a metaphorical thought and their implications for science

2.1. Reversibility

At once, we aim to notice that the "projective" power of metaphor is not a one-way function: the transparency of the frame-image (mixing Black's and Brena's terms) permits a filtered and qualified vision of the focal referent, but also allows us to see the focal referent as the background of the superposed icon. As Black says, «if to call a man a wolf is to put him in a special light, we must not forget that the metaphor makes the wolf seem more human than he otherwise would» (Black 1954: 291). Using a classical example, if I say "Achilles is a lion" I can see not only Achilles as a lion, but even the lion as "the Achilles of the animals". This potential reversibility of each metaphor was deeply analysed by Douglas Berggren in his *Use and abuse of Metaphor* (1962-63).

This feature has a certain impact on the scientific metaphors: let us analyse, for example, the natural selection. In the first chapter of *The Origin of Species*, Darwin describes the "artificial" selection of some plant and animal varieties made by the farmer or cultivator. Here we should seriously overcome the historiographical tradition which interprets this selection only as a rhetorical *ploy* in order to gradually introduce a revolutionary theory into right-thinking people's minds. As if Darwin wanted to "sweeten the pill" and disguise what was disconcerting in his theory beneath the garb of an act of nature. Nevertheless, artificial selection, that is human selection, is an experiential model, and on that model the notion of natural selection is built analogically. Nature does "as" men do: it selects living species according to its own logic.

> But when we compare the dray-horse and race-horse, the dromedary and camel, the various breeds of sheep [...] we must, I think, look further than to mere variability. We cannot suppose that all the breeds were suddenly produced as perfect and as useful as we now see them. [...] *The key is man's power of cumulative selection.* [...] *he* [i.e., man] *may be said to have made for himself useful breeds* […] Over all these causes of change, the accumulative action of selection, whether applied methodically and quickly, or unconsciously and slowly, but more efficiently, seems to have been the predominant power. […]
>
> I have called this principle, by which each slight variation, if useful, is preserved, by the term natural selection, *in order to mark its relation to man's power of selection*. (Darwin, 1859)[5]

We also aim to highlight that in 1866, even Alfred Russel Wallace was fully aware of the theoretical issues and ambiguities implied by the metaphorical and anthropomorphic notion of "natural selection". Therefore, in a letter to Charles Darwin, he suggested the adoption of the more suitable Spencer's expression, "the survival of the fittest". Thus, in the fifth edition of the *On the Origin of Species* (1869) we find Spencer's expression, confirming the ambiguity of Darwin's original notion[6].

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[5] There is an online free version of the darwinian masterpiece (see the references). The last quote is from the third chapter, the others from the first.

[6] Here what Wallace wrote to Darwin in 1866: «My dear Darwin, I have been so repeatedly struck by the utter inability of numbers of intelligent persons to see clearly or at all, the self acting & necessary effects of Nat. Selection, that I am led to conclude that the term itself & your mode of illustrating it, however clear & beautiful to many of us are yet not the best adapted to impress it on the general naturalist public. [...] I think this arises almost entirely from your choice of the term "Nat. Selection" & so *constantly comparing it in its effects, to Man's selection*, and also to your so frequently *personifying Nature as "selecting" as "preferring" as "seeking only the good of the species"* etc. [...] I wish therefore to suggest to you the possibility of entirely avoiding this source of misconception in your great work, (if not now too late) & also in any future editions of the "Origin", and I think it may be done without difficulty & very effectually by adopting Spencer's term (which he generally uses in preference to Nat. Selection) viz. "Survival of the fittest." This term is the plain

Now, as nature is seen through the human being's filter – as his typical selective activity – we should reverse the terms, and see the "survival of the fittest" being a way to "naturally" describe human society, as a "struggle for life" in which the winners are the best adapted individuals: in short, "evolution" is also a law of men, a law which men follow, (even) consciously and systematically. There is no need, in this regard, to dwell upon the catastrophic effects of such a vision of human beings and races between XIXth and XXth Centuries, with the so-called "social darwinism".

2.2. Hermeneutic openness and social use

Using a metaphor means exposing a concept to a potentially wide hermeneutic process: this is why the substitution view and Blaga's plastifying metaphor both seem to be too simplistic models. Of course, we can develop a lot of different "analogies of proportionality" to explain a metaphor, but each analogy would be also a limitation of the revealing power of metaphors. In what sense "Achilles is a lion"? One can say: he is as brave as a lion; or: Achille's war cry is like lion's roar; or: Achilles rushes against the enemies like a lion on the prey; and so on…

We can grasp, here, the limit of Davidson's literalistic concept of metaphor. Davidson writes that «the most semantic difference between simile and metaphor is that all similes are true and most metaphors are false. The earth is *like* a floor […] because everything is like everything […], but it *is not* a floor. […] We use a simile ordinarily only when we know the corresponding metaphor to be false» (Davidson 1984: 257). This observation is certainly interesting and original, but it belongs to the domain of the formal analysis of language, and not to the theoretical meaning. In other words, the difference between simile and metaphor, which Davidson recognizes, is not semantic, but syntactic and referential-logical. Davidson argues that «most metaphors» are false, but, if we accept his concept of truth, then *no metaphor* can be true. The problem, here, is the overlap between "truth" and "meaning": an identification which Wittgenstein has definitively demonstrated as false – but not meaningless.

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expression of the *facts*, — *Nat. selection is a metaphorical expression of it* —and to a certain degree indirect & incorrect, since, even personifying Nature, she does not so much select special variations, as exterminate the most unfavourable ones». To see the full letter: <http://www.darwinproject.ac.uk/letter/DCP-LETT-5140.xml>

Similes and metaphors can be obviously used in different ways – they can belong to different "linguistic games", to take another Wittgenstein's concept –, but they can certainly have the same meaning. In many occasions, syntactically, a metaphor is simply an abbreviated simile: a simile without the explicit logic nexus ("like"), but with the same meaning. We can add that the grammatical form of a simile can be used to clarify, specify, translate and often reduce the meaning of a metaphor, as we have seen for "Achilles is a lion".

Brena, in this regard, underlines that a metaphor signifies «not only in a global way», but «in an *open* way» (Brena 1984: 222), meaning that it can be differently understood by different men and cultures.

This means, among other things, that a metaphor established by a scientist for a precise purpose can be used and understood in several ways and for several purposes… even far from the scientific field. Let's think about the "Gaia theory", which has been developed since 1979 by the British biologist James Lovelock: according to him, the Earth must be studied as a macro-organism whose purpose is to keep constant some conditions which are necessary for the presence of life on its surface. As just said, Earth must be studies *as* a macro-organism, "as if" it is a macro-organism, because there are some emergent properties which are impossible to understand if we focus only on a single part of it. Lovelock uses the metaphor of Gaia, taking it from Greek mythology, to indicate such a holistic and organicistic vision of the nature, and to easier divulge it. It was William Golding, author of *Lord of the Flies*, to suggest the simple and evocative name of "Gaia", as Lovelock himself remembers (Lovelock 2000: tr. 292)[7].

[7] We can detect a transfer of meaning – from the Gaia of greek mythology to the Gaia of contemporary science – in the very beginning of Lovelock's theory. He describes his first insight with these "mystical" words: «suddenly, *as a revelation*, I saw the Earth as a living planet. The quest to know and understand our planet as one that behaves like something alive, and which has kept a home for us, has been the Grail that beckoned me ever since. It came to me suddenly, *just like a flash of enlightenment*, that to persist and keep stable, something must be regulating the atmosphere […] My mind was well prepared emotionally and scientifically and it dawned on me that somehow life was regulating climate as well as chemistry. Suddenly the image of the Earth as a living organism […] emerged in my mind. At such moments, *there is no time or place for such niceties as the qualification "of course it is not alive—it merely behaves as if it were"*» (Lovelock 2000: it tr. 276). In other works, Lovelock persists with a similar metaphorical language – which is anthropomorphic and religious, in the same time –: he writes that Virgin Mary, in the catholic cult, is an «incarnation of Gaia», i. e. «the Mother of humanity and the source of eternal life» (Lovelock); but he also clarifies that this "mother" is not a lenient one: «Gaia is strong and

This idea has had a certain impact: Gaia theory, today, is not only seriously debated within the scientific community, but also provoked interesting reactions among people who simplified the essential meaning and transformed it into something different from a scientific theory: “Gaia” can represent a pseudo-political revolutionary utopia, an ecologic engagement, a web mental connection attempt, and finally – as the name directly indicates – a form of religion. The Earth becomes a kind of divinity (Gaia) with a purposive will. Lovelock is now completely aware of what has happened, and accepts his metaphor has escaped from its creator’s will. He even said that, maybe unconsciously, he used the Gaia metaphor because it awakened in him a deep need of “sacred”. Yes, «Gaia is both a religious concept and a scientific one» (Lovelock 1988: tr. 206-224) – he says – and therefore we must show «respect to people who even desire to pray Gaia» (Lovelock 1991: tr. 31).

2.3. Death and resurrection

As Richard Boyd points out, «metaphorical expressions constitute, at least for a time, an irreplaceable part of the linguistic machinery of a scientific theory» (Boyd 1993: 486). As we said, scientists often use metaphors not only to divulge new theories but also in order to express and explain the “unknown”, connecting it with something already “known”.

Therefore, «at least for a time», these metaphorical expressions are irreplaceable: using a famous metaphorical Ricœur’s expression, they are “alive”[8]. But there is a curious paradox about this: especially in science, if a living metaphor really works and is successful, then *it will die as metaphor*. This means that it will be no longer interpreted as a connection between two elements; while losing its metaphorical power, metaphors become uniquely and properly terms of scientific language. As an example, the “field” or the “force” in physics, or the “circulation of blood” in medicine, or even the “natural selection” (no more perceived as metaphors but as scientific terms). Maybe one day in the future, “Gaia” will represent *only* a way to call the scientific explanation of the maintenance of the average temperature and the chemical composition of the atmosphere provided by the biota; something like the color “orange”, which, according to Black, comes from the name of the fruit (Black 1954: 280; see also Davidson 1984: 261).

resistant, and keeps the world in optimal conditions», destroying without mercy those who transgress the rules. (Lovelock 1988: tr. 224; Lovelock 1991: tr. 104).

[8] Cf. Ricœur 1975.

Finally, we have to notice that, if points 2.1 and 2.2 are true, a "dead metaphor" can also resurrect in other forms, or in other domains, like a sleeping vulcan that suddenly wakes up. Today, while past metaphors are dying, or are already dead, new metaphors are springing out. It is possible that today's world has completely lost awareness of ancient metaphors but their essential poietic element is hard to ignore, even through ages. The poietic power of metaphors continues to exist through history and cultures, lying at the very basis of the theory of metaphor. Essentially, this poietic and timeless power is what drives the current inquiry on human being throughout different fields. In times of transition when new scientific discoveries push us into something new - new disciplines, theories, perspectives - metaphors show how past and "already known" concepts are applied to new settings (the "unknown" or "not known yet", and not said yet): es an example, we went through the time-based metaphors at the birth of the darwinian biology - as the Lamarkian "soft inheritance" or the "evolution" - and now we are within the current space-based metaphors - as the artificial intelligence, the "web", "search engine", "platforms", "torrents", "swarm"... Therefore, metaphors do have changed across history, but our own approach to new phenomena has not changed, and never will. This approach is reflected into a recursive pattern, shaped out of ever changing metaphors. In this sense, we say that by framing new phenomena, metaphors allow this transition: from the "already known" to the "unknown" or "not known yet". Herein lies their timeless and poietic power: metaphors themselves show us the - eternal - human approach to knowledge.

3. Conclusions

The "danger" which Black sees in the philosophical use of metaphors – cf. the initial quotation – can be surely extended to their use in science. But we would extend to science also the «power of inquiry» of metaphorical thought. This "danger", therefore, is a necessary risk if we want to continue to try to comprehend ourselves and the world around us, as well. We tried to underline that metaphors have a sort of autonomy in producing sense, that sometimes goes even farther than what scientists expected (creating it or deriving it from other semantics fields). In addition to the heuristic and cognitive role, metaphorical thought has also a semantic poietic power. Anyway, as Blaga says, «the genesis of metaphor coincides with the genesis of human being, and it is one of the permanent synthoms of the man-phenomenon» (Blaga 1944: 348): a phenomenon who tries to give sense to other mysterious phenomena, and risk the adventure of knowledge. Therefore, the sovereignty of science upon metaphor, he said, is not understood as a sort of control on a yet-used metaphor, but as a preventive limit to the abuse of metaphorical language, due to our awareness of its autonomous semantic power. It would be important, for a precise scientific metaphor, to ask if it is an irreplaceable way to approach a mystery in order to try to give sense to it — and therefore an important and necessary instrument of knowledge —, or if it contributes to obstruct the comprehend-sion, producing a Baroque catachresis which could be fully welcome in poetry, but not in science.

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Science and Illusion
Metaphors and Visions of the Posthuman

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1. Introduction

The reflection on the role of metaphor as a heuristic tool is nowadays established and quite classic, being broached in standard texts (Black 1962; Hesse 1966) as well as in more recent works such as *Making Truth: Metaphor in Science* (Brown 2008). The fundamental hypothesis, which I will adopt in this paper, is that metaphor can guide us towards new fields of meaning and epistemic perspectives. In other words, a metaphor opens a context, more or less wide-ranging, hitherto ignored: the assumption here is the linguistic nature of human cognition, which means that any significant change at a linguistic level has effects on the cognitive level. However, as will be seen, this also implies cognitively less desirable consequences, as I have tried to suggest in the title of the essay.

As well as metaphor in the strict sense I will take into account the more general force of storytelling, a force which is effective also in allegedly aseptic areas. In fact, it is the same asepticity, real or imaginary, that is liable to become a powerful rhetorical strategy: promoting science is based in no small measure on suggestions of dispassionate neutrality and flawless quantification. To say that something is scientific means crediting it as such, because of its objectivity, although this is still to be demonstrated and defined in its validity and scope. Hence, for example, images of atomic microscopes or of fMRI, derived from complex technological practices and widely conventional procedures, convey the strength of the tangible and 'scientific' reality of atoms or brain processes as something that can be finally seen. Documentation and advertising, or even propaganda, intersect

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programmatically, as do presentation and representation. Needless to say, also the competition for funding often works into the hybrid space to which I am pointing.

This paper wants to be to some extent a contribution in this direction of study, therefore insisting on some representative *metaphors* and on the power of *visions* disseminated by effective narratives. Nevertheless, it has some peculiar features and qualifications, due in part to its specific theme. From a theoretical point of view, the most important of these is the claim that metaphor and storytelling, taken seriously in their strength, cause or may cause ambivalent effects. In fact, there is also a cognitive *dulling*, parallel to the cognitive *opening* on which the literature to which I have referred insists. In other words, the thesis (that I will just mention and use, and not defend directly) is that the cognitive phenomena of 'openness' and 'dulling' are inseparable, similarly to a paradigm change - which to be such implies, in hindsight, the *closure* of the former paradigm.

From a methodological point of view, the most important feature is that my subject theme proceeds programmatically, and not only factually, in an ambiguous light between science and conjecture, between the asepticity I mentioned before and a vibrant mythopoeic ability. But this duality is the key to performative effectiveness. For this reason, I will not attempt here to discern between what is 'scientific' and what is not. The story is always 'true' to the extent that it produces social effects: the human world is simply inconceivable without massive operations of symbolic representation, that intersect and complicate a 'material' substrate which is largely hypothetical (because its very existence and importance is ultimately a postulate of the intellectual reflection on it). This is especially true in an age like ours, fraught with massive post-truth phenomena, which are the outcomes of the lack of distinction between virtual and real.

The fact is that posthumanism, which will be the focus of the investigation, is as a whole built on the ability to activate a different variety of revelation, thanks to scientific credentials that pretend to be impeccable. As has been noted, for example, the frequent propensity to the lexicon of the 'nano' (as in nanotechnologies and related topics), starts, in a way, a narrative on the verge of the fabulous and mythological (Maestrutti 2011). As in *Gulliver's Travels* (but obviously on an immensely larger scale), the oscillation between infinitely small and infinitely large displays a wonderful and estranging effect, due in the first instance to the sheer off scale of the mid-size objects with which we are confronted daily and to which we belong, compared to the incalculable worlds that open below and above us. Therefore, nanotechnologies don't perform actually as an appropriate reference to a specific domain of research, but as the opening of a revelation of manipulation of the infinitely small with bursts of virtual omnipotence. They promise intervention on the fundamental constituents (i.e. the only actual factors) of reality; the production of entirely new properties of matter; the repair of diseases on the most intimate and vulnerable bodily level, working within the space of those innermost links (atomic or molecular bonds; cells as tiny machines) that mechanism has always postulated but never really approached operationally. The scientific reference, in this light, actually serves only to legitimize the disclosure, much more effective, of the wonderful.

One important consequence is that the narrative hegemonic until a few years ago, which, paradoxically, enunciated the end of the (great) narratives, is superseded by this reactivation of traditional themes of modernity, hitherto eclipsed by the well-known disappointments that science and technology went through during the twentieth century. But since strictly political disappointments have been much worse, the technocratic religion has everything needed to catch the scenario deserted by its discredited siblings - although it is doubtful that this development could be positive. A remarkable function of re-enchantment of the world is, in fact, at work. The ability itself to look to the future in a perspective of hope, can replace political, and formerly religious, instances, that for centuries have played a fundamental function. Salvation has no longer a transcendent or political origin, but it is technological, in a wide range of variants, which do not refer only to the posthuman as such. Its most obvious indicator is an aspiration to a final valediction to the traditional limits of man.

1. Metaphors of immortality

What are the crucial data of this incipient mythology? There are, inevitably, some *longue durée* instances.

First of all, and I would say crucially, a multifaceted yet strangely monotonous insistence on the issue of longevity, and ultimately immortality. One consequence of this pervasiveness is the difficulty of choosing a representative text, simply because there are too many. However, an appropriate example would be *The Fable of the Dragon Tyrant* (Bostrom 2005a), where the struggle against death is equated to the liberation of a community forced to a constant toll of victims by a cruel dragon. Recovering the stylistic features of legends legitimates the narrative: the silver bullet against the dragon considered invincible, and immortal, is guaranteed by technology, which updates the legendary swords of medieval knights, which are in turn surrogated by scientists engaged night and day in a feverish search for the great antidote. The story ends with the opening of a vast future of growth, beginning once humanity is liberated of its fragility:

> My dear friends, said the king, we have come a long way… yet our journey has only just begun. Our species is young on this planet. Today we are like children again. The future lies open before us. We shall go into this future and try to do better than we have done in the past. We have time now – time to get things right, time to grow up, time to learn from our mistakes, time for the slow process of building a better world, and time to get settled in it. Tonight, let all the bells in the kingdom ring until midnight, in remembrance of our dead forbears, and then after midnight let us celebrate till the sun comes up. And in the coming days… I believe we have some reorganization to do!

Immortality[1] is therefore one of the more typical themes. This should not come as a surprise, given the opposition of the posthuman movement to the finitude of human experience. Seeing that the human is defined by mortality, that unicum composed of my death and my awareness of it, the genuine posthuman theorist will aim at the elimination of this burden that keeps us irremediably amid the windings of our perennial condition. Postmortality, in this light, is not an optional hypothesis, in the effort to posthumanity. But this step shows how posthumanity, in order to be such, must imply a tendency to leave the human dimension. All the charm and the difficulty of the posthuman resides on a distance from humanity, which should be consistent to be able to talk about *post*human, but which must still allow us to recognize ourselves in these improved versions. Now, this difficulty is exactly that faced by traditional religions (i.e., opening a condition different from the mundane, yet to some extent still human), as well as by political utopias (resolving the space of the conflict through the production of a new man; but retaining in it a traditional human physiognomy so that we could still *understand* what it could possibly *mean* for the heirs of the revolution to enjoy their new condition).

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[1] Or *semi*-immortality, because no technology can make death such as *violent death* impossible (or such as the destruction of the inorganic base where the identity of the subject would be allegedly collected), or can extend the existence *prior* to birth. In the end, the possibility of immortality would seem to find an insuperable barrier in the heat death of the universe: see Bostrom (2010: 4): "Any death prior to the heat death of the universe is premature if your life is good." On "immortality" in this limited sense, see Morin (2002).

The emblematic texts most often cited are perhaps those of R. Kurzweil (1990)[2] and K.E. Drexler (1996). While the former focuses, in a somewhat obsessive way, on the idea of a future singularity[3] that should, given certain parameters in exponential progress, determine a sort of unbelievable quantum leap and an almost eternal life, the latter, using visionary tones which have been much criticized, emphasizes the developing of a bewildering nanotechnology to build a future of perfect health for mankind[4]. The goal is thus not different. Kurzweil presents an array of versions of the human body, numbered like the releases of the software, to ensure a bridge to a future of immortality. The body becomes a rough draft, at most a trace, readjustable, reprogrammable, integrable, etc. Intercepting the magic moment of the so-called 'singularity', which in its most plausible version should be a novel sort of intelligence capable of self-improvement and then rapidly superhuman, is analogous to reaching the escape velocity to the limits of the human condition, breaking away from the weight of the Earth's gravity. Once past this border, men liberate themselves from the gloomy ballast that so far has marked their status. The dream of perfectibility is adapted to an individualistic and biological context[5] detached from any political background and from any hope of originality, as the historical path is ultimately predetermined by an inevitable technological evolution.

Drexler, on the other hand, submits a peculiar and extremely powerful fantasy. This consists in the image of an extreme, almost infinite, miniaturization, able as such to act, staunch, repair, within a body conceived as a complex machine, in the best mechanistic tradition. If in Leibniz's fantasy the brain was expanded to the size of a mill, with its parts proportionately magnified and therefore perfectly visible and accessible, as in some old science fiction stories, Drexler, by shifting to the side of the infinitely small, achieves the same imagery. The metaphor of the body or the brain as machines, which for centuries had, and still has, an absolutely crucial weight, is reactivated in a way that meets an intimate space of the imagination.

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[2] Kurzweil (1990). By Kurzweil see also (1999), (2004) (with Grossman; this is the work focused most directly on immortality), and (2005).

[3] The concept, which is of physical and mathematical origin, was fixed in the sense relevant here by Vinge (1993).

[4] Nanotechnology has a very rich and ancient fictional history, to which I already made some passing reference. Its twentieth-century version has an inflection point in the famous Feynman (1959).

[5] See Morin (2002: 348).

So the therapeutic machines intervene and repair the great machine of the body. But these microscopic molecular robots should be capable of replication, just like the cells to which they are analogous; and this opens the chance of their uncontrolled and apocalyptic reproduction. In the hands of criminals, or simply because something goes wrong, the tide of nanomachines might, says Drexler, plainly consume the biosphere and submerge or supplant humanity[6]. An uncontrolled self-replication engenders a deep fear, because it alludes to the reproduction of living beings themselves and therefore indicates a deviation from the typical condition of the machines. Just as humans, according to the dystopias of the Seventies associated with the (semi) scientific speculation of the Club of Rome and still present in our public discourse albeit less straightforwardly, severely overpopulate the Earth, literally covering it with their presence and activities, so nanomachines will proliferate frantically and out of control, ousting all forms of biological life. In fact, the theme underlying the proposal of Drexler, and cyborgs in general, is precisely the abolition of the boundary between man and machine. The replacement by artificial prostheses of not functioning, or not optimal, parts of human body, merges machine and biology. From the very beginning, technology has served to control the dangerous world that surrounds us, but given that over time our own body becomes pernicious because of its frailty, technology is now employed to intervene within and against it. In other words, to effectively control our own body implies fixing it, surrogating it, improving it. This can extend from the limbs or organs of sense, up to (parts of) the brain itself (as in some experiments, the hippocampus for Alzheimer's patients).

Not surprisingly, the most important and characterizing strategy, well aware of what is involved in becoming immortal, reduces the individual to its information and thus makes it downloadable into inorganic supports absolutely durable or indefinitely replaceable. In this case it is the brain as such, primarily the cortex as the seat of the higher intellectual functions where we maintain our identity, that is replaced. The strategy consists of a mapping obtained through almost perfect three-dimensional scans of the brain, or else, through nanomachines slowly patrolling the cerebral convolutions, taking their images step by step. The outcome is a total spiritualization of human identity. The concept of brain death is already based on an informational notion of human subjectivity[7]: the downloadable

[6] That these concerns are taken seriously within the movement, is confirmed by the significance given to them by a much more balanced author like Bostrom (2000). See also Dinello (2005: 6); Maestrutti (2011: 99 ff.).
[7] Lafontaine (2009: 105).

self just takes a step beyond the bond still lingering with the body. In short, between organic and inorganic there is no real difference; the difference that matters is the mind, which must be saved while the body may wither away without consequences[8]. The proposal regains the most radical dualism present in some moments of Western cultural tradition. This point is extremely important: posthumanism in this respect does nothing more than take up a precise legacy – humanistic and rather anthropocentric.

On the one hand, it is obvious that the safety instance engenders a preferential option for the information and the virtual rather than for the body and material. As observed by one of the characters of Bostrom:

> I, for one, would much rather be uploaded than having my biological brain repaired. I already spend most of my time in virtual reality, and I'd like the security of being able to make a back-up copy of my mind every hour or so. If for some reason I want to manipulate physical objects, I would rent a robot body that was suitable for what I wanted to do[9].

As one can see, here the typical trend of contemporary people towards safety backups becomes compulsive, in an anxious need to immunize *ourselves* from any power interruption. After all, the realization of the ultimate control over our body (a tendency that is no doubt already present in current techniques of constructing and modeling it, from the gym to the surgery) can be fully expressed in the possibility to get rid of it, to discard or hire it as needed or preferred. As an occasional hardware of a software that is elsewhere, ontologically more than physically, the body becomes an

[8] In addition to Kurzweil's books, the text most engaged in a detailed analysis on the actual, even if futuristic, technological feasibility of this perspective is Sandberg – Bostrom (2008).

[9] Bostrom (2000). Although another character immediately replies: "Even though our virtual reality is pretty good at vision and sound, I still think it can't compete with the meatspace in the other sensory modalities. Virtual sex is great, but I prefer to touch my husband's body directly." "Meatspace" is significant: "meat" here indicates an almost derogatory factor, biological and impure. (Similar terms are also used, for example "meat-puppet", "meat bag"). In any case, the claim is interesting because it shows, obliquely but unmistakably, what the background to virtualization actually is. It is the wide world of online sex, incomparably more prudent and less demanding than the traditional one. In fact, the sexual sphere is enormously important because its connection with the corporeal is obviously structural, and the attempt to detach it says a lot about the fundamental trends of present age. But sexual emphasis fits well with a rejection of corporeality, as the body now serves as a collector of pleasure, an entity properly fungible and replaceable rather than definitive. It is controlled and used by the mind and replaced if a more refined model is available. As usual, is asserted the guarantee of immune safety: if the body can be replaced it is no longer a threat, no more than a mobile's obsolescence.

accident of our self, something that defines us no more than the clothes we happen to wear. In this distinction between hardware and software there lies a remarkable series of relevant and philosophically meaningful presuppositions. Here I can highlight only one of these, namely, that it is a distinction active in slightly different forms in all contemporary analyses that focus on the essential significance of information. This is a robust paradigm, albeit perhaps not dominant. It is not just intelligence or identity that are constituted by information, but also life, as well the structure of the inorganic, when complex and differentiated. So iron or hydrogen atoms possess properties whose diversity can be traced to variations of information[10]. This metaphor in fact succeeds in readmitting in a soothed form, metaphysically more acceptable to contemporary tastes, the insight that the structural and formal dimension is decisive compared to the material substrate. It is no coincidence that the obvious similarity of the thesis focused on the dematerialization of identity is with Descartes. And it is precisely this kind of intuition that acts as the quantum of plausibility in transhumanist proposals, on the one hand because it is rooted on a venerable philosophical and religious tradition; on the other, and more significantly for our present purposes, because it reactivates a deep imagery: the disembodied spirit, the guardian angels, the myths of reincarnation, everything is convened by the simple and suggestive idea of an ego that is immaterial and thus preserved from the fate of matter.

It is perfectly consistent with all this that some authors[11] affirm the advent of immortality through preventing biological growth (puberty coinciding with the onset of aging): "Individuals so transformed will not know the sufferings of aging and can live indefinitely. Made artificially sterile by the arrest of their development, they are neither men nor women, but asexual beings physically immature though intellectually adults."[12] A constellation of significant features, highlighted by Bostrom, alludes to the same neutral, locked, and defensive condition: implants, plastic surgery, an intensive relationship with telecommunications, a nomadic and cosmopolitan lifestyle, androgyny, artificial reproduction, the absence of religion, the rejection of traditional family values[13]. The tendency to

[10] See Hayles (1999: 112).
[11] See Shostak (2002).
[12] Lafontaine (2009: 112). My translation.
[13] Beyond other possible observations on all of this, as Bostrom (2005b: 14) himself has noted "it was never satisfactorily explained why somebody who, say, rejects family values, has a nose job, and spends a lot of time on jet planes is in closer proximity to posthumanity than the rest of us". Actually, this battery of options says much more about the expectations

neutralization against everything that orients and characterizes humans, from sexuality to ethnicities and cultures, should make it possible to achieve a sort of immunization from the contagion of impurity, in a word from contamination, disease, death. Political correctness here reveals its secret defensive nature against everything that is outside of it - against what is possibly disruptive. As a removal strategy, the appeasing language is symmetrical to the role of metaphor with which we began: it has the task of making a field epistemically inaccessible, as is a source of potential disturbance from the protected status that Western men and women crave above all else.

2. Visions of happiness

To supplement what observed so far, we can conveniently make use of the work by David Pearce[14], who has developed a transhumanistic and hedonistic utilitarianism. In *The Hedonistic Imperative* this philosopher uses the tools of classical utilitarianism in an ambitious and challenging program of technical implementation of happiness. In short, he plans to eliminate suffering in human animals (as well as in not human ones, because a Darwinian premise is here crucial) using neurotechnological tools (i.e., in the short term with neuroactive drugs, in the long term with genetic engineering). The abolition of suffering is preliminary to a program of paradise engineering where sentient beings are to be redesigned and stimulated at the level of their cerebral centers of pleasure, so that everyone could experience unprecedented levels of well-being. Our motivational system would then become the well-being gradient instead of the pleasure-pain axis; the atavic dualistic and traditional wisdom would be replaced by the exclusive pole of pleasure, thanks to the appropriate and accurate administering of its physiological ingredients: a classification of gradients as they are more or less intense. Hedonism accompanies coherently the denial of death. Perpetuation of life is built around the idea of a structurally unlimited sum of pleasures: from the point of view of utilitarianism only a temporally indefinite extension of gradients is acceptable, because each interruption must be thoroughly unbearable.

Pearce's proposal has somehow the merit of going to the root of transhumanistic well-being: its deep essence is utilitarian happiness. As

of the cosmopolitan intellectuals who lead the movement rather than about the actual fate of humanity, which is still unthought of.

[14] Pearce (1995). See Hauskeller (2013: 57 and ff.).

noted by Michael Hauskeller, however, the abolition of pain has a peculiar consequence. Leaving aside its possible function in view of the maturation of the individual (because anything that requires effort and overcoming obstacles, that is everything that gives existence its worth, might be dismissed), the point is that if nothing could represent suffering to us it is not clear why should we care to *avoid* it. In other words, a possible consequence of the proposal by Pearce seems to be a general apathetic indifference, completely invulnerable to variations which are not really such because they cannot tarnish a pharmacologically induced bliss. Eventually, not only would caring for oneself be compromised, but even more so towards others. Frankly, the prospect of humans that are indifferent and satisfied, slaves to indispensable drugs, incapable of empathy (in a sense, also to themselves) and of every effort as soon any effort is required, cannot be embraced as an ideal for upcoming humanity. They would resemble much more the last man than a superman, to use a pertinent Nietzschean lexicon. Yet, Pearce's proposal seems to go in this direction, if carried out consistently until its completion.

The ideological role of immortality as a political program will not be fully comprehended if it is not associated with this other typical posthumanistic instance. It is clear, in fact, that immortality as such says nothing about the quality of life of immortals. Some melancholic or even desolate literary reflection showed the plausibility of the counterproductive consequences of immortality[15]: infinite aging and endless boredom are just the most obvious possible repercussions of an immortality which does not include some decisive boundary conditions. It is not enough to be immortal: the same almighty technique must also guarantee happiness. All in all, this is a goal that is relatively simpler and to some extent at hand. Careful monitoring therapeutics and prevention, and above all a shrewd dose of chemicals, seem plausible candidates in order to route the individual to happiness - if it is defined, of course, in terms of maximization of hedonistic pleasure.

Actually, the emphasis on happiness helps us to understand that transhumanism is, even when not openly deployed in this sense, a form of hedonism. After all, the visible insistency on immortality is motivated by a constant pursuit of opportunities for happiness (intended as pleasure, which explains the importance of sexual issues, which are being *claimed*, in

[15] Just see Čapek, *The Makropulos Case* (1922); Borges, *El inmortal* (1949) and *Utopia de un hombre que está cansado* (1975). On the work by Čapek, see also the classic reflection by B. Williams (1973: 82-100).

contrast to the attempts of the utilitarian classics to evade such charges) and the parallel avoidance of unhappiness. Probably the deeper distinction from the superman consists precisely in this: contemporary paganism tries to escape the risks. The tragic outlook is programmatically avoided, in the belief that this escape is possible and worthy, rather than a radical anthropological impoverishment, as both Greek classics and Nietzsche would have thought.

From a philosophical point of view but also when any in-depth analysis is employed, the conceptual limits of these efforts are obvious. However, it is fair to recognize that they are relevant above all as attempts that directly express an urgency and aspiration. This is not to deny that it is legitimate to question precisely the awareness of these authors with respect to their premises, which, paradoxically, show the power of visions absolutely far from any demystification. A paradoxical re-enchantment of the world is, as we have observed, already underway. Without this broader framework the brute factors, as it were, of transhumanism do not acquire their full meaning. One thing to keep in mind is the religious background that strengthens the instances that we have identified. David Noble, but also other authors, have pointed out that the fundamentalist roots of ethical and political American visions explain, in addition to numerous other phenomena, the unmistakable tones of redemption and thrust to overcome - even if this overcoming is absorbed entirely within immanence[16]. Here it is enough to hint at their gnostic inflection: the liberation of the spiritual or mental principle from its inadequate prison made of flesh[17].

3. Apocalyptic ambivalences

The inventory so far, even though short, offers a glimpse of the deepest reasons behind the captivating imaginative storytelling of posthumanism. It is all about the distinction between real and imaginary, actual and virtual: in a way, the promise of its final abolishment is the real hidden agenda of posthuman ideology. As may be recalled, in starting the essay I mentioned a sort of inevitable slippage between the level of science, useful because of its epistemological and social prestige, and the (parascientific) level of utopia, necessary in order to provide the fuel that makes of science an ideology. Now, this overlapping is deeply strategic, indeed structural. If science and pseudoscience mingle, the fundamental mechanism of utopia is

[16] Noble (1997); see also Schummer (2006) and (2009).
[17] For a better analysis of posthumanistic Gnosticism, see Allegra (2015).

consolidated: to abolish the reality principle thanks to the ability to move the boundaries of humanity elsewhere. Dreams can become reality - because the reality in which we live is *already* increasingly crossed by the construction of arbitrary and fabulous scenarios. Posthumanist ideology then expresses itself not only in the content offered, but also in its form.

This framework is by no means contradicted by the existence of tales, though less common, dedicated not just to refuting the optimistic narratives but rather to building an alternative and coherent apocalyptic fantasy. The oscillation between Heaven and Apocalypse functions in order to make it difficult to escape from the vision: the prospects of salvation evidently dominate, but one cannot neglect its disastrous reversal. Similarly, the narratives of Christ and Antichrist have an uncanny similarity, which is what makes the discernment of the Christians so important and arduous; or, the hopes of the Revolution slip, from the inside, into the abjection of Terror. As for posthumanism, there is not only the sharp criticism, fueled by hostile principles, of intellectuals like Habermas (2003) or Fukuyama (2002). At times disturbing visions are formulated even from within posthuman premises. The validity of the posthumanist prediction is not put into question: the advent of a different man is really plausible, perhaps imminent; but rather the sense, positive or not, of this advent. It is no coincidence that these concerns have been expressed by a novelist like Michael Crichton (2002), to exemplify the traditional literary oscillation between utopia and dystopia, and by a brilliant computer scientist and technologist like Bill Joy (2000) - the classic figure of the repentant shocked by the excesses of a revolution[18]. Specifically, their distress stems from the vision, which we have already mentioned, of a world of nanomachines out of control, capable of reproduction or replication until enveloping the Earth in a nightmarish ‘gray goo’. The model of aseptic repairs is superseded by its opposite, in which organized life is submerged by an overwhelming chaos that can only increase itself exponentially. Self-replication and self-assembly suggest an out-of-control experiment, as in the sorcerer’s apprentice story. The model is that of uncontrollable viruses or bacteria, as in the stories of secret laboratory research. Despite the commonplace, these views are taken seriously and are part of official documents as possible risks of nanotechnology.

The interweaving of fantasy, storytelling, metaphor, ideology, confirms its power for grip and fascination. What is difficult, caught between hopes

[18] The well-noted biography of this author shows that these fears are not necessarily due to the usual humanistic diffidence towards technology.

of salvation and images of destruction, is precisely the task of demanding and dialectic intellectual reflection. Metaphor and narrative are useful, perhaps essential, to proceed in an innovative way to the transformation of theories, but the difficulty to break free from the subtle blackmail they contain is also confirmed: as if it were always impossible to think, even think otherwise, without adhering to a dogma – even though different from the previous one.

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Part 2

The Heuristic Use of the Metaphors in Science

The Infinite Cosmos, *Similitudo* or Data?
Giordano Bruno and the Astronomers of XVI-XVII Century

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1. Introduction[1]

In the history of science, some metaphoric concepts contributed to the development of new theoretical perspectives. Nonetheless, in order to become efficient and liable to empirical determination, those concepts had been formalized and, above all, weighed up against experience before and against instrumental verification then. In the hereby essay the idea of infinite cosmos will be examined: firstly, the practice of astronomers before the telescope will be reasoned out, in the matter of some problems concerning the dilatation of the size of the universe and lying outside of other uses of the concept of infinite in contemporary sciences. The idea of infinite cosmos outside the observational and geometrical procedures will then be observed, facing Giordano Bruno and the legacy of his notion of infinite, through that cosmos and God are inside a relation of *similitude*, just like in the Neoplatonic tradition according to which the cosmos is an

[1] Paragraphs 2 and 4 have been written by Flavia Marcacci, paragraph 3 by Valentina Zaffino. However, the authors are completely accountable for the whole paper.

Flavia Marcacci and Valentina Zaffino,
"The Infinite Cosmos, Similitudo or Data? Giordano Bruno and the Astronomers of XVI-XVII Century"
in Flavia Marcacci and Maria Grazia Rossi, *Reasoning, metaphor and science*, pp. 119-140.

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http://isonomia.uniurb.it/epistemologica

imperfect God's *imago*; finally, we will get back to astronomy, which tried by various means to dilate the size of cosmos through the use of the telescope before Newton. The aim is to bring into focus how professional astronomers built an always larger cosmos and to what extent Bruno's thought prompted them, before and after the telescope, in observational astronomy as well as in metaphysical cosmology.

2. Outside the metaphor: dilating the celestial sphere with the naked eye

The constellations 40° above the equator (declination) are more or less visible in the European territory: 48 of them were listed by Ptolemy in his *Almagestum*, and these were the astronomers' landmarks until the arrival of the telescope, that allowed them to increase the number of observable celestial objects. The observation of constellations was particularly important for the astro-gnosis (’Αστρόγνωσις), the study of the celestial sphere's orientation. Another reason for importance was the determination of the sky's depth. The sky was perceived as a material, real sphere, due to its apparent continuous rotation, which brought along the celestial objects that were firmly stuck in the *Sphaera stellarum fixarum*. Only telescopes, even barely powerful ones, could observe their proper motion, while the planets' motility was an ordinary experience. Above all, the variability of these objects' apparent distance was evident even to the naked eye, so much so that it was immediate to try and set down the dimensions of the celestial sphere and of the orbits the planets (whose brilliance was still and not variable as the stars' one) ran into.

"Sphaericum esse Caelum motusque ipsius ac syderum nobis manifestos, circulares esse, cum antiquis Astronomis asserunt (…). & qui non?"[2]. The image related to the universe was unanimously acknowledged to be a sphere. *Qui non?* Astronomical trigonometry was thus called "science of the sphere", and *De Sphaera* is the title of the most widespread astronomical manual in the Middle Ages, by John of Holywood (1195 ca.-1256). Hence, it is immediately understandable how spherical geometry was the formal tool to make universe far more than intelligible: it should have made it measurable. Also in the Middle Ages it was in use to talk about

[2]Riccioli (1651: I, 1, 3). From here on out the quotations in note by Riccioli 1651 will provide the volume, the book and the pages.

sphaera infinita, indeed, when referring to God[3]. Alain de Lille (1125-1202) inserted the variant of *sphæra intelligibilis*, and Michael Scot (c. 1175-1232/1236) and Bartholomeus Anglicus the one of *sphæra intellectualis*. The locution of *sphæra infinita* is instead followed by authors like Thomas Bradwardine (1290-1349), up until Nicholas of Cusa (1401-1464). Mixed forms like *sphæra intelligibilis infinita* can also be found. In the vast and rich semantic scenario these acceptations assume in order to tell the infinity of God by various means, the *intellegibilis* variant is especially noteworthy: the sphere, the infinite one too, "[…] makes at least thinkable a 'different' world, no longer finite, hierarchical and centered, but boundless and completely in motion"[4]. This thinkability, that was totally speculative in the Middle Ages, had to face the observation and measurement tools at the times of the birth of modern science. Without recalling speculative reasons, but referring to the instrumental and practical ones that were typical of the astronomers' activity, big efforts were spent on the determination of the Eighth Sphere's diameter. That was the sphere of the fixed stars, the eighth for it followed the ones of Moon, Sun, Mercury, Venus, Mars, Jupiter and Saturn. The order of the planets could change depending on the use of the homocentric system or the deferent-and-epicycle one[5].

In his *De Revolutionibus orbium coelestium* (1543) N. Copernicus (1473-1543) debunked the problem of the Eighth Sphere's distance, so that the problem of the world's dimension dissolved. Like Plutarch maintained that an immense interval existed between the sun and the fixed stars sphere (*De facie*, 9, 925a), the canon from Frombork resorted to the term 'immense' (*immensum factum est coelum*[6]) to avoid establishing whether the sky's size was finite or infinite, an undecidable problem in his opinion.

[3]Hudry (1997), definition 2: "Deus est sphaera infinita cuius centrum est ubique, circumferentia nusquam", cit. in Lucentini (2012: 2), where an interesting philological recognition on the term *sphaera* hereby reported can be found.

[4]Lucentini (2012: 11): "Rende almeno pensabile un mondo 'diverso' non più finito, gerarchico e centrato, ma sconfinato e tutto in movimento".

[5]For instance, the order of the planets in the Ptolemaic system was of Moon, Mercury, Venus, Sun, Mars, Jupiter, Saturn; in the homocentric system it was of Moon, Mercury, Venus, Sun, Mars, Jupiter, Saturn; in the Platonic one it was of Moon, Sun, Mercury, Mars, Jupiter, Saturn; in the Egyptian one it was of Moon, Sun with Mercury and Venus as satellites, Mars, Jupiter and Saturn. These systems were later joined by Copernicus' one, whose order was of the Sun in the middle with Mercury, Venus, Earth with the Moon, Mars, Jupiter and Saturn around. Finally, Tycho Brahe proposed another system, in which the Earth was in the middle, the Moon and the Sun were its satellites and all the other planets stood around the Sun. From this starting point, many semi-tychonic variants assumed further different orders.

[6]Copernicus (1543: 5).

The sky's vastness would imply a too high speed for its motion, indeed: for this reason Ptolemy resorted to the axiom for which what is infinite cannot move, thinking thus to prove the sky's finiteness. Now, Copernicus asked, how to justify that there would be nothing outside the sky? How can nothingness serve as a container and contain something? Hence, he concluded: "Let us therefore leave the question whether the universe is finite or infinite to be discussed by the natural philosophers"[7].

What brought him to dilate the sky's size was the assumption of the Earth's motion around the sun. As it is well known, without entering the complicated analyses of Copernican geometry, that assumption was based on the determination of the planets' position through the careful analysis of their orbits, reconstructed on the basis of the measurement of each planet's distance from the Sun (elongation). Copernicus did not only need to dilate the sky's size, he also needed to stop it: a second motion of the Earth, the one of rotation around its own axis, was the real cause for the notional rotational motion of the celestial sphere. The fixed stars sphere is then the first one, "which contains itself and everything, and is therefore immovable"[8], thus becoming the background on which to compare the other celestial objects' motions.

The problem of the fixed stars sphere's size immediately brought along two more issues at least: the one of the Earth's motion and the one of the center of the universe. About the first one, there were scientists who embarked on an in-depth study of the issue, that was discussed until the beginning of the 19th century. There was also somebody who faced the problem from a less technical and, as it can be said, more epistemological point of view, in the same year as when *De revolutionibus* was first published. It was Celio Calcagnini (1479-1541) who published *Il cielo sta fermo e la terra si muove* ("The sky stands still and the Earth moves"), where the theses of the Earth's rotation around itself and the sky's stillness are backed. Calcagnini gave up on solving the problem of infinity: "it is, indeed, way superior to human intelligence to define how big its [= the sky's] circumference is"[9]. Yet while backing the idea of the sky's

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[7]Copernicus (1543: 6): "Siue igitur finitus sit mundus, siue infinitus, disputationi physiologorum dimittamus". The hereby translations of *De revolutionibus* are excerpted from Copernicus (1543/1992).

[8]Copernicus (1543: 9): "Prima et suprema omnium, est stellarum fixarum shaera, seipsam & omnia continens: ideóq. Immobilis nempe uniuersi locus, ad quem motus & position caeterorum omnium syderum conferatur".

[9]Calcagnini (1543: 183): "è infatti di molto superiore a intelligenza umana definire quanto grande sia la sua [=del cielo] circonferenza".

immensity he makes an interesting remark: “what is the ratio between the center and the circle’s extreme width? The ratio is such that any arc of the Earth can be considered as null, when it is referred to the stellar circle, which surrounds everything extensively”[10].

For what concerns the issue of the center of the world, this had been one of Galileo’s interests even before he aimed his telescope at the sky. The topic is more technical, whilst using strong approximations. These are usual in the science of those times and the recalled concepts are not metaphors at all, but constructs that support the demonstrative practice.

2.2. Galileo Galilei and the center of the world before the telescope

In 1597 Jacopo Mazzoni (1548-1598) published his *In universam Platonis et Aristotelis philosophiam prœludia*, where he recalled Aristotle’s argument in the *Meteorology* (I 13 25-36), according to whom Caucasus was “the greatest of the mountains that lie to the northeast, both as regards its extent and its height”, so that “the sun shines on its peaks for a third part of the night before sunrise and again after sunset”[11]. According to Mazzoni, this implied that from the mountain peak two thirds, maybe even three quarters of the sky were visible: if the Earth had been in motion, then its center would have been far above the center of the world, as Copernicus maintained, and then the people would have perceived a way bigger part of the world[12], with no need to climb up the Caucasus.

Galileo’s answer was peremptory, in a May 30, 1597 letter[13].

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[10] Calcagnini (1543: 183): “qual è il rapporto tra il centro e l’ampiezza estrema del circolo? Il rapporto è tale che si può ritenere nullo qualsiasi arco della terra, se lo si riferisce al cerchio stellare, il quale abbraccia estesamente tutte le cose”.

[11] Aristotle (1994).

[12] Mazzoni 1597, 133: “Hoc itaq´ue Aristotelis dicto supposito, ita argumentor. Si montis Caucasi altitudo tanta est, vt tempore sol stitij aestiualis (nā in eo tēpore intelligo ductū Aristotelis) quicunq; in eius apice esset per tres horas, si coniunctim affumatur vtrumque crepusculum, & per sex, si diuisim, Solem videret, & per consequens de duodecim Zodiaci signis, aut septem cum dimidio alterius, aut nouem integra, supra terram aspiceret, proculdubio altitudo centri terræ supra centrum mundi secundum Copernicum multo maior, quàm sit altitudo Caucasi, nō potest esse adeò insensibilis, ut ex utraque; parte æqualem nobis obtrudat mundi portionem. Hæc omnia uolui exactius expendere, ut Aristoteleus sensus in re valde ancipiti, & lubrica in promptu magis esset, atque vt unus quisque scire posset, quot modis mathematicorum subtilitatibus occurrere possumus”.

[13] Galilei, *Lettera a Jacopo Mazzoni*, in Galilei (1929-1939: II (1932), 193-202). See Shea (1972: 145-148).

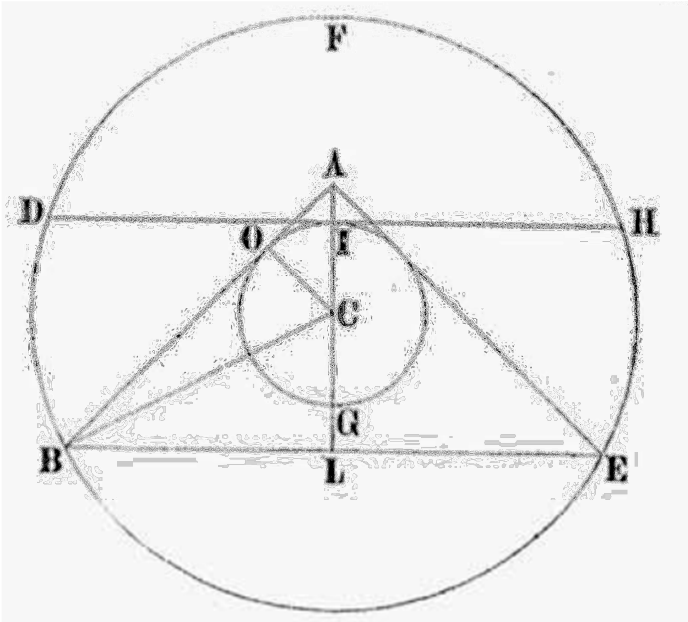

Figure 1. Galileo to Mazzoni.[14]

$BL = \sqrt{(45225^2-1216^2)} = 45208$.

With reference to figure 1, be BFE the sphere of the stars, IOG the Earth with CO as its semi-diameter, L a point as distant from C as the Sun from the center of the Earth. Being the observer in I, the sky's visible horizon will be DH, being the observer in A it will be BAE, being him in L it will be the arc BLE. The reference unit for the measurement is the Earth's radius, 3035 miles long[15]; CL is the distance between the Sun and the center of the Earth, tantamount to 1216 Earth semi-diameters; BC is the radius of the fixed stars sphere, tantamount to 45225 Earth semi-diameters. The line BO, from the Earth's surface to the firmament, will be "imperceptibly lower than BC"[16]. Moreover, be CL perpendicular to BL: BL amounts to 45208 diameters. Lengthen BL to the point E. DIH is tangent in I with the circle IOG and parallel to BLE. Trace the tangent BO that encounters in A the lengthening of LCI. Be A the peak of a very high mountain (for instance Caucasus) and DIH the mountain-foot. BFE is the arc of sky that is seen by an observer on the A peak of the mountain.

[14]Galilei (1929-1939: II (1932), 201).
[15]See § 3.1.
[16]Galilei (1929-1939: II (1932), 201): "Insensibilmente minore della BC".

Now let's suppose to move the C center of the Earth in L, tantamount to a CL distance, which is exactly equal to the radius of the Earth orbit around the sun. Hereupon, the horizontal plane BLE cuts the same BFE section of sky. Hence, an observer would still see the same section of sky that is visible from a mountain peak.

Galileo makes another remark. The triangles BCL and COA are similar and the values of length of BCL's sides are all known. He then establishes the congruence between the right angles ALB and COA and supposes the angles BAL and BCL to be equal (being the angle ABC as null, "we will deem the angle BAL to be equal to the angle BCL"[17]). This leads Galileo to set the proportion BL:BC=OC:CA ("as BL is to BC, thus OC is to CA, as well as CI"[18], as IC=OC). Finally, approximating CA to CI and converting, he gets: BL: (BC-BL) = OC:(AC-OC). Substituting the semi-diameters for the measures: 45203: 17 = 3035: AI. The ultimate value is AI = 1,141 miles, so 1 mile and 141 steps, hence 1 mile and 1/7.

Working on this similarity, the conclusion is that the height IA should be of 1141 miles ("1 mile and 1/7"). From the peak of such a mountain, only 1°32' more of the stellar sphere would be visible, a quantity that is immeasurable to the naked eye. Hence, the Earth's motion and the shift from the center of the world do not imply any variability of the sky's observable section[19].

Actually, Galileo's argument needs some clarification: while shifting the center of the Earth from C to L, the observer would not exactly perceive BFE, since we should consider the mountain peak, in A before and later below. Moreover, setting the center of the Earth in L and the Sun's one in C, the Earth's motion would imperceptibly change the quantity of visible sky. Galileo does not provide these explanations.

Finally, it should be observed that the distances are strongly approximated in the sequence of similarities Galileo enacts in his reasoning, deeming their difference to be imperceptible ("incomprensibilmente", "insensibilmente", "del tutto insensibile"). This is acceptable since Galileo

[17] Galilei (1929-1939: II (1932), 201): "Diremo l'angolo BAL esser eguale all'angolo BCL".

[18] Galilei (1929-1939: II (1932), 201): "Come BL a BC, così sarà OC a CA, ciò è a CI".

[19] Galilei (1929-1939: II (1932), 202): "Parmi, dunque, che da questo si concluda, che il porre la terra lontana dal centro del firmamento quanto è la distanza tra essa e il sole, non possa far maggior differenza, circa il segar l'orizonte la sfera stellata disegualmente, di quello che farebbe l'inalzarsi (costituita la terra nel centro) dalla sua superficie un miglio e 1/7 (…). Ma, per non infastidire più lungamente V.S. Eccellentissima, non voglio darli più lunga briga, ma solamente pregarla a dirmi liberamente, se li pare che in questa maniera si possa salvare il Copernico".

meant to mark the visible sphere with the tangent to the apparent orbit of the Sun around the Earth[20]. However, Galileo's purpose was not to give an exhaustive defense of his preference for the heliocentric system, but only to highlight Mazzoni's error.

3. Dilating the sky in a *simulacrum* world

The topic of infinite is the nodal point of Giordano Bruno's thought. He knows the astronomical concepts and topics, especially Copernican astronomy's ones, and he elaborated original ideas about the orbits and shape of the universe being very close to the technical issues. Nevertheless, he takes it on with a very different style than the astronomers' geometry-bound one[21]: all his philosophy is a theory of infinity, meaning both the metaphysical cogitation and the cosmological system. Nonetheless, for Bruno the necessity of an open universe, populated by infinite worlds, is validated even under an astronomical point of view by the theological assumption for which, from the overflowing and unlimited power of the primary cause, a likewise inexhaustible effect is generated[22]. Since God is the act *in se*, the world – which is his *simulacrum*[23] – turns out to be a continuous actualization of all the possible forms, pertaining to an infinite matter, full of the countless entities that, moved by *vicissitudo*, seamlessly alternate in the process of becoming[24].

The assertion of infinity in action proves the distance of Bruno's thought from Scholasticism. Recalling Melissus, Plotinus and Nicholas of Cusa, Bruno maintains that outside every finite body there is always something and rebuts Aristotle's thesis, according to which the cosmos is perfect for it is concluded in itself, and thus finite[25]. He rather states that a

[20]Shea (1972: 147).

[21] See Tessicini (2016). E.g. one notes the mixture between weak technical arguments and interesting ideas about the Bruno's reference to spiral motions of planets: "Bruno's definition of the spiral is not geometrically accurate and the explanation of its function is fickle, but the motives for its adoption and, quite temptingly, some possible sources as well are sufficiently clear to help make any final assessment less provisional" (Tessicini 2016: 156).

[22]Bruno, *De Immenso et Innumerabilibus* (1879-1891: I, II, 295): "Qui potuit facere infinita, putandum est fecisse, ac totum sancte explevisse vigorem, nec servasse in se vanum, vel inutile quicquam".

[23]See Bruno, *De la causa, principio et uno* (2002: I, 693).

[24] See Firpo (1993: 22-23).

[25]Bruno, *De l'infinito, universo e mondi*, (2002: II, 46): "Per che deve esser frustrata la capacità infinita, defraudata la possibilità de infiniti mondi che possono essere, pregiudicata

limited universe is marked by the non-value of deprivation, and to the Aristotelian definition of entire as "οὗ μηδὲν ἄπεστιν"[26] he rebuts: "Omnium particularium finitorumque compositorum aliquid est extra"[27].
Bruno introduces his immanentist vision of nature, stating that divine infinity and the infinity of matter coincide to make up the One-All, dynamic union of form and matter, i.e. of *natura naturans* and *natura naturata*, and result of the infinite actualization of God's unlimited power. The Nolan radically affirms the coexistence of actuality and potentiality in the divine principle, indeed, since "having a distinction between potentiality and actuality is suitable for mutable things only"[28]. This determines that the single contingent entities that arise from the cycle of becoming and get back to it are parts 'of' the All, not only parts 'in' the All[29], with the inescapable consequence that the same God is ultimately identified with the infinity of the generated and generating matter[30].

Bruno's ontological infinity, moreover, calls for a duplicity of planes, so that the actual dimension is followed by privative infinity, that determines a ratio of proportional analogy between limited and unlimited, comprising the infinite bodies and the infinite worlds that populate the infinite universe. Hence, in an ontological sense Bruno's infinity is image of the actuality of the efficient cause's unlimited potentiality, since in the One-All cause and effect of the generation equate, in compliance with Nicholas of Cusa's principle of the *coincidentia oppositorum*[31], and the nature God created does not differentiate from its creator. This way, the metaphysical discourse on infinity is extended to important cosmological remarks, though struggling to delineate a real astronomical system.

The Nolan adopts the Copernican heliocentric model[32], but he shifts from the essentially mathematical framework to reinterpret the notion of space infinity. The infinity Bruno theorizes implies quantity and quality together, indeed, since the quantitative dimension of the Copernican

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la eccellenza della divina immagine, che devrebbe più risplendere in un specchio incontratto, e secondo il suo modo di essere, infinito, imenso?".

[26]Aristotele, *Physica*, III 6, 207a 9-10.

[27]Bruno, *Acrotismus Camoeracensis* (1879-1891: I, I, 121.

[28]Bruno, *De l'infinito, universo e mondi* (2002: II, 49): "l'aver potenza distinta da l'atto conviene soltanto a cose mutabili".

[29]This is the basic difference between Bruno and Nicholas of Cusa's assertions of infinity, whereas the latter considers the individual entities as parts in an entire and not parts of the entire, Mancini (2014: 40).

[30] See, e.g., Bruno, *De la causa, principio et uno* (2002: I, 180).

[31] See, e.g., Bruno, *De Immenso et Innumerabilibus* (1879-1891: I, I, 280).

[32]See Gatti (2001: 51 ff.).

unlimited space is flanked by the qualitative one of reality moved by a vitalistic principle that eludes geometrical calculation, as usually conceived by the Hermetic tradition of the Renaissance[33].

Under this perspective the homogeneity of matter and space is affirmed, following a principle of equal dignity for all the infinite worlds. Like the Copernican heliocentric theory dismisses the Earth from being the center of the Universe, Giordano Bruno assigns our planet the same ontological and cosmological role as all the other celestial bodies. Unlike Copernicus, though, he eliminates totally the concept of center, or else, under another perspective, he makes every point of the universe the center of the All[34]; such a doctrine is based on the principle of plenitude, which, in turn, depends on the ones of sufficient reason and homogeneity[35]. Therefore, the acknowledgment of heliocentrism under an astronomical point of view is followed, in Bruno, by the ontological destructuring of the center of the universe, since the homogeneity of matter necessarily corresponds with the lack of a universal fulcrum.

3.1. Physics for a centerless universe

The Brunian theme of infinity stands in antithesis with the Aristotelian thought about two essential topics: the distinction between potential and actual infinity and the issue of physical minimum. For what concerns the first point it can be seen that, while Bruno affirms the actuality of infinity changing thus the Aristotelian logical-mathematical dimension for an ontological-cosmological one[36], in *Physica* III Aristotle does not deny the ἄπειρον, but he rather assumes it as a potential and mathematical reality with which some otherwise unacceptable logical processes can be justified.
In the Middle Ages the alternative between actuality and potentiality as applied to the unlimited is rephrased through the concepts of categorematic and syncategorematic infinities, one being somehow comparable to the framework of actual infinity and the other closer to the Aristotelian notion

[33]This is only a quick mention of the importance the Hermetic tradition of the Renaissance had for Bruno's thought; to this purpose, particularly noteworthy hints come from Yates (1981; 1995).
[34]We can then talk of "omnicentrism": Mancini (2014: 47). See Bruno, *De Immenso et Innumerabilibus* (1879-1891: I, I, 329 ff.).
[35]Mancini (2000: 171). Bruno assumes the principle of plenitude Plato exposed, in *Timeo*, 29e-30a and Peter Abelard recalled, in *Theologia christiana*, V 29-58. See Granada (1994).
[36]A. Bönker-Vallon, "I paradossi dell'infinito nel pensiero filosofico-matematico di Giordano Bruno", in Meroi (2004: 163-194).

of potential infinity. Nonetheless, potentiality as such always needs a purpose, i.e. the possibility of the actuality in which to realize, while the Aristotelian infinity is totally incompatible with actuality. Potential infinity is, therefore, a problematic concept, as it reduces to the same positive reality the same potentiality and its very denial, when the first one always finds in the actuality its conclusion, namely its final cause.

Bruno's traditional, dominican education is the reason why he knows Aristotle through the thomist interpretation and, most of all, Thomas' commentaries on Aristotle's works. Regarding the theme of infinity, Thomas Aquinas reconsiders potential infinity as syncategorematic, leaving the unlimited process of logical-mathematical repetitions of the finite open. On the other hand, categorematic infinity is the – always partial – attribute of a subject that is bigger than any actual finite magnitude. Since the medieval interpretation of potential infinity needs a shift to actual infinity, it can be seen in embryo some resolution of the opposition between potentiality and actuality, and thus a first cautious consideration of the non-limited. Thomas shares with Aristotle the denial of actual infinity, and then the thesis for which only what is finite is perfect; Aquinas, though, limits these evaluations to the only created reality, image of God that is perfect in its fullness, as finite. In God, instead, infinite and perfection coincide, as infinity also includes the attribution of perfection and the form has perfection in its own infinite, while the matter in its own limit[37]. Hence, only in the Self-subsistent being, that is pure actuality, the infinite becomes actual, though still impossible in created reality. Bruno, therefore, recalls Thomas Aquinas' position, but he acknowledges to the cosmos the attributes of infinity and perfection that Thomas only conferred to God.

The second important difference between Bruno's and Aristotle's conceptions of infinite concerns the concept of minimum. In Giordano Bruno's works, the issue is investigated from three different perspectives, which are complementary among them. The atom is the physical minimum, the monad is the metaphysical one, the point – and the number too, somehow – is the ontological-geometrical one. In the Frankfurt trilogy, the author builds the cosmological, metaphysical and ontological-mathematical realities by following the infinite aggregation of the respective minimums, describing as a result the One's totality as boundless infinity of mathematical-geometrical beings as much as of metaphysical beings

[37]Cf. Thomas Aquinas, *Summa theologica*, I 7, 1.

stemming from the universal Monad and of the countless physical worlds that populate the infinity of infinite universes[38].

He assumes magnitude to be a discrete structure and the atoms to be the indivisible elements that make up the infinite matter[39]. Since physical beings are formed by the process of aggregation and fragmentation of the very atoms, Bruno can assert that all is in all and that the existent worlds are made up by a single matter, moved by the life force of *vicissitudo* and held up by the very laws that shape our world[40].

The Aristotelian theory of natural minimum distinguishes the divisibility of matter from the divisibility of form (Aristot., *Phys.*, I, 4, 187b 35-188a 13). For the Stagirite, on the other hand, indivisibility only exists in qualitative movements (*Phys.*, VI 5, 236b 17-18), while for what concerns quantity no minimum size is given (*Phys.*, I 4, 188a 11-12). Hence, Bruno does not retrieve the Aristotelian distinction between notional divisibility of number and actual divisibility of substance[41]: while Aristotle denies actual infinity with regard to the maximum, if accepting it as positive infinity in the unlimitedly small, for Bruno maximum and minimum correspond[42], though actual infinity is only admitted for what concerns the cosmological dimension. In this case, the contradictory aspect of Bruno's thought appears under both the points of view of quality and quantity.

In the first case, Bruno expands the cosmos' dimensions to describe an infinite universe, but he does not apply the same logical category to smaller dimensions; this way, natural investigation reaches the physical minimum, locating it in the atom, that faces the framework of an unlimitedly open cosmos[43]. In the second case, though justifying the actual cosmological infinite with the boundless power of creation of God that ceaselessly produces all the possible forms, the Nolan denies that the same infinity may apply to the *minimum*.

It comes to light, then, that for Giordano Bruno the thesis of the infinity of cosmos and cosmoses is not so much of a scientific theory, but rather a metaphysical one, thus also philosophical and theological. He does not back his arguments with applied data, does not provide mathematical calculations coming from the observation of the sky and does not propose any model to justify the cosmos' enlargement in relation to the traditional Ptolemaic

[38]Bruno, *De triplici, minimo et mensura*, (1879-1891: I, III, 140).
[39]Bruno (1879-1891: I, III, 139-140).
[40]See Védrine (1997: 177 ff.); Rowland (2011: 242 ff.).
[41]See De Bernart (2002: 208-209).
[42]See Bruno *De triplici, minimo et mensura*, (1879-1891: I, III, 140).
[43]Aquilecchia (1993: 319-326).

system. Furthermore, he stayed away from the astronomical dispute in its more technical details, debate that took place in the second half of the 16th century, and he showed no interest in corroborating his thesis with the help of the astronomical observations or instruments of that time.

3.2. The notion of *similitudo* in Bruno's cosmology

Bruno's cosmology rather assumes a metaphysical and ontological meaning, and the affirmation of the actual infinity of form and matter is based on the Neoplatonic doctrine of *similitudo*[44] between immanence and transcendence. The notion of *similitudo* links up two elements – in this case world and God – in a stronger and more immediate way than a metaphoric relation could do. The infinite matter is infinite image of the divine *virtus*, and the Nolan recalls the theme of similarity between God and the world also in his terminology, putting in correspondence "Forma, Similitudo, Imago, Figura, Exemplar, Character, atque Signum"[45]. Bruno maintains that *similitudo* is what gives rise to the "a producente in productum"[46] shift, so that the universal matter, full of the infinite possible forms, turns every potentiality into actuality through the similarity between these two planes of being, that ultimately overlap one another.

According to Bruno, in fact, the ontological distance between generated and generating matter is overridden in a *similitudo* that marks the *coincidentia* between divine and material. The similarity between this two terms in Bruno is thus radicalized in comparison with, for example, Nicholas of Cusa's thesis of *coincidentia oppositorum*. Bruno assumes as foundation of the only reality the universal One-All, in which the likelihood between the One and the multiple is comprised within the only material principle. Nicholas of Cusa, instead, keeps the divine level distinct from the one of the corruptible world, though still considering the first one the *exemplum* – i.e. the *complicatio* – of its perceivable image – that reveals itself as *explicatio* of the divine form[47]. On the other hand Bruno, as seen above, acknowledges an equal ontological dignity to *forma*, *similitudo*,

[44]Bruno provides the following definition of *similitudo*: "Est similitudo, seu relatio inter simile et inter id cui assimilatur, quae est in omnibus; ita tamen ut inferiora dicantur similia superioribus, non e contra, illa vero dicuntur quibus ista assimilantur" (Bruno, *Lampas triginta statuarum* (1879-1891: III, 193).
[45]Bruno, *De Umbris Idearum*, in Bruno (1879-1891: II, I, 79).
[46]Bruno, *Figuratio Aristotelici physici auditus*, (1879-1891: I, IV, 155).
[47]Nicholas of Cusa (1970-2009: XIX, III, 235): "Nihil participative perfectum nisi inquantum est imago absolute perfecti".

imago and *exemplar*, in his *De umbris idearum*, considering the matter to be perfect image of the infinite form, while in his *De imaginum compositionem* he seems to show some difference between *similitudo* and *imago*, whereas the latter is more inspirited by the divine model, while the *similitudo* is bound to a mere dependency relation of the generated on the generating[48].

In both the solutions Bruno proposes, though, the analogical relation between the divine and cosmos is marked by an essential ontological correspondence between the two levels of the actuality, that ultimately makes infinity an attribution that can be investigated from a merely metaphysical and not also mathematical perspective.

4. Outside the metaphor: dilating the sky with the *perspicillum*

Giordano Bruno's evocative reflections were never regimented through an observational verification by the same philosopher, in the true sense of the astronomical praxis. Nonetheless, when the dispute intensified, for stating what system was true among the Ptolemaic, the Copernican, the Tychonic, the semi-tychonic, the Egyptian and so on, it really became essential to establish the shape of the universe in order to set a center. The infinity of sphere and circumference made the localization of the center difficult to conceive, even abstractly. Therefore, the semantic swing between the terms *globulus*, *globulosus* and *sphairoeides*, from Copernicus on, became quite interesting, as the sphere is a mathematical being of which physical entities can be an approximation at best[49]. The only sure aspect is that a finite sphere makes the issue of its center more feasible.

When exposing his arguments on the spherical universe and complies with astronomers' habits, the Jesuit astronomer Giovanni Battista Riccioli (1598-1671), who employed the telescope in his work, highlighted how *a priori* speculations were not enough, but *a posteriori* arguments were needed, even counterfactual ones in case[50]. Therefore, it is necessary to provide concepts and nomenclature to orient oneself all along the greatness of cosmos, with an eye to a strict confrontation with the contemporaneous authors who took part in the argument. Thus, a good summary of what was

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[48]Bruno, *De imaginum compositione*, in Bruno (1879-1891: II, III, 99-100).
[49]G. Stabile, "Intorno alla sfera prima e dopo Copernico", in Totaro-Valente 2012, 429-440.
[50]Riccioli (1651: I, 1, 3) distinguishes between an *Argumentum a priori ex congruentia*, an *Argumentum a posteriori, & experimento sensuum* and an *Argumentum ex absurdis*. The latter starts with the typical counterfactual form: "si Caelum non esset sphaericum aut motus omnis circularis denegaretur Caelo, …".

going on in astronomy after the invention of telescope and before Newton's synopsis can be inferred from the Jesuit. Many issues of *Primum Mobile* are in fact the general ones of planets and fixed stars, as well as of all the necessary elements to describe it; such issues, then, are both the ones that strictly regard the *Primum Mobile* and the ones that indirectly concern it[51]. The first elements that should be identified are horizon, meridian and equator; then the zodiac, the equinoctial colure and the solstitial one; the circles of altitude, the circles of declination, the ones of latitude, the hour circles, the position circles, the circles of astrological houses and the great-circle distance. These are the *Circoli maximi*, among whom the vertical circle, the horizon and the circle of altitude are immobile. Along with the mobile circles, they are useful in order to understand the *doctrinam Primi Mobilis*, despite the latter being ultimately very complex and rich in theorems[52]. The first thing to do is to set the proper motion of the skies, eastwards, on the basis of which the motion of the other mobiles is established[53].

Riccioli lingers over the motion of the first mobile[54], quantifying it: the length of the solar day is of about 24 hours[55]. To be precise, it lasts less than the time needed for a complete rotation of the equator (what we call a sidereal day nowadays): the 360° of the equatorial circle correspond to 23h 56' 2'' 24'''[56], while the 24 hours of the solar day correspond to 360° 59' 8''[57]. The hereby data are treated to have a hourly estimation of the size of

[51]Riccioli (1651: II, 10, 550): "Prohemium. Problemata Primi Mobilis appellamus ea, quae Generalia sunt & omnibus stellis siue Fixis, siue Erraticis communia; nec non punctis ipsis aut partibus Eclipticae, Aequatoris, Meridiani, Horizontis, Verticalis, & aliorum circolorum maximorum, qui in supremo caelo designari solent (…), sine deinde supremum illud caelum sit reipsa Primum Mobile, siue non".

[52]Riccioli (1651: I, 1, 10 ff.). These problems are treated to a bigger extent in Riccioli (1651: II, 10, 550-575), i.e. *Sectio* II: *Problemata Primi Mobilis*.

[53]Riccioli (1651: I, 1, 18): "MOTVS PROPRIUM SYDERVM ORIENTEM VERSVS. EClipticae, & Zodiaci introducendi in Sphaeram Artificialem, & agnoscendi in Naturali, ac Caelesti, causa sunt motus proprius syderum ab Occidente Orientem verus, quem obseruarunt Astronomi fieri in circulo hoc obliquo, aut in circulis illi parallelis". And above all, Riccioli (1651: I, 1, 15): "Est mensura moti diurni, seu Primi Mobilis, qui est communis omnibus omnino syderibus".

[54]Riccioli (1651: I, 1, 14).

[55]Riccioli (1651: I, 1, 15).

[56]Riccioli usually stated the thirds of arc, too. The slight discrepancy with the current value of 23h 56' 4,1'' (correspondent with Riccioli's value of 23h 56' 2,4'') can suddenly be noticed.

[57]Riccioli (1651: II, 10 575), at the beginning of *Sectio* III *in qua problemata temporis* of the tenth book. In the very page a detailed conversion table is provided.

the First Mobile, which needs to be put in correspondence with the Earth's size. Celestial and earthly spheres are in a proportion, whose amount is yet to be agreed.

4.1. Enlarging the sky by comparing it with the Earth

Before establishing the size of cosmos, a measurement unit is needed. Because of the relation between celestial sphere and earthly sphere, the biggest possible measure is the Earth's diameter, expressed in the astronomers' calculation as a semi-diameter. The determination of the Earth's radius had been a matter of research for many astronomers. Riccioli used Eratosthenes' estimation[58], though now it is not this article's aim to linger over the original procedures that motivated such a choice for him. The process of construction of a measurement of the sky, for which the rotation time has been calculated, seems interesting to this here work's purposes, instead.

Riccioli largely investigates the different methods of determination of the Earth's diameter[59]: the ones of Francesco Maurolico, Cristoph Grienberger, Mario Bettini, Christopher Clavius, Paolo Casati, Johannes Kepler, Nicola Cabeo. The following issue is the problem of determining the Earth's curvature, that is the suitable meridian degree to determine the measurement system and the distances on Earth. For this reason, many methods are compared, from the ancients' ones to the ones of Jacopo Mazzoni and Willebrord Snell (1580-1626), and finally to his own method, elaborated alongside Francesco Maria Grimaldi[60]. Riccioli faces the problem of the altitude of mountain ridges, including a meticulous disquisition on determining the highness of Caucasus[61], already seen in the Galilean argument of the center of the world: Riccioli reports the solutions many scholars provided, Mazzoni in the first place, but he does not mention Galileo at all. Accurate hypotheses are to be carried out, though it is necessary to overlook them here.

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[58] See Riccioli (1651: I, 1, 62 ff.).

[59]The whole *sectio* IV: *Problemata geographica* del libro X di *Almagestum Novum* is dedicated to these issues, Riccioli (1651: II, 10, 585-612).

[60]In *Problema 18. Ambitum Terrae Methodo Nostra & P. Francisci Mariae Grimaldi* Riccioli provides the essential measure of his calculation system for the measurement of the earthly and celestial dimensions: the *piede bolognese* ('Bologna foot'), i.e. 38,5 cm. See M.T. Borgato, *Riccioli e la caduta dei gravi*, in Borgato (2002: 79-118, 84).

[61]Riccioli (1651: II, 10, 597).

Once the measures of the Earth's diameter and the longitude are taken, Riccioli faces the problem of the estimation of the distance between the fixed stars and the Earth, scrupulously taking into account the phenomena of diurnal parallax[62] and refraction[63], that is the apparent shift of a faraway object. Many cases are treated, like for example the ones of parallax in declination and right ascension, or those where parallax and refraction are disturbing factors at the same time[64]. It is particularly noteworthy the one for determining the "parallaxin Maximam Profunditatis Sideris in Horizonte Astronomico seu vero constituti *explicare ac inuenire*, Data Distantia Sideris à Centro Terrae"[65]. The determination of the distance of the stars, whose parallax would only be observed in 1838 by F.W. Bessel, was not enough: Riccioli even wanted to specify to what extent that distance could be affected by the phenomena of parallax and refraction.

The fixed stars' distance from the center of the Earth was the most important figure in order to determine the measure of cosmic radius. Since every star was determined with a specific distance, it was necessary to give an average estimation, expressed by providing a maximum and a minimum value. Every astronomer proposed a solution, always in Earth semi-diameters (s.d.). For instance, according to Magini the fixed stars' distance from the Earth oscillated between 20.110 and 40.220 s.d.; according to Tycho between 13.000 and 14.000 s.d.; according to Anton M. Schyrleus from Rheita the minimum value of 20.000.000 s.d. was enough[66]. Riccioli only gives the minimum measure, too, but through two methods that confer to such measure either a value of 100.000 semi-diameters or one of 210.000 semi-diameters. These values are useful to the purpose of the calculation of the fixed stars' sphere's width, equal to twice the semi-diameter. This measure, in turn, helps Riccioli calculate the fixed stars' velocity[67].

The sky's width Riccioli estimated complies with the figure he provided for the stars' distance. The latter was usually estimated to be over 100.000 s.d., except for the North Star which was a bit more distant than

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[62]See Lib. X, *Sectio* V. *De Parallaxibus*, di Riccioli (1651: II, 10, 613-642).

[63]See Lib. X, *Sectio* VI. *Problemata Refractionum Siderearum in aere*, Riccioli (1651: II, 10, 642-668).

[64]Riccioli (1651: II, 10, 654): "Sideris supra horizontem apparentis Refractiones in circulo altitudinis Refractiones in circulo altitudinis inquirere: & Inuenire terminum altitudinis, in quo cessant sensibiles refractiones, Datis praeter Parallaxim ijs…".

[65]Riccioli (1651: II, 10, 615).

[66]The data are given in one of Riccioli's tables (1651: I, 6, 419).

[67]Riccioli (1562: II, 419): "Duplica distantiam Fixarum à Terramaximam, & fiet diameter sphæræ quam duc per 314. & summam diuide per 100. & fiet circumferentia, seu ambitus, in semidiametris Terræ, quas Fixæ uno die motu diurno percurrunt…".

70.000 s.d. Sirius turns out to be the furthest star, at over 170.000 s.d. In Philippus Lansbergen (1561-1632), a concise dissertation for comparing the fixed stars' size with the Earth and estimate the stars from their first order to the sixth on the basis of their apparent diameter can be found[68]. In Athanasius Kircher (1602-1680) it is also possible to find a comparison between the estimations of the Primum Mobile's radius ("*De distantia fixarum à Terra*"), stating the opinions of contemporaneous astronomers: Tycho 13.000; Albategnius 19.000; Maurolico 20.077; Magini 20.110; Alfragranus 20.220; Clavio 22.612; Riccioli "ex uno indagandi modo 100.000, ex alio modo 210.000, Rheita 20.000.000"[69]. The progressive rise of such a measure is evident[70], so that the author states, when talking about Copernicus: "omitto Copernicanorum sententias, qui distantiam illam in immensum fere augent"[71].

Christophori Scheiner, though arguing against the thesis of infinite universe[72], states that the distance of the fixed stars from the sky amounts to an extraordinary high number ("distantiam porro firmamenti a terra 13.133.376")[73], while Nicolaus Mercator does not report at all the last sky's width in the tables of the fixed stars' longitudes[74].

The astronomers were strenuously committed to "enlarge" the cosmos, often obtaining very different amounts: from Tycho's cosmic radius, in the amount of 13000 Earth semi-diameters (circa 8.4×10^{10} m), to Rheita's one, tantamount to 20000000 (circa 1.3×10^{14} m). These dimensions are incomparable with the ones that are estimated nowadays; yet they are a symptom of an assiduous and rigorous research in order to understand the cosmos' dimensions, in a non-metaphorical sense at all.

[68]Lansbergen (1631: 130-134).

[69]Kircher (1657: 338).

[70]This early problematic approach to the universe's measurement marks an essential step towards the modern attitude of scientific research.

[71]Kircher (1657: 338).

[72]See Scheiner (1615: 18 ff.). See the paragraphs: *Contra multitudinem infinitam*; *Contra extensionem infinitam, terminis espertem*; *Demonstratio altera*; *Contra infinitum terminis conclusum, demonstratio*; *Lineam componi ex indivisibili bus sive finitis sive infiniteis est impossibile. Demonstratio*.

[73]Scheiner (1615: 27).

[74]Mercator (1685: 206-207).

5. Conclusions

When reflecting upon the role of infinite at the origins of modern science, the discipline that started the Scientific Revolution – namely astronomy – cannot be overlooked. The infinity of cosmos could not be only a theoretical or metaphysical suggestion for who really practiced on a daily basis observation of the skies: the astronomers needed what we nowadays call "experimental praxis". The astronomical practice required specific procedures and reasoning, within which the idea of an infinite cosmos without an actual center could only be conceived with a big effort and way after the Scientific revolution. For this reason, it was important that another kind of reflection could head off on the metaphysical level, undoubtedly due to Bruno. In any case, the idea of an infinite cosmos in astronomy and in cosmology oscillated between metaphorical use and calculation for a long time. Who exercised science obviously grounded on numerical data and geometrical evidence, not on metaphors: astronomers measure, build models of cosmos and calculate distances; in Bruno, the cosmological reflection leads to affirm the actuality of a divine matter which has got infinity in itself. The two approaches are not easy to overlap, though their coexistence is meaningful in order to analyze the history of that period's scientific thought.

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The *Fiction* of the Infinitesimals in Newton's Works.
On the Metaphoric use of Infinitesimals in Newton

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1. Introduction

In *Philosophiae Naturalis Principia Mathematica* (hereafter *Principia*) and in other mathematical works, Isaac Newton (1643-1727) *resorts to magnitudes*, which, in current modern language, should be called *infinitesimal quantities*. It is well known that Newton did not recognize the existence of *actually* infinitesimal quantities and numbers. His conception considers the infinity and infinitesimal as *potential* quantities. Nonetheless, on several occasions – (i.e., *Principia*, Book I: Proposition XXXIX, sect. VII and Proposition XLI, sect. VIII) where he deals with the so called *inverse problem of the central forces* – Newton argues of given infinitesimal quantities. The fact that these quantities are given, might induce to think of actually infinitesimal magnitudes. This is not the case. However, they cannot be considered ordinary potentially infinitesimal quantities. Rather we will show that they represent a *fiction*, which gets a particularly significant role as to the development of Newton's physical and logical argumentative structure. Furthermore, if from a scientific point of view, these quantities are

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fictions, while, as far as a linguistic analysis of Newton's argumentation is concerned, they can be considered *metaphors*.

In mathematics – and for our aims in the relationship between physics and mathematics[1] – the concept of infinitesimal occurs usually in two meaning as:

1) *Potential infinitesimal*. As well known, a quantity is considered potentially infinitesimal if it can become smaller (not coinciding with zero) than a given finite quantity of the same kind. This concept (jointly with that of potential infinity) has been mainly codified in the 19th century (Pisano & Capecchi 2013) through the formal definition of *limit* by means of the ε-δ method. Though such a formalization is recent enough, the concepts of limit and potentially infinitesimal quantity play *implicitly* a pivotal role in Newton's science, in particular with regard to the most significant propositions of the *Principia*, where instantaneous quantities are looked for. The use of potentially infinitesimal quantities is an unavoidable reference point for physics.
2) *Actual infinitesimal*. Whereas the potential infinitesimal is invariably connected to a process in which a quantity, although remaining finite, becomes smaller than a given quantity of the same kind, the actual infinitesimal is a *given* quantity smaller than *any* finite quantity of the same kind. If one recognizes the existence of actual infinitesimals, the *continuum* assumes properties, which are completely different from the ordinary ones: for example, it is not–Archimedean, it is hyperdense, and so on. In order to avoid ambiguities, it is hence necessary to introduce a series of appropriate postulates. The main events of this interesting story can be considered the works of mathematicians as Paul Dubois–Reymond (1831-1889), Otto Stolz (1842-1905) and Giuseppe Veronese (1854-1917) and, later on as Abraham Robinson (1918-1974), the inventor

[1] This article is a part of a large project on the relationship between physics and mathematics in the history and philosophy of science (i.e: Pisano 2011; Pisano & Capecchi 2013; Pisano & Bussotti 2012, 2017). Particularly on Newton research, we work on an editorial project (Oxford University Press, 2020, 5 vols.) for a complete critical–translation from Latin into English of the whole *Geneva Edition* of the *Principia*, also adding a volume of commentaries. On that see: Bussotti & Pisano, 2104a,b; Pisano & Bussotti 2016.

of non-standard analysis, who reworked some of Veronese's ideas[2]. Nonetheless, the long period between the 17th and the first half of the 19th century was an epoch, in which, the *status* of the infinitesimal quantities was not always performed. Some scholars thought of actual infinitesimal quantities, without having clear the problems, which this conviction might imply. However, Newton did not work with actual infinitesimal quantities and did not believe in their existence.

In this paper, we:

- Propose a conceptualization regarding the notion of infinitesimal in Newton, according to which, he also resorts to infinitesimal quantities, which – properly speaking – are neither potential nor actual infinitesimals, rather they are *fictitious and metaphorical* entities used in physics and factually connected with the *infinitesimal geometry* (see below). The very *Master* of this geometry was Newton, but, other scientists play an important role, as, for example, Leibniz, too.
- Deal with a limited number of arguments, references and subjects as our aim is – in this context – to face a specific problem directly referring to Newton rather than to trace a vast historic and historiographical fresco. We basically face some propositions of the *Principia*. We are perfectly aware that other examples can be found in Newton as well as in other scholars.

Two more linguistic aspects has to be clarified:

a) Newton, in the final *Scholium* of the *Principia* (second edition, 1713), uses the famous remark *Hypotheses non fingo* [I do not feign hypotheses][3] (Newton 1999, p. 943). The term "fingo" is used, as

[2] On that see: Dubois–Reymond 1882; Robinson 1966; Stolz 1883, 1884, 1885, 1888; Veronese 1891, 1896, 1898. Particularly on Veronese, see Bussotti 1997, Freguglia 1998; Cantù 1999.

[3] Sometime it reads as "I frame no hypotheses" or "I contrive no hypotheses". In the following, the best–accredited passage translated into English by Cohen, 1999 reads: "I have not as yet been able to discover the reason for these properties of gravity from phenomena, and I do not feign hypotheses. For whatever is not deduced from the phenomena must be called a hypothesis; and hypotheses, whether metaphysical or physical, or based on occult qualities, or mechanical, have no place in experimental philosophy. In

well known, to express the idea that Newton has no intention to construct hypotheses he cannot verify by means of experiments. We use the term *fiction* in a different meaning and with no reference to Newton's famous remark. We mean an element, which is a part of the linguistic and demonstrative apparatus, but not of the world, either the physical or the mathematical one (while, for example, the potentially infinitesimal quantities exist from a mathematical standpoint). Its something not existing. Nonetheless, in a phase of the reasoning, its supposed existence is useful.

b) Fiction is, in general, something different from metaphor. However, let us accept the definition of metaphor as "a figure of speech in which a term or phrase is applied to something to which it is not literally applicable in order to suggest a resemblance"[4]. Thus, we are exactly in our case: we will see that the words "which is as small as possible and of a given length" could not be litteraly applied, as Newton did, to an entity as his lineola, because such a lineola is, as a matter of fact, something not literally existing, whereas those words seem to denote an actually infinitesimal lineola. Therefore, they allude to Newton's lineola, but do not denote such entity.

2. Metaphors in Newton's *Principia*

Here we explain the concept of *infinitesimal geometry* and the use of infinitesimal quantities within Newton's physics.

2.1. Infinitesimal Geometry and Potential Infinitesimal Quantities

In the *Principia*, during the proofs of his propositions, Newton resorts to the following method, where infinitesimal quantities are looked for:

a) He constructs the geometrical figure relative to the problem he is going to solve or to the theorem he is going to prove;
b) He develops the initial steps of his proof/construction working on the figures according to the classical Greek geometrical methods (Newton, as it is easy to imagine, used both synthetic and analytical

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this philosophy particular propositions are inferred from the phenomena, and afterwards rendered general by induction" (Newton 1999: 943; see also pp. 274-276).

[4] Definition drawn from: http://www.dictionary.com/browse/metaphor.

methods in the Greek sense[5]), which is often complicated taking into account that the figures are, in many cases, conic sections or curve of higher degree or transcendental;

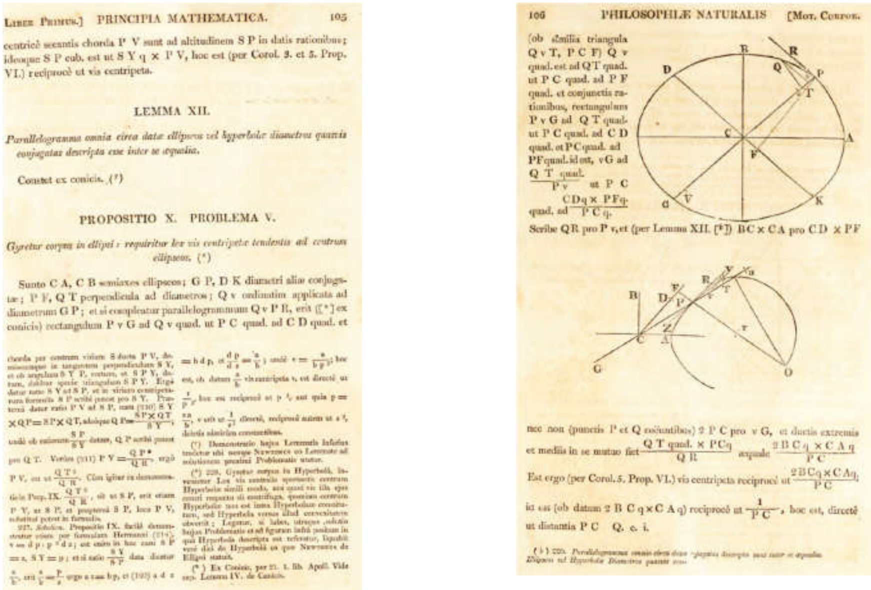
c) After having obtained, in this way, a finite quantity or ratio of quantities (in general lines, areas) or he considers the situation when the quantities become evanescent – in modern term, he passes to the limit –, so obtaining the instantaneous physical magnitudes. This work, which allows Newton to deal with potential infinitesimal quantities, is carried out on the figure, too. Thence, in the *Principia*, the relations are not transcribed into differential equations. Since it is almost sure that Newton was able to develop this step, an interesting historical and conceptual question is why he did not do. Our aim is not to deal here with such a problem[6].

In the following, an example is presented to show how Newton proceeded on this subject.

Let us consider the *Proposition X*, *Problem V*, *section II* (Book I, *Principia*. See Fig. 1). Newton looks for the law of the centripetal force when a body moves on an ellipsis in which the force-centre is in the geometrical centre of the ellipsis. He reasons like this:

[5] The difference between the concept of *analytic*, as referred to the Greek geometry, and to the *modern mathematical analysis* is well known. On the analytical–geometrical reasoning in Newton within his proof concerning the inverse problem of central forces see Bussotti and Pisano 2014b, pp. 431-435.

[6] On the problems connected with the relations between *infinitesimal geometry* and *mathematical analysis* in Newton, there is a vast literature. See i.e., Cohen 1990; De Gandt 1995; Guicciardini 1998, 1999, 2002; Hankins 1990; Chandrasekhar 1995; Rouse Ball [1893] 1972; Westfall 1983 [1995]; Wright 1883.



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centricè secantis chorda P V sunt ad altitudinem S P in datis rationibus; ideoque S P cub. est ut S Y q × P V, hoc est (per Corol. 3. et 5. Prop. VI.) reciprocè ut vis centripeta.

LEMMA XII.

Parallelogramma omnia circa datæ ellipseos vel hyperbolæ diametros quasvis conjugatas descripta esse inter se æqualia.

Constat ex conicis. (†)

PROPOSITIO X. PROBLEMA V.

Gyretur corpus in ellipsi: requiritur lex vis centripetæ tendentis ad centrum ellipseos. (*)

Sunto C A, C B semiaxes ellipseos; G P, D K diametri aliæ conjugatæ; P F, Q T perpendicula ad diametros; Q v ordinatim applicata ad diametrum G P; et si compleatur parallelogrammum Q v P R, erit ([*] ex conicis) rectangulum P v G ad Q v quad. ut P C quad. ad C D quad. et

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(ob similia triangula Q v T, P C F) Q v quad. est ad Q T quad. ut P C quad. ad P F quad. et conjunctis rationibus, rectangulum P v G ad Q T quad. ut P C quad. ad C D quad. et P C quad. ad P F quad. id est, v G ad $\frac{QT \text{ quad.}}{Pv}$ ut P C quad. ad $\frac{CDq \times PFq}{PCq}$.

Scribe Q R pro P v, et (per Lemma XII. [*]) B C × C A pro C D × P F

nec non (punctis P et Q coeuntibus) 2 P C pro v G, et ductis extremis et mediis in se mutuo fiet $\frac{QT \text{ quad.} \times PCq}{QR}$ æquale $\frac{2 BCq \times CAq}{PC}$.

Est ergo (per Corol. 5. Prop. VI.) vis centripeta reciprocè ut $\frac{2 BCq \times CAq}{PC}$;

id est (ob datum 2 B C q × C A q) reciprocè ut $\frac{1}{PC}$, hoc est, directè ut distantia P C. Q. e. i.

Fig. 1. Proposition X, as it appears in the Geneva Edition of Newton's *Principia* (Newton [1726] [1739-1742] 1822, I, pp. 105-106). Google Books.

Let us consider the ellipsis (Fig. 1): *CA* and *CB* be the semi–axes, *GP* and *DK* the conjugate diameters, *PF* and *QT* the perpendiculars to the diameters, *Qv* the ordinate to the diameter *GP*[7]. Let us now complete the parallelogram *QvPR*.

Because of a property of the conic sections[8], it is:

$$Pv \cdot vG : Qv^2 = PC^2 : CD^2 \quad 1)$$

Since the triangles *QvT* and *PCF* are similar, it holds

$$Qv^2 : QT^2 = PC^2 : PF^2 \quad 2)$$

Newton multiplies the two proportions, so obtaining:

[7] Given a point of a conic section and two conjugate diameters, the ordinate to a diameter is the parallel traced from the point to the other diameter. We remind the reader two diameters are defined conjugate if one divides in two equal parts the chords parallel to the other diameter.

[8] Newton is here referring to the property proved by Apollonius in the *Proposition I*, 21 of his *Conics* (Apollonius 1896: 19-20).

$$\frac{Pv \cdot vG}{Qt^2} = \frac{PC^2 \cdot PC^2}{CD^2 \cdot PF^2} \quad 3)$$

That is:

$$vG : \frac{Qt^2}{Pv} = PC^2 : \frac{CD^2 \cdot PF^2}{PC^2} \quad 4)$$

Since *QvPR* is a parallelogram, it is possible to replace *Pv* by *QR* and, because of the *Lemma XII* (Newton [1726] [1739-1742] 1822, I, p. 105), Newton has previously proved[9], $CD \cdot PF$ by $BC \cdot CA$.

It is important to remark that, until the use of *Lemma XII*, Newton has used only finite segments resorting to classical geometrical reasoning in Euclid's – or better say in Apollonius' – style. Later on, he develops (said in modern terms) a passage to the limit, so operating with potentially infinitesimal quantities: when *P* and *Q* coincide, it is possible to replace 2*PC* for *vG* because the points *P*, *Q* and *v* coincide (Newton [1726] [1739-1742] 1822, I, p. 105). The replacements are:

$$Pv \to QR$$
$$CD \cdot PF \to BC \cdot CA$$
$$vG \to 2PC$$

So, one can write:

$$2PC : \frac{Qt^2}{QR} = PC^2 : \frac{BC^2 \cdot CA^2}{PC^2} \quad 5)$$

Lastly, he obtains:

$$\frac{2BC^2 \cdot CA^2}{PC} = \frac{Qt^2 \cdot PC^2}{QR} \quad 6)$$

[9] In *Lemma XII* an important property is referred to: all the parallelograms described around the conjugate diameters of a given ellipsis or hyperbola are equivalent (Newton [1726] [1739-1742], 1822: I, 105).

Thence, according to the *Corollary 5* of the *Proposition VI*[10], the centripetal force is inversely proportional to

$$\frac{2BC^2 \cdot CA^2}{PC},$$

but since

$$2BC^2 \cdot CA^2$$

is given, thence the force is inversely proportional to 1/*PC*, that is directly proportional to *PC*. This concludes the reasoning. The proof of this proposition is an example of a prototypical reasoning of Newton's style. Particularly:

1) The method is based on *synthetic geometry* (axiomatic geometry/pure geometry) and, until a certain point, the proof proceeds referring to figures as well.
2) When necessary, a reasoning concerning infinitesimal quantities is introduced by Newton; while *Q* tends to *P* – "the points *P* and *Q* coinciding" [11]– nowadays we say *PQ* and, hence also *Pv* tends to *0*.
3) The quantities continue to be treated as geometrical entities.

This is Newton's infinitesimal geometry. Once explained from a theoretical point of view and by an example drawn from Newton the use of the potential infinite in the *Principia*, let us analyse the other use of infinity.

2.2. Infinitesimal quantities as fictions and metaphorical entities

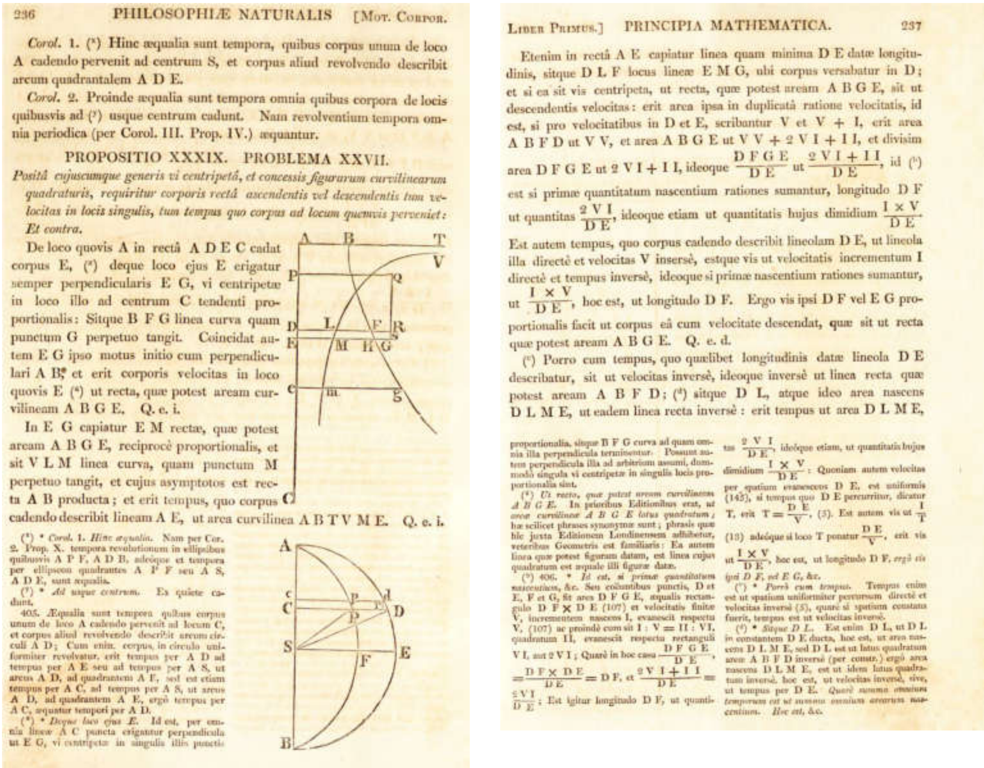
Once clarified how Newton used the potential infinitesimal, let us consider the context in which Newton deals with the famous so called *Inverse problem of the central forces* solved in general terms in the *Proposition XLI*,

[10] In the *Proposition VI* and in its *Corollary 5*, Newton offers an important geometrical characterization of the centripetal forces (Newton [1726] [1739-1742] 1822: I, pp. 79-85. English translation Newton 1729, pp. 68-70).

[11] "[…] punctis P et Q coeuntibus […]" (Newton [1726] [1739-1742] 1822: I, p. 106; see also English translation Newton, *Id*., 1729, p. 76).

section VIII, *Book I* (see below). Here Newton, given a centripetal force and granted the quadrature of the curvilinear figures, looks for the trajectory of the bodies and the times along those trajectories. A necessary presupposition to solve this problem is the *Proposition XXXIX* of the *section VII, Book I* (see Fig. 2), which sounds:

> Supposing a centripetal force of any kind, and granting the quadratures of the curvilinear figures; it is required to find the velocity of a body, ascending or descending in a right line, in the several places through which it passes; as also the time in which it will arrive at any place; And vice versa.[12]



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Corol. 1. (x) Hinc æqualia sunt tempora, quibus corpus unum de loco A cadendo pervenit ad centrum S, et corpus aliud revolvendo describit arcum quadrantalem A D E.

Corol. 2. Proinde æqualia sunt tempora omnia quibus corpora de locis quibusvis ad (y) usque centrum cadunt. Nam revolventium tempora omnia periodica (per Corol. III. Prop. IV.) æquantur.

PROPOSITIO XXXIX. PROBLEMA XXVII.

Positâ cujuscumque generis vi centripetâ, et concessis figurarum curvilinearum quadraturis, requiritur corporis rectâ ascendentis vel descendentis tum velocitas in locis singulis, tum tempus quo corpus ad locum quemvis perveniet: Et contra.

De loco quovis A in rectâ A D E C cadat corpus E, (z) deque loco ejus E erigatur semper perpendicularis E G, vi centripetæ in loco illo ad centrum C tendenti proportionalis: Sitque B F G linea curva quam punctum G perpetuo tangit. Coincidat autem E G ipso motus initio cum perpendiculari A B, et erit corporis velocitas in loco quovis E (a) ut recta, quæ potest aream curvilineam A B G E. Q. e. i.

In E G capiatur E M rectæ, quæ potest aream A B G E, reciprocè proportionalis, et sit V L M linea curva, quam punctum M perpetuo tangit, et cujus asymptotos est recta A B producta; et erit tempus, quo corpus cadendo describit lineam A E, ut area curvilinea A B T V M E. Q. e. i.

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Etenim in rectâ A E capiatur linea quam minima D E datæ longitudinis, sitque D L F locus lineæ E M G, ubi corpus versabatur in D; et si ea sit vis centripeta, ut recta, quæ potest aream A B G E, sit ut descendentis velocitas: erit area ipsa in duplicatâ ratione velocitatis, id est, si pro velocitatibus in D et E, scribantur V et V + I, erit area A B F D ut V V, et area A B G E ut V V + 2 V I + I I, et divisim area D F G E ut 2 V I + I I, ideoque $\frac{DFGE}{DE}$ ut $\frac{2VI + II}{DE}$, id (b) est si primæ quantitatum nascentium rationes sumantur, longitudo D F ut quantitas $\frac{2VI}{DE}$, ideoque etiam ut quantitatis hujus dimidium $\frac{I \times V}{DE}$. Est autem tempus, quo corpus cadendo describit lineolam D E, ut lineola illa directè et velocitas V inversè, estque vis ut velocitatis incrementum I directè et tempus inversè, ideoque si primæ nascentium rationes sumantur, ut $\frac{I \times V}{DE}$, hoc est, ut longitudo D F. Ergo vis ipsi D F vel E G proportionalis facit ut corpus eâ cum velocitate descendat, quæ sit ut recta quæ potest aream A B G E. Q. e. d.

(c) Porro cum tempus, quo quælibet longitudinis datæ lineola D E describatur, sit ut velocitas inversè, ideoque inversè ut linea recta quæ potest aream A B F D; (d) sitque D L, atque ideo area nascens D L M E, ut eadem linea recta inversè: erit tempus ut area D L M E,

Fig. 2. Proposition XXXIX, as it appears in the Geneva Edition of Newton's *Principia* (Newton [1726] [1739-1742] 1822: I, 236-237). Google Books.

Newton's reasoning runs like that. Let the body *E* fall along the right line *ADEC*[13]; and let the perpendicular *EG* to *AC* be proportional to the

[12] Newton (1729: 163); see also Cohen (1980: 68 ff).

[13] Newton indicates both the body and a point of its trajectory by *E*, but no ambiguity arises.

centripetal force whose centre is *C*. To each given point of the line *AC*, a perpendicular will correspond, whose length is proportional to the force. Let us suppose that the place of these perpendiculars is the line *BFG*. Furthermore, let *AB* be the perpendicular at the beginning of the motion. Then – Newton claims – the velocity of the body in any given place *E* of the line *AC* is proportional to a straight line whose square is the curvilinear area *ABGE*, *this is the first assertion to be proved*[14].
Let *EM* on *EG* be assumed inversely proportional to $\sqrt{ABGE}$ and let the curved line *VLM* be the place of *M*. Obviously the right line *AB* is the asymptote of *VLM*. The time during which the body describes the line *AE* is proportional to the curvilinear area *ABTVME*. *This is the second assertion to be proved* (from a dimensional point of view, it is possible to show things work with a reasoning similar to that expounded below in the footnote 12). On our side, we focus on Newton's proof of the first assertion. Newton's reasoning is: on the line *AE*, let us assume the line *DE*, *which is as small as possible and of a given length*. Let *DLF* be the place of the line *EMG*, where the body is in *D*. This passage is crucial and we refer to it as in its original Latin text:

> Etenim in recta *AE* capiatur *linea quam minima DE datae longitudinis*, sitque *DLF* locus lineae *EMG*, ubi corpus versabatur in *D*.[15]

Here a typical analytical (in the classical Greek sense of this term) reasoning begins. Newton supposes that the velocity is as

$$\sqrt{ABGE}.$$

Thereafter the velocity's square is as *ABGE*. Newton replaces the velocity in *D* by *V* and the velocity in *E* by *V+I*. Therefore, the following proportion holds:

[14] This is a typical physical–geometrical reasoning often used by Newton. From a dimensional point of view things work: the perpendiculars to *AC* as *AB*, *DF*, *EG* are proportional to the force, thence their dimensions are $\left[\frac{kg\cdot m}{s^2}\right]$, while the straight line *AC* is expressed with $[m]$. The product of these two quantities – this means the area to which Newton refers – is thence expressed in $\left[\frac{kg\cdot m^2}{s^2}\right]$. Therefore its square root is $\left[\frac{m}{s}\right]$, that is a velocity, apart from a constant indicating the mass by a pure number, which, in this kind of problems, can be neglected. We have no enough room to deal with the problem of the quadratures or with the question that other physicists had utilized areas to indicate physical quantities, which is well known.
[15] Newton [1726] [1739-1742] 1822, I, p. 237. Italics is ours.

$$ABFD{:}V^2 = ABGE{:}V^2 + 2VI + I^2 \qquad 7)$$

By dividing, the area *DFGE* will be as:

$$2VI + I^2.$$

Thence one can write:

$$\frac{DFGE}{DE}$$

and as

$$\frac{2VI+I^2}{DE} \qquad 8)$$

Now, Newton, following the method already expounded in the previous section 2.1, operates (to use modern terms) a passage to the limit. Newton writes "[…] primae quantitatum nascentium rationes […]"[16], when *D* tends to *E*. Then *DFGE* tends to *DF·DE* and *I* tends to *0*. Therefore, from 8), it follows *DF* is as:

$$\frac{2VI}{DE} \qquad 9)$$

Thus, as the half of these quantities, namely *DF* is as

$$\frac{I{\cdot}V}{DE} \qquad 10)$$

Furthermore, the time in which the falling body describes the "*very small line*"[17] *DE* is directly proportional to *DE* and inversely proportional to the velocity *V*[18]. The force is directly proportional to the increment of velocity *I* and inversely proportional to the time. To summarize, and indicating the time by *t* and the force by *f* it is *t* is as:

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[16] "[…] First reasons of nascent quantities […]" (Newton [1726] [1739-1742] 1822: I, 237).

[17] This is Motte's translation (Newton 1729: 165) of the Latin expression "lineola(m)" (Newton [1726] [1739-1742], 1822: I, 237).

[18] This depends on the fact that, in an infinitesimal time, the motion can be considered rectilinear uniform.

and f is as:

$$\frac{DE}{V}$$

$$\frac{I}{V} \qquad 11)$$

Thence f is as

$$\frac{I \cdot V}{DE}$$

Finally, assuming the first ratios of the nascent quantities and according to 10) the force is proportional to *DF*. In this way, Newton has proved that a force, which is proportional to *DF* or *EG*, implies that the body falls with a velocity which is as

$$\sqrt{ABGE}.$$

Since the force was posed equal to *EG* by construction, the theorem is proved. In this proof, many paradigmatic elements of Newton's method are present as in the following we summarize:

a) The resort to geometrical construction showing a profound knowledge of the way in which the analytical method acts;
b) The introduction of the potential infinitesimal quantities at a certain step of the proof;
c) The representation of the physical quantities by means of geometry. All these are elements which are typical of his infinitesimal geometry. Nonetheless, there is something different, too: let us focus on the way in which Newton uses the little line (*lineola*) *DE*.

We have seen he argues of such *lineola* as a quantity whose length is given, he wrote: "linea quam minima *DE* datae longitudinis" (Newton [1726] [1739-1742] 1822, I, p. 237). Thus, questions arise: *What is Newton's aim? What kind of entity is this lineola? What kind of infinitesimal?*

It is not a potential infinitesimal, no limit–process is involved in the definition of such *lineola*, it is not a variable quantity. Newton is clear: the *lineola* is of a given length and no potential infinitesimal quantity is of a given length. Such quantities are nascent—or—evanescent, are not *given*. It is true that, in the further phase of the demonstration, Newton makes to move the *extrema* of the *lineola* within a limit process, but this is possible only because in the immediately previous phase the *lineola* is considered as given. Thus, a first answer might be: Newton considers the *lineola* as an actual infinitesimal. In fact, though infinitesimal, it is a given segment, which we can make potentially infinitesimal if we let to converge its *extrema*. Exactly as it is the case with the given finite segments: when we make to converge their *extrema*, the actually infinitesimal segments become potentially infinite quantities, which, by the way, was assumed as a realizable possibility (for example as Veronese suggested[19]). However, as we outlined above, this is not in Newton's way of arguing–style. There is no reason to suppose Newton thought of something as actually infinitesimal quantities, which are far from his mentality. Then, a question remains unanswered: *what is this mysterious lineola*?

We suggest the following historical hypothesis and epistemological interpretation. *It is a fiction, a fictitious entity useful to Newton in the reasoning*. It is well known that Newton – as many physicists – had a scientific way of thinking based on a synthetic way of proceeding. In addition, at a certain point, he had to consider a quantity which, in that particular not–experimental circumstance, could be thought as smaller than any given finite quantity, which is an intuitive manner of reasoning. In this case, such a quantity remained finite but was so little, in comparison with the other finite quantities used in the reasoning, to be considered as a given, actual infinitesimal. However, (as above cited in the Newtonian pages) Newton is dealing with proofs within the crucial relationship between physics and mathematics. We mean that the arguments–proofs do not proceed by means of a rigorous mathematical method typical of pure mathematics. Emergencies came from physics, not from an advanced use of mathematics. Thus, the *lineola* is a quantity, which can be considered approximately as null in comparison with the other finite quantities, but in a proper sense, it is neither null, nor actually infinitesimal. In addition, it is not exactly a physical quantity: it has no ontological value, either a mathematical value or a physical measurement. It is a rational quantity, which is an expression of the relationship between physics and mathematics which enters to the physical structure of the theory: this highlights the role played by a non–measurable quantity in physical reasoning as expounded in

[19] Veronese (1891: 84-176). See also Bussotti 1997.

Principia (Book I). Such a *lineola* is a mere physics–mathematics[20] quantity (Pisano's works) supported by logics at a new level of abstraction within the birth of Modern Science. In effect, it is also a part of the language, for sure not of the mathematical or physical Newton's world. In this sense, it can be considered as a *fiction*.

Consequently, if we want to interpret the *lineola* going beyond mathematics and physics, we should point out its high *metaphorical value*. In terms of the analysis of the language, it is a *metaphor*, which alludes to the actual infinitesimal, without being compromised – as far as it is a metaphor – with ontological questions typical of the actual infinitesimals. At the same time, it resembles infinitesimals which are something bigger than zero but not coincident with it. The *lineola* introduces to a new *cognitive dynamic reasoning* framework, which has connections both with the potential infinitesimals connoting the calculus and with the actual infinitesimal, but it cannot be identified with either of them (Pisano 2013, 2014).

In other words, the *lineola* appears as a mere mental device in Newton's hand to conceptualize his genial intuitions within the World of the Science at that time. Finally, a different meaning of the terms *infinitesimal* is suggested: neither actual, nor potential, rather, a physical-mathematical device/fiction useful during a proof: a mere logical, linguistic and procedural instrument.

[20] Not physical–mathematical quantity. Pisano showed that, after Newton's mechanics, particularly in 19th century, physics and mathematics worked as a unique discipline as physics mathematics: not mathematical applications to physics and vice versa, but physics mathematics as a new approach to physical and mathematical studies integrated; and above all different from mathematical physics. It built a structured discipline with its own hypotheses, methods of proofs, and with an internal coherent logic. New methodological approaches were conceived to solve physical problems (in their background) where an object can be both physical and mathematical quantity (1st novelty) and measurement is not a priority or a prerogative (2nd novelty). However, it is a coherent and valid physical science. One can think, for example, to reversibility in thermodynamics as interpreted by infinitesimal analyses: each point is a quasistatic point that is a quasistatic thermodynamic process that happens infinitely slowly. In effect, it is far from a measurable physics because it is not a real process, but such processes can be approximated by performing them very slowly. In other words, it is typical of intellectual dynamics of analyses infinitesimal applied to an idealistic physics; but the power of methods, application and results are formidable and undisputable. On these HPS subjects see Pisano's works.

3. Concluding remarks

Newton resorts more than once to constructions similar to the one we have analysed: let us remind the reader that in the *Proposition XLI* (Book I) while dealing with the inverse problem of central forces he speaks of "the lineola *IK* described in the least given time […]".[21] By the way, Newton mentions the *Proposition XXXIX*. In the *Proposition LXXXIII*, (Section XII, *Book I*) Newton poses the problem to find the force under whose effect a corpuscle posed in the centre of a sphere is attracted towards any segment of the sphere. During the proof Newton specifies:

> Let us suppose that surface to be not a merely mathematical, but a physical one, having the least possible thickness[22].

Once again: not a mathematical entity, but, as we have clarified, a physics–mathematics fiction useful in the reasoning. We could also offer some examples drawn from other scientists and mathematicians. For example let us see, Leibniz in *Illustratio Tentaminis de Motuum Coelestium Causis* (Bussotti 2015; Bussotti and Pisano 2017). Leibniz spoke of *element of time*. For example in the two following passages of the *De Vi Centrifuga Circulantis*, a section of this work, we read:

> Let us suppose that a mobile traverses, in an element of time, the side *EA* with uniform speed, and, continuing its motion, tends towards *F*, so that, if nothing prevents it, the body would traverse the segment *AF* with a time element equal to the previous one[23].

Again, he wrote:

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[21] Newton (1729: 171). "lineola *IK,* dato tempo quam minimo descripta […]" (Newton [1726], [1739-1742], 1822, p. 246).

[22] "Sit autem superficies illa non pure mathematica, sed physica, profunditatem habens quam minimam". From Newton [1726] [1739-1742] 1822, I, p. 385. In this case, we consider Motte's translation not appropriate. Thence we have offered, in the running text, a new one.

[23] Leibniz [1706], [1860], 1962, II, p. 258. Original Latin text: "Ponamus jam mobile *elemento temporis* aliquo percurrere latus *EA* celeritate uniformi, motuque eodem continuato tendere in *F*, ita ut si nihil impederet, aequali cum priore temporis elemento percursurum sit rectam *AF* […]". Italics are ours.

> Let us suppose that a heavy body, which descends from *K* in the first element of time, equal to the previous elements, has descended of an altitude *KL*[24].

In this last quotation, Leibniz is considering a series of elements of time and the descents in these elements. Therefore, the approach is different in comparison to that used when the limit of a certain quantity or ratio of quantities is calculated, tending one quantity to 0. In this latter case, whatever the used language is, one deals with the concept of *potential infinity*. While, in the case of the time-element, Leibniz considers the element of time as a given quantity in which something happen. No doubt, that Leibniz was not referring to actually infinitesimal quantities. On that, Eberhard Knobloch dissipates every doubt on this question[25]. Thus, this time element is used exactly in the same manner as the fictitious-metaphorical infinitesimals by Newton.

Finally, our aim has not been to offer a plurality of examples, but to offer a new perspective on the use of an image, of a fictitious entity, of a metaphor, within physics and mathematics relationship in the history and philosophy of science, which has played an important role for the comprehension of the history of physics methods; and whose importance has not been always pointed out, as it deserved.

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[24] "Ponamus autem grave descendens ex *K primo temporis elemento* prioribus aequali descendisse ex altitudine *KL*" (*Ivi*, p. 259). Italics are ours. See also: Bussotti (2015: 51-53; Bussotti & Pisano 2017).

[25] Knobloch 2008. On Leibniz, in the occasion of his anniversary, see also *Leibniz and the Dialogue between Sciences, Philosophy and Engineering, 1646-2016. New Historical and Epistemological Insights* (Pisano, Fichant, Bussotti, Oliveira 2017).

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The Use of Metaphors and Analogical Representations in Social Simulation Models

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1. Introduction

Agent-based computer simulation is currently spreading in sociology and social psychology (Squazzoni 2008). It is based on the creation of computational models, which are computer programs that allow social scientists to reproduce some aspects of social behaviour (Gilbert 2006). A model is a construct, M, developed by researchers to study a particular social phenomenon, F (Squazzoni 2008: 21), called the target of the model (Gilbert & Troitzsch 2005: 15). Its definition is based on a set of theoretical assumptions, and it constitutes a representation of those aspects of the target phenomenon that are considered the most interesting for a certain type of study (Squazzoni 2008: 21; Redhead 1980: 146). More specifically, an agent-based model comprises a collection of autonomous decision-making entities called agents, which can represent individuals or aggregates of individuals. «An agent is an autonomous computational process capable of performing local actions in response to various stimuli and communications with other agents» (Drogoul & Ferber 1994: 130). Each agent individually assesses its situation and makes decisions on the basis of a set of rules. So, the definition of an agent-based model that aims to study a given social phenomenon is based on certain theoretical hypotheses about the rules that guide the behaviour of the agents.

A simulation is the computer-based execution of a model, which allows researchers to analyse all its implications and manipulate its parameters and rules. It can be considered an experiment involving the "artificial society" defined by a model (Gilbert & Conte 1995: 5). In effect, the computer

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becomes a kind of "virtual laboratory" in which to explore and check the theoretical assumptions embedded in the model (Epstein & Axtell 1996: 4; Neumann 2009: 69; Terna *et al.* 2006: 22).

Despite the increasing spread of computer simulations in sociology and social psychology, from a methodological point of view some issues remain open (Küppers & Lenhard 2005; Marney & Tarbert Heather 2000). One of these is related to the relationship between the data of a simulation, on the one hand, and the empirical facts, on the other (Squazzoni 2008; Moretti 2002).

A crucial aspect in all the empirical sciences is the agreement between facts and cognitive aims. Therefore, since sociology and social psychology are empirical sciences, we must establish, in some way, the degree of isomorphism between a model and its target, just as in physics, for example, formalised models (mathematical and computational models) often use variables whose meaning is closely related to the operational procedures of detection and measurement. Instruments for surveying the physical dimensions produce numerical data, or at least data that can easily be integrated into a simulation model (Hartmann 1996). Sociology and social psychology have difficulty in identifying observational procedures and standardised measurement tools, so the detection of social facts is based in part upon the intuition of researchers (Marradi 1992; Pitrone 2012).

How do social scientists deal with the relationship between empirical reality and the model? What are the criteria that guide the evaluation of a simulation model? When can a model be considered a valuable tool for studying its target social phenomenon?

An agent-based model defines a representation of a particular social phenomenon based on certain assumptions, by using the symbols provided by computational languages. These assumptions are theoretical propositions that generally constitute a «privileged interpretation, perhaps linked to a more or less distant empirical origin of the reflections that have led to the construction of the system» (Marradi 1984: 170). They express a particular reading, among the many possible, of a set of social facts.

The plausibility of these propositions depends on the criteria used to justify the particular interpretation of some empirical facts or the transposition of theoretical concepts across sectors. This process is not exclusively logical. In addition to inductive and deductive logic, there is an interpretative reasoning, whereby "tacit knowledge" (Polanyi 1966) come into play. Often it is an "analogical reasoning" (Sternberg 1977) in which the correspondences between similar rules are not made explicit but remain implicit. This form of reasoning refers to a body of specialist knowledge specific to a community of researchers in a certain field, or to a body of common-sense knowledge.

In the following sections two examples are presented, which show how the agreement between facts and cognitive aims is determined also by resorting to an analogical reasoning: two classes of models that have formed the basis of simulations that we can define "successful", because they are widely cited by researchers dealing with social simulation.

The second section considers a class of models used to simulate the diffusion of technological innovations and new ideas. Their plausibility arises from the use of the scientific metaphor of infection by viruses, which establishes an analogy between models. Hesse (1966), in his attempt to analyse the working mechanism of scientific metaphors, defined the concept of "material analogy". The starting point of the author's reasoning is the fact that the process of the analogy is interactive. This interactivity is established between the *explanandum* domain – the primary system of analogy – and the model used in scientific explanation – the secondary system. The primary system is then re-described semantically through the secondary system, thanks to an analogical process that transfers properties and concepts of the secondary system to the primary system. The transfer process has a selective character: the similarities are emphasised and the differences are disregarded, and this, in turn, leads us to notice additional similarities, whereas further differences will be overlooked. The interactive process that transforms the semantic context of the two analogues develops following a logic of possibility, and cannot be described by a strict deductive rule.

The third section illustrates a class of models that use analogical representations, based on images, able to reflect the spatial structure of the represented object and the relationships between theirs parts. According to Sloman (1971), an analogical representation defines a set of correspondences between a syntactic configuration and the represented domain, which may be procedural – when the correspondence is between the operations elaborated in the representations and those elaborated in the domain – or structural. These correspondences are implicit and context-sensitive because they derive from intuitions. Analogical representations allow scientists to capture the aspects of an empirical system that they consider most meaningful, while eliminating unnecessary details. Also in this case there is an interactive and adaptive relationship between the model and its referent.

2. The contagion-spreading metaphor

A metaphor used in many agent-based models is the metaphor of infection by viruses. In the applications that study the mechanisms of the diffusion of innovation technologies and new ideas, these ones are conceived as "viruses" that propagate, with a certain probability, between actors that somehow come into contact with others. Abrahamson & Rosenkopf (1997) compare cases of epidemic-spreading with the diffusion of new ideas, to demonstrate that the mechanisms that drive them are the same. Epidemic models – models that analyse how, and how fast, viral diseases propagate in animal and human populations – assume that individuals can be in three possible states: 1) susceptible to infection; 2) infected, and so able to infect other individuals; 3) recovered, that is immune to the contagion (Kermack & McKendrick 1927).

This metaphor allows scientists to apply epidemic models starting with the assumption that new ideas or new technologies spread, as do viruses, via contact from person to person. Accordingly, agents (people, organisations, *etc*.) are classified as susceptible, infected and recovered (Cointet & Roth 2007). Agents who have adopted the new technology are "infected"; agents who have not yet adopted the new technology but may do so if they come into contact with the infected are "susceptible"; finally, agents who, for some reason, never adopt it are "recovered".

In these models, pieces of information replace viruses, and social contact replaces physical contact. They simulate the process in which a new idea or a new technology "invades" a community. An infected node exposes its neighbours to infection, which in turn may either be infected or remain immune for the rest of the run (Stocker *et al*. 2001). The objective of these simulation studies is to identify the distribution of infected nodes, the rate of diffusion, and especially the structural features of the social network that affect spreading, and in what manner these features act. In this way, the study of innovation spreading focuses mostly on the effects caused by the structure of the social network, and it leaves out other causes such as information costs, the evaluation of possible risks, the estimation of results derived by its adoption, or the processes of legitimation (Abrahamson & Rosenkopf 1997).

For example, Delre *et al*. (2010) have applied an epidemiological model to analyse the spreading of a new product in the marketplace. Their model assumes that consumer decision-making processes are affected by social influence and word-of-mouth processes. An infected agent is a consumer who has purchased the new product, whereas a susceptible agent is a potential buyer whose choice will be affected by his or her social interactions with the infected agents. To each agent is associated a function that determines the predisposition to be infected. The decision of each agent to buy the new product depends on this function and its network of social interactions. In this way, authors can study how the social network structure affects the speed of the diffusion of a new product.

The use of this metaphor allows scientists to abstract a phenomenon by selecting a particular point of view, in order to reduce the empirical complexity, and to focus only on a few aspects that should be reproduced in the simulation model. In particular, it highlights the structure of the social network that connects a set of actors, and its ability to spread new ideas. It is thereby possible to represent a phenomenon through a conceptual structure, such as a "graph", wherein the nodes are the consumers and the links are social contacts (see Figure 1).

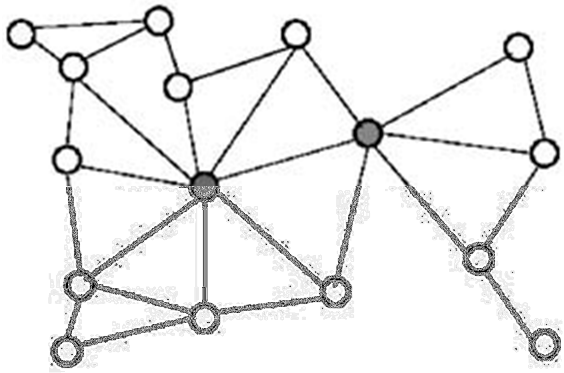

Figure 1 A social-network representation. The nodes of this graph represent individuals, and the edges social relationships. Each infected node can infect its neighbours (Janssen & Jager 2003: 349).

3. The Shelling's model

The cellular automaton (Wolfram 1986; von Neumann 1966) is a mathematical object used in simulation models to represent some social phenomena[1], consisting of a chessboard whose squares are occupied by

[1]Among the most famous simulations are Schelling's segregation model (1971), Axelrod's model of the evolution of cooperation (1984), and Epstein and Axtell's model of the growing artificial societies (1996).

entities with certain characteristics[2]. The most famous model that uses the cellular automaton is certainly Schelling's model created to study racial segregation. Schelling (1971: 143)[3] states that his model studies the dynamics of segregation that may develop, in general terms, among people with different race, age, religion, income, social class or gender, although his own use of the model related to the racial segregation between whites and blacks. There may be a lot of factors that cause segregation. Here only the "discriminatory" individual behaviour is considered, while economically induced segregation and that which derives from organised action that tends to intentionally exclude those who are different are omitted. According to Schelling, "discriminatory" individual behaviour means the behaviour reflecting an awareness, conscious or unconscious, of sex or age or religion or colour or whatever the basis of segregation is: an awareness that influences decisions on where to live, whom to sit by, what occupation to join or to avoid, whom to play with or whom to talk to (Schelling 1971: 144).

Schelling illustrates several examples in which the discriminatory behaviour can produce segregation: a neighbourhood, a hospital, a church, *etc*. In each of them we can identify a physical context with clearly defined boundaries, populated by people distinctly divided into two groups. Each person has a number of "neighbours": those who sit close to him or her in a church, those who live in an adjacent house, those who occupy a bed in the same room of a hospital, *etc*.

This model is based above all on a discrete spatial organisation composed of many "cells", each of which may be occupied by an agent. Each cell has a number of adjacent cells that represent the neighbourhood of the agent. Each agent belongs to a group, graphically distinguished by a colour, and "wants" at least a certain percentage of its neighbours to have

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[2] Thomas H. Huxley (1868) described the world as chessboard. Usefulness of this image is doubtful, but the mathematician John von Neumann (1966) resumed this metaphor to define the cellular automaton, a computational model constituting of a grid composed by cells, each of which can assume a certain state. Then, John H. Conway proposed a famous cellular automaton that made its first public appearance in the October 1970 issue of Scientific American, in Martin Gardner's "Mathematical Games" column, under the title of "The fantastic combinations of John Conway's new solitaire game life": «the grid cells in this case can be occupied (by a creature) or empty, and are represented painting them a colour or leaving them blank, respectively» (Marro 2014: 23).

[3] Actually, Schelling executed this simulation manually, without using a computer. The simulation was based initially on a one-dimensional space and subsequently was applied to a two-dimensional space of small dimensions. Schelling's model has given rise to numerous computer programs that also realise different variations of the original.

the same colour. If this does not occur, the agent moves to another free cell of the chessboard. The simulation continues until it reaches a situation of equilibrium – that is, when all agents are "happy" and do not move anymore (see Figure 2). This chessboard is an analogical representation of the phenomenon of segregation that is able to capture some aspects of an empirical system while eliminating some details that the author considers unnecessary.

Through this model, scientists can do experiments that allow them to verify the consequences, in terms of segregation, derived from the modification of certain factors, such as the size of groups, the preferences of agents, and the size of neighbourhoods. The model refers to an idealised context, and is not directly associated with specific empirical cases. Schelling shows that it may explain the phenomenon of "tipping"[4], referring to some particular case studies.

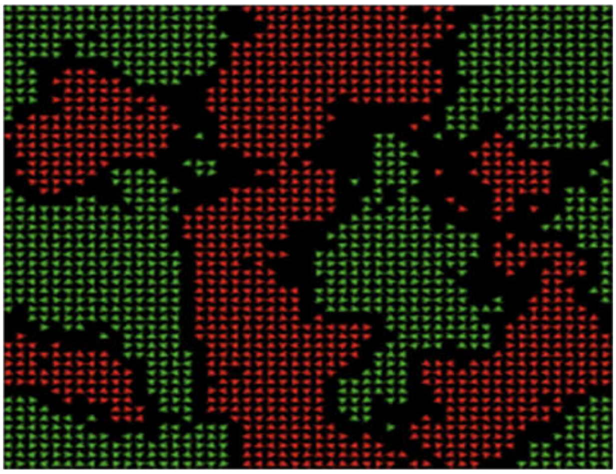

Figure 2 Schelling's segregation model. Space is divided into many elementary parts called cells, which can be occupied by people belonging to one of two races: the green race and the red race. In this simulation, agents of the same race tend to aggregate in clusters, thus giving rise to a segregation (NetLogo demo).

The connection with the empirical facts is justified, not by an explicit definition of the rules of correspondence, but through an analogical relationship using tacit knowledge. The empirical system in which the segregation process develops – a city, a neighbourhood, a church, and so on

[4]«Tipping is said to occur when a recognizable new minority enters a neighborhood in sufficient numbers to cause the earlier residents to begin evacuating» (Schelling 1971: 181).

– is represented by a chessboard. The main feature of the empirical system that is emphasised by Shelling is the spatial structure in which subjects live.

Generally, all the concepts that express patterns of aggregation (*e.g.* coalition, group) can be represented by means of cellular automata. A field of application of these types of model is the study of the emergence of opinion groups.

Public opinion – which can refer, for example, to the marketing of a product or voting preferences – develops from the social interactions and the mutual influence between individuals regarding certain arguments or behaviours. The possibility to persuade, to give orders and to provide information are forms of interaction that influence the behaviour of others. These aspects constitute an important field of social psychology (Latanè 1981).

According to Latanè's theory of social impact, the influence of certain individuals over others is one of the most important processes that define social phenomena. Social impact is proportional to the following three factors: 1) the strength of opinions of the members of a group; 2) the inverse of the distance between individuals; 3) the number of individuals in a group. The first factor reflects the fact that some individuals have a strong conviction about a particular point of view and are therefore unlikely to change their opinion, and are also better able to persuade others. The second factor reflects the assumption that interactions occur only between individuals who are neighbours – spatially or socially. The last factor relates the size of a group to the number of interactions that occur in it, such that larger groups have more interactions than smaller ones.

Nowak & Lewestein (1996) have defined a cellular automaton to model the emergence of public opinions in a population of individuals. The model considers a set of agents who have an opinion on a particular subject. Opposite opinions are expressed by means of two colours: white, which represents a favourable attitude, and black, which represents an unfavourable attitude. In addition, a value is assigned to each agent, representing the strength of his or her opinion. The spatial distribution of the agents is very important because the mutual influence depends on the distance (see Figure 3). During the simulation of a model, at each iteration each agent can change his or her opinion if the total strength of the neighbours who have the same opinion is greater than the total strength of the neighbours who have the opposite opinion. Simulation stops when the system reaches a state of equilibrium – that is, when no change of opinion occurs anymore. The results of simulations show the formation of clusters of opinions – groups formed by adjacent cells of the same colour. In a model, authors visually represent the strength of the opinion of each agent through the height of the cell, turning a cellular automaton into a three-dimensional image. It is thereby possible to obtain visual results that we can interpret in an intuitive manner, using an analogical reasoning. In fact, the final arrangement of all agents in a network allows researchers to control how minority groups emerge; for example, they can infer that everyone is inclined to take the opinion that dominates in their local environment, and that the survival of a minority group depends on the presence of agents with a strong force of opinion (see Figure 3).

Authors admit that the definition of a model is an insightful act. «The goal is to try to capture just the essence of the modeled phenomena disregarding the details. There is no simple algorithm indicating how to achieve it. Often the construction of such a model is simply an act of an insight» (Nowak & Lewestein 1996: 253).

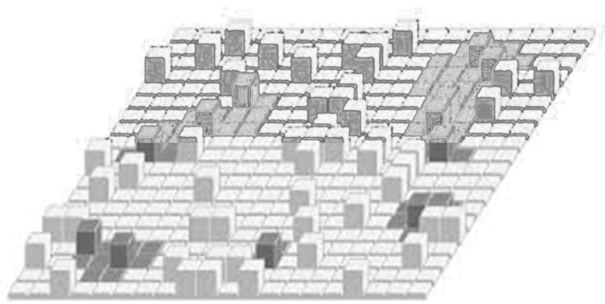

Figure 3 Nowak & Lewestein's model. Each cell is occupied by an agent who can take one of two colours: white, if he or she has a favourable opinion towards a particular object (political party, commercial product, idea, etc.); black, if he or she has an unfavourable opinion. In this example the black colour represents the minority opinion. The height of each cell represents the strength of the opinion (Nowak & Lewestein 1996: 265).

4. Concluding remarks

In the cases analysed before, the plausibility of computational models is justified also by resorting to metaphors or analogical representations. So, we can arrive at the following conclusions.

1) As already said, a fundamental constitutive value of empirical science is the agreement between facts and cognitive aims. Although the facts are unique, there are different ways of understanding them. They may be simple sensible experience, the results of a scientific experiment,

observations obtained by some instruments (e.g., the telescope), or ideal experience. In simulation models, facts are interpreted as "ideal-typical situations" (Squazzoni 2008) – i.e., approximations of reality that are representative of a certain class of events, but which we cannot verify empirically.

Weber's ideal types were an attempt to construct generalisations of specific actions and events, by extracting the common characteristics from the multifaceted reality of the empirical objects. They meet the need «to control the complexity of the target universe. The ideal types are simplifications of systems too complex to be integrally represented» (Bruschi 1971: 114). The simulation models are based on the definition of an ideal type of situation that we assume to be crucial for the evolution of the phenomenon. Obviously, any reduction in the multiplicity of social phenomena results in only a partial representation – one of many possible approximations of the social reality. Metaphors and analogical representations offer a method to define an ideal-typical situation, allowing scientists to consider the facts according to new points of view that are heuristically fertile and significant. A metaphor or an analogical representation can symbolise an event or a class of events according to a particular point of view: researchers start from a "level of observation" that guides the selection of "essential performance" (Negrotti 1999) – namely, of some feature that they consider fundamental, and which they try to reproduce in a computational object. So they create a conceptual structure that is, in some ways, similar to some structures of computational languages. This structure always constitutes some *partial* vision of an object. Its definition is linked to a particular cognitive demand, and it starts from a series of assumptions that render the model just one of many possible models that might represent the object in question (Moretti 2011).

2) It is not possible to define any universal methods or principles valid in all situations. Rather, the definition of a model is based on unwritten rules, and depends on the aims of the research in question. What is not explained is taken as tacit shared knowledge, such as the knowledge evoked by metaphors and analogical representations. To validate a simulation model, we need to define the objectives well, and then verify whether it is able to attain them. It is not possible to apply universal criteria, since each evaluation depends heavily on the context of the given application. Schelling's segregation model, for example, has the purpose of checking how the degree of individual "intolerance" can influence segregation, but it is not able to predict the real-world phenomenon of segregation. The association between the variables of a model and observable facts is

established not through the definition of some quantitative and standardised operating procedures, but through a form of analogical and interactive reasoning. Therefore, inductive and deductive logic are not sufficient to establish the plausibility of a model. We also have to use: a form of reasoning based on a body of specialist knowledge specific to a community of researchers in a certain field, or to a body of common-sense knowledge.

In conclusion, the validity of a model is the result of an agreement between the members of a group of experts in a specific field, reached as a consequence of scientific discussion. It depends on the argumentations used to justify the assumptions of this model: a «simulation therefore relies fundamentally on the fact that its structure and its output are acceptable for rationally thinking people» (Schmid 2005: 3.11). These argumentations can also be based on a form of reasoning that includes the use of metaphors and analogical representations.

Generally, the strength of this type of analogical reasoning depends on its heuristic value. In fact, it allows scientists to define models that analyse a phenomenon according to a point of view that can be fruitful if it is able to discover new scenarios and to propose new cognitive challenges. By means of the consequent simulations, scientists can find some possible regularities that have not yet emerged, and can infer new knowledge about social processes that may guide empirical and theoretical research. They are able to carry out experiments in a virtual-reality environment by exploring all possibilities, including counterfactual situations. We might say that a model acts as a "scaffold" for the empirical experimentation and organisation of our ideas.

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What is a Physical Realization of a Computational System?

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1. Introduction

The concept of a physical realization of a computational system is one of the key notions of both functionalism and the symbolic approach to cognitive science or AI (Pylyshyn 1980: 113, 1984; Chalmers 1996: 309). Notwithstanding a widespread consensus on the theoretical importance of this concept, it comes somewhat as a surprise that a precise analysis or shared definition does not exist yet, either in the philosophical camp, or in the cognitive science and AI community[1]. In this paper, I will present my attempt at such an analysis. Before doing this, however, I will say a few words on why I believe that a seemingly promising alternative strategy is misguided.

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[1] Endicott (2005) distinguishes at least three different technical meanings of the term 'realization' among philosophers. Putnam claims that "every ordinary open system is a realization of every abstract finite automaton" (1988: 121) and, in the same vein, Searle (1990) argues that any physical system can be seen to realize any computation. Both Putnam's and Searle's arguments are clearly flawed (Chalmers 1996), but they do show that a precise explication of the notion of realization of a computational system is badly needed.

Marco Giunti, "What is a Physical Realization of a Computational System?"
in Flavia Marcacci and Maria Grazia Rossi, *Reasoning, metaphor and science*, pp. 177-192.

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According to this strategy, both a computational system and its multiple physical realizations are to be thought as dynamical systems[2], and the realization relation is then analyzed as a special kind of structure preserving mapping from the state space of the computational system into the state space of the physical one (Giunti 1997: ch. 1; for a similar approach, see Fano *et al.* 2014). As the same kind of structure preserving mapping (i.e., an emulation function)[3] may very well exist between a single computational system and many physical systems, it might seem that we have a clearcut explanation of the basic feature of the realization relation, namely, multiple (low level) realizability of the same (high level) system.

However, there are two main reasons why the realization relation cannot be analyzed in terms of some form of emulation of a computational system by a physical one. The first is that emulation is a structure preserving mapping between two *mathematical* systems (*i.e.*, *dynamical* systems), and thus this kind of approach merely shifts the problem, for the realizing system (the physical one) is not a real or concrete system, but another mathematical or abstract system. So the question now is: what is a realization of a physical system? This question is not unsolvable in principle, but the only solution I can think of is subscribing to a form of Platonism, according to which at least some mathematical systems (those at the lowest level) are real.

Second, the emulation based strategy provides us with an *in principle* solution, which makes us think of realization as a relation between two dynamical systems — a high level computational system on the one hand, and a low level physical one on the other. However, no one would maintain that we could in fact know *the details* of the low level physical system, for

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[2] Giunti and Mazzola (2012: Definition 1) define a deterministic dynamical system on any time model $L = (T, +)$ that satisfies the minimal requirement of being a monoid, as follows. *DS is a dynamical system on L* := *DS* is a pair $(M, (g^t)_{t \in T})$ and L is a pair $(T, +)$ such that (i) $L = (T, +)$ is a monoid. Any $t \in T$ is called a *duration* of the system, T is called its *time set*, and L its *time model*; (ii) M is a non-empty set. Any $x \in M$ is called a *state* of the system, and M is called its *state space*; (iii) $(g^t)_{t \in T}$ is a family indexed by T of functions from M to M. For any $t \in T$, the function g^t is called the *state transition of duration t* (briefly, *t-transition*, or *t-advance*) of the system; (iv) for any v, $t \in T$, for any $x \in M$, (a) $g^0(x) = x$, where 0 is the identity element of L; (b) $g^{v+t}(x) = g^v(g^t(x))$.

[3] Let $DS_1 = (M, (g^t)_{t \in T})$ be a dynamical system on $L = (T, +)$, and $DS_2 = (N, (h^v)_{v \in V})$ be a dynamical system on $P = (V, \oplus)$. An emulation function u of DS_2 *in* DS_1 is defined as follows (Giunti 2010a: sec. 2, 2014: sec. 2, Definition 8); *u is an emulation of* DS_2 *in* DS_1 := u is an injective function from N to M and, for any $v \in V$, for any $c \in N$, there is $t \in T$ such that $u(h^v(c)) = g^t(u(c))$. Furthermore, we say that DS_1 *emulates* DS_2 just in case there is an emulation u of DS_2 in DS_1.

those details would admittedly be too complex. I believe that this kind of in principle solution is not in agreement with the question we have in mind when we ask what it means for a computational system to be realized by a physical one. This question does not ask for abstract in principle answers, but for detailed and concrete ones. For, in many cases, we can very well tell that a real system is a physical realization of a computational one, even though we do not have any low level description of the real system, nor do we even mention such description, think of, or make any reference to it.

2. Computational systems as setup interpreted dynamical systems

My present strategy envisages that an adequate solution to the realization problem will emerge once the quite complex nature of computational systems is fully recognized and brought to light. According to this view, computational systems are more similar to *empirically correct dynamical models* than to dynamical systems tout court. Thus, the solution of the realization problem is to be sought among the *modeling* relations between *dynamical systems* and *phenomena*, and not among the *emulation* relations between purely mathematical dynamical systems.[4]

In my view a computational system $\boldsymbol{CS} = (DS, H, I_{DS,H})$ is a complex object which consists of three parts. First, a mathematical part $DS = (M, (g^t)_{t \in T})$, which is a *discrete*[5] *n-component*[6] *dynamical system.*[7] Second, a

[4] While emulation is the wrong kind of relation for an analysis of *realization*, emulation is indeed an adequate basis for a representational analysis of *reduction* of empirically interpreted dynamical systems (Giunti 2010a, 2014). The two issues are closely related but, in order to avoid conceptual confusion, they cannot be lumped together. The first one has to do with a relation between a computational system and its realizers, where each realizer is a *concrete* or *real* system. The second one deals with a relation between two mathematical dynamical systems, both of which are *models* of real phenomena.

[5] A dynamical system $DS = (M, (g^t)_{t \in T})$ is *discrete* := (i) the time model of DS is the additive monoid $(T, +)$, where the time set T is either the set of the non-negative integers $Z_{\geq 0}$ or the integers Z, and + is the usual operation of sum of two integers; (ii) the state space M is at most countably infinite (Giunti 2010a: sec. 2, 2014: sec. 2).

[6] For any i $(1 \leq i \leq n)$, let X_i be a non-empty set, and let $DS = (M, (g^t)_{t \in T})$ be a dynamical system whose state space $M \subseteq X_1 \times \ldots \times X_n$; for any i, the set $C_i = \{x_i :$ for some n-tuple $x \in M$, x_i is the i-th element of $x\}$ is called the *i-th component of M*, and DS is called an *n-component dynamical system* (Giunti 2014: sec. 4.1, 2016: Definition 2).

[7] The two requirements of (i) being a *discrete* dynamical system with (ii) a *finite* number of state space components make up a *necessary*, but not sufficient condition for the mathematical part DS of a computational system. The debate on which other requirements should be considered for an adequate definition of the purely mathematical part of a computational system is still open (Gandy 1980; Giunti 1997, 2006; Giunti & Giuntini

computational setup[8] $H = (F, B_F)$, which is made up of a *theoretical* part F, and a *real part* B_F. And, third, an interpretation $I_{DS,H}$, which links the dynamical system DS with the setup H.

2.1. The computational setup *H*

Let us now see in more detail what the computational setup $H = (F, B_F)$ looks like. First, its theoretical part F is a *functional description* which provides a sufficiently detailed specification of:

a) the internal constitution and organization, or functioning, of any real system of a certain *type* AS_F;
b) a *causal scheme* CS_F of the external interactions of any real system of type AS_F. In particular, the description of the causal scheme CS_F must include the specification of:
   (b.1) the *initial conditions* that an arbitrary temporal evolution of any real system of type AS_F must satisfy;
   (b.2) the *boundary conditions* during the whole subsequent evolution;
   (b.3) and, possibly, the *final conditions* under which the evolution terminates.

Second, the real part B_F of the computational setup H is the set of all real or concrete systems which satisfy the functional description F or, in other words, B_F is the set of all real systems of type AS_F whose temporal evolutions are all constrained by the causal scheme CS_F. B_F is called the realization domain[9] (or application domain) of H. Any real system $b_F \in B_F$ is called an *F-realizer*.

As $H = (F, B_F)$ is a *computational* setup, any temporal evolution of an arbitrary F-realizer $b_F \in B_F$ proceeds in discrete time steps, which correspond to basic operation cycles of b_F. A basic operation cycle can always be interpreted as the (serial or parallel) execution, by b_F, of a finite

2007; Sieg 1999, 2002a, 2002b; Shagrir 2002; Dershowitz & Gurevich 2008; Fano *et al.* 2014).

[8] A *computational setup* is in fact a special kind of *dynamical phenomenon*, see Giunti (2010a: sec. 4, 2010b: Appendice, 2014: sec. 4.1, 2016: sec. 3).

[9] Since the functional description F typically contains several idealizations, no real system *exactly* satisfies F, but it rather fits F up to a *certain degree*. Thus, from a formal point of view, the realization domain B_F of a computational setup $H = (F, B_F)$ would be more faithfully described as a *fuzzy* set.

number of instructions for symbol manipulation. Therefore, the temporal evolutions of an F-realizer are in fact its *computations*.

A clear example of a computational setup is provided by a typical informal presentation of a Turing machine. An arbitrary *Turing machine setup*, $H_{TM} = (F_{TM}, B_{F_{TM}})$, is detailed below.

F_{TM}: Functional description of a Turing machine (theoretical part of a Turing machine setup H_{TM})

(A) SPECIFICATION OF ANY REAL SYSTEM OF *TURING MACHINE TYPE* $AS_{F_{TM}}$

A real system of Turing machine type $AS_{F_{TM}}$ is made up of two main parts: an external part and an internal one. The *external part* consists of two devices. First, the *external memory*, which may be thought as a linear arrangement of a finite number of cells (*e.g.*, a tape divided into squares). Each cell always contains exactly one symbol taken from a finite alphabet $A = \{b, a_1, \dots, a_m\}$ of m+1 ($m \geq 1$) different symbols. The number of cells is always finite, but new cells can be added as needed (see below), either to the left of the leftmost cell, or to the right of the rightmost one. However, when a cell is added, it always contains the special symbol b, called the *blank.*

Second, a *read/write/move head*, which is a device that, at each instant, is located on exactly one cell of the external memory, and is capable of doing three operations: (1) read the symbol contained in the cell where it is located (*scanned symbol*), and send it to the *control unit* (in the internal part) to which it is constantly connected; (2) replace the scanned symbol with a symbol received from the control unit; (3) move one cell to the right, one cell to the left, or stay put, according to the moving command +1, −1, or 0 that it receives from the control unit. If the head receives the command +1 (−1) when it is located on the rightmost (leftmost) cell, it first adds one blank cell to the right (left), and then moves to the newly added cell.

The *internal part* of the system also consists of two devices. First, an *internal memory*, which may be thought as a single cell that always contains exactly one symbol (*internal state*) taken from a finite alphabet $Q = \{q_1, \dots, q_n\}$ of n ($n \geq 1$) different symbols. The internal memory is constantly connected to the control unit and, besides being just a container for an internal state, it is also capable of two operations: (1) read its internal state, and send it to the *control unit*; (2) replace its internal state with an internal state received from the control unit.

The second internal device is a *control unit*, which is a deterministic input/output mechanism. Its inputs are state-symbol pairs $q_i a_j$, while its outputs are symbol-movement-state triples $a_k X q_l$. (X stands for one of the three commands +1, −1, 0.) For any possible input pair $q_i a_j$, the control unit always responds with a fixed output triple $a_k X q_l$. The input-output behavior of the control unit is thus completely described by three finite tables, **T1**, **T2**, **T3**, in which each input pair $q_i a_j$ is listed together with, respectively, the corresponding output symbol a_k, the movement command X, or the new internal state q_l. Both the symbol a_k and the command X of an output triple are always sent to the head, while the new internal state q_l is sent to the internal memory.

An operation cycle of the whole system is as follows. First, the current internal state q and the symbol a in the cell where the head is located are simultaneously read and sent to the control unit, which responds with an output triple $a'Xq'$. Second, the new symbol a' and the moving command X are sent to the head, which first replaces a with a' and then moves according to X; at the same time, the new internal state q' is sent to the internal memory, where it replaces q. The operation cycle is thus complete, and the system is ready to start a new cycle.

(B) SPECIFICATION OF THE CAUSAL SCHEME $CS_{F_{TM}}$ OF THE EXTERNAL INTERACTIONS OF ANY REAL SYSTEM OF TURING MACHINE TYPE $AS_{F_{TM}}$

(1) *Initial conditions*. A sequence of operation cycles (*i.e., a temporal evolution, or a computation*) of a system of type $AS_{F_{TM}}$ starts as soon as the following settings are performed: (i) an initial internal state is fixed, (ii) a symbol in each cell of the external memory is fixed, and (iii) the cell where the head is initially located is fixed.

(2) *Boundary conditions*. During the whole subsequent computation there is no further interaction with the external environment.

(3) *Final conditions*. The computation terminates immediately after an operation cycle that satisfies *all* the following conditions: (i) $q' = q$, (ii) $a' = a$, (iii) $X = 0$.

$B_{F_{TM}}$: Realization domain (real part of a Turing machine setup H_{TM})

The realization domain $B_{F_{TM}}$ of a Turing machine setup H_{TM} is the (fuzzy)[10] set of all real or concrete systems that satisfy the given specification of the Turing machine type $AS_{F_{TM}}$, and whose temporal evolutions all satisfy the given specification of the Turing machine interaction scheme $CS_{F_{TM}}$. Any system $b_{F_{TM}} \in B_{F_{TM}}$ is called a *Turing machine realizer.*

[10] See footnote 9.

2.2. The discrete *n*-component dynamical system *DS*

So far, we have mainly focused on the setup part *H* of a computational system. But, as mentioned above, a computational system is a complex object that also includes a purely mathematical part *DS*, and an interpretation $I_{DS,H}$ of the mathematical part *DS* on the setup *H*. In particular, we have seen that the mathematical part *DS* is a *discrete n-component dynamical system*. Let us now see what this dynamical system looks like in the special case of a Turing machine. An arbitrary *Turing machine dynamical system*, DS_{TM}, is described below.

An arbitrary Turing machine dynamical system DS_{TM}

From the purely mathematical point of view, an arbitrary Turing machine can be identified with the discrete, 3-component dynamical system $DS_{TM} = (Q \times P \times C, (g^t)_{t \in Z_{\geq 0}})$, which is the one completely specified by the difference equation stated below (Table 2.3). Note first that this dynamical system is *discrete*, for its time model is the additive monoid $(Z_{\geq 0}, +)$ of the non-negative integers, and its state space $Q \times P \times C$ is *countably* infinite (because of the finitary restriction on the functions in *C*, see next paragraph).

Second, DS_{TM} is a 3-*component* dynamical system, for its state space has the three components *Q*, *P*, and *C*. $Q = \{q_1, \ldots, q_n\}$, where q_i is an arbitrary internal state of the Turing machine; $P = Z$ is the set of all integers, which is intended to represent all the possible positions of the head, and *C* is the set of all functions $c: P \to \{b, a_1, \ldots, a_m\}$ that satisfy the finitary restriction: $c(x) \neq b$ for at most finitely many $x \in P$. Any such function is intended to represent a possible content of the Turing machine external memory. Let us now consider the five variables and the six functions defined in Tables 2.1 and 2.2 below.

Variable	*Domain*	*State variable*
a	$A := \{b, a_1, \ldots, a_m\}$	*NO*
q	$Q := \{q_1, \ldots, q_n\}$	*YES*
p	$P := Z$, the integers	*YES*
c	$C :=$ the set of all functions $c: P \to A$ such that $c(p) \neq b$ for at most finitely many $p \in P$	*YES*
m	$M := \{-1, 0, +1\}$	*NO*

Table 2.1 The variables needed for describing an arbitrary Turing machine dynamical system $DS_{TM} = (Q \times C \times P, (g^t)_{t \in Z_{\geq 0}})$.

Then, an arbitrary *Turing machine dynamical system* is the 3-component discrete dynamical system $DS_{TM} := (Q \times P \times C, (g^t)_{t \in Z_{\geq 0}})$, whose time set is $Z_{\geq 0}$, whose state space is $Q \times P \times C$, and whose family of state transition functions $(g^t : Q \times P \times C \rightarrow Q \times P \times C)_{t \in Z_{\geq 0}}$ is defined by the 3-component difference equation shown in Table 2.3.[11]

Function	***Codomain***	***Definition***
$\mathbf{READ}(c, p)$	A	$\mathbf{READ}(c, p) := c(p)$
$\mathbf{WRITE}(a, c, p)$	C	$\mathbf{WRITE}(a, c, p) := c' \in C$ such that, for any $x \in P$, if $x = p$, $c'(x) = a$; else, $c'(x) = c(x)$
$\mathbf{MOVE}(p, m)$	P	$\mathbf{MOVE}(p, m) := p + m$
$\mathbf{A}(q, a)$	A	$\mathbf{A}(q, a) :=$ for any q and a, $\mathbf{A}(q, a)$ is listed in a given finite table T1
$\mathbf{M}(q, a)$	M	$\mathbf{M}(q, a) :=$ for any q and a, $\mathbf{M}(q, a)$ is listed in a given finite table T2
$\mathbf{Q}(q, a)$	Q	$\mathbf{Q}(q, a) :=$ for any q and a, $\mathbf{Q}(q, a)$ is listed in a given finite table T3

Table 2.2 The functions needed for describing an arbitrary Turing machine dynamical system $DS_{TM} = (Q \times C \times P, (g^t)_{t \in Z_{\geq 0}})$.

State variable	***Difference equation***
q	$q' = \mathbf{Q}(q, \mathbf{READ}(c, p))$
p	$p' = \mathbf{MOVE}(p, \mathbf{M}(q, \mathbf{READ}(c, p)))$
c	$c' = \mathbf{WRITE}(\mathbf{A}(q, \mathbf{READ}(c, p)), c, p)$

Table 2.3 The 3-component difference equation that univocally individuates an arbitrary Turing machine dynamical system $DS_{TM} = (Q \times C \times P, (g^t)_{t \in Z_{\geq 0}})$.

2.3. The interpretation $I_{DS, H}$

The final step of my analysis focuses on the nature and role of the third part of a computational system, that is, the interpretation $I_{DS,H}$ of the mathematical part DS on the computational setup H. Let $DS = (M, (g^t)_{t \in T})$

[11] More precisely, the family of state transition functions $(g^t: Q \times P \times C \rightarrow Q \times P \times C)_{t \in Z_{\geq 0}}$ is defined as follows: (i) g^0 is the identity function; (ii) g^1 is the function defined by the 3-component difference equation in Table 2.3; for any $t \in Z_{\geq 1}$, g^t is the t-th iteration of g^1.

be a discrete n-component dynamical system, and $H = (F, B_F)$ be a computational setup. An interpretation $I_{DS,H}$ of DS on H consists in stating that (i) each component C_i of the state space M is included in, or is equal to, the set $V(\boldsymbol{M}_i)$ of all the possible values of a magnitude $\boldsymbol{M}_i$ of setup H, and (ii) the time set T of DS is equal to the set $V(\boldsymbol{T})$ of all the possible values of the time magnitude $\boldsymbol{T}$ of setup H.[12] In other words, an interpretation $I_{DS,H}$ can always be identified with a particular set of n+1 statements. We thus define:

$I_{DS,H}$ is an interpretation of DS on H := $I_{DS,H} = \{C_1 \subseteq V(\boldsymbol{M}_1), \ldots, C_n \subseteq V(\boldsymbol{M}_n), T = V(\boldsymbol{T})\}$, where C_i is the i-th component of M, $\boldsymbol{M}_i$ is a magnitude of the setup H, $V(\boldsymbol{M}_i)$ is the set of all possible values of $\boldsymbol{M}_i$, $\boldsymbol{T}$ is the time magnitude of H and, for any i and j, if $i \neq j$, then $\boldsymbol{M}_i \neq \boldsymbol{M}_j$.

For example, let us consider a Turing machine dynamical system $DS_{TM} := (Q \times P \times C, (g^t)_{t \in Z_{\geq 0}})$ and a Turing machine setup $H_{TM} = (F_{TM}, B_{F_{TM}})$. Then, the *intended interpretation* of DS_{TM} on H_{TM} is described below.

The intended interpretation of DS_{TM} on H_{TM}

Let $\boldsymbol{Q}$ be the content of the internal memory of an arbitrary Turing machine realizer $b_{F_{TM}} \in B_{F_{TM}}$; then, $Q = V(\boldsymbol{Q})$.

Let $\boldsymbol{P}$ be the position of the head of $b_{F_{TM}}$. The head position is always individuated by the cell where it is located; as the cells are linearly arranged and their number is finite, if we choose one of them as the origin, we obtain a one-one correspondence between the cells and an initial segment of Z (in either the positive or the negative direction). Once such an integer coordinate system is fixed, an arbitrary possible value of $\boldsymbol{P}$ can be identified with the coordinate of the cell where the head is located; thus, $V(\boldsymbol{P}) = Z = P$.

Let $\boldsymbol{C}$ be the whole content of the external memory of $b_{F_{TM}}$, *i.e.*, the distribution of symbols over each of its cells. Then, with respect to the fixed integer coordinate system for the cells (see previous paragraph), an arbitrary

[12] In general, we take a magnitude of a computational setup $H = (F, B_F)$ to be a property $\boldsymbol{M}_j$ of every F-realizer $b_F \in B_F$ such that, at different instants, it can assume different values. The set of all possible values of magnitude $\boldsymbol{M}_j$ is indicated by $V(\boldsymbol{M}_j)$. We further assume that, among the magnitudes of any computational setup H, there always is its time magnitude, which we denote by $\boldsymbol{T}$. The set of all possible values (instants or durations) of the time magnitude of H is indicated by $V(\boldsymbol{T})$, Since the time of a computational setup evolves in discrete steps that correspond to its basic operation cycles, we take $V(\boldsymbol{T}) = Z_{\geq 0}$ (or $V(\boldsymbol{T}) = Z$, only if the setup is reversible).

possible value of magnitude $\boldsymbol{C}$ can be thought as any of the functions $c \in C$;[13] therefore, $C = V(\boldsymbol{C})$.

Finally, let $\boldsymbol{T}$ be the temporal ordering according to which an arbitrary temporal evolution of $b_{F_{TM}}$ occurs. Since any such evolution is in fact a sequence of successive operation cycles, each operation cycle corresponds to a non-negative integer; thus, $Z_{\geq 0} = V(\boldsymbol{T})$.

In short, *the intended interpretation of* DS_{TM} *on* H_{TM} consists of the following set of four identities.

$I_{DS_{TM},H_{TM}} := \{Q = V(\boldsymbol{Q}), P = V(\boldsymbol{P}), C = V(\boldsymbol{C}), Z_{\geq 0} = V(\boldsymbol{T})\}$.

Turing machines as setup interpreted dynamical systems

Finally, as a typical example of a computational system, we can define a Turing machine as follows.

TM *is a Turing machine* := ***TM*** is a triple $(DS_{TM}, H_{TM}, I_{DS_{TM},H_{TM}})$, where $DS_{TM} = (Q \times C \times Z, (g^t)_{t \in Z_{\geq 0}})$ is a Turing machine dynamical system, $H_{TM} = (F_{TM}, B_{F_{TM}})$ is a Turing machine setup, $I_{DS_{TM},H_{TM}}$ is the intended interpretation of DS_{TM} on H_{TM}, and the three tables T1, T2, T3 which, respectively, define the three functions **A**, **M**, **Q** of DS_{TM} are identical to the three tables **T1**, **T2**, **T3** that completely describe the input-output behavior of the control unit of an arbitrary real system of Turing machine type $AS_{F_{TM}}$, as specified by the functional description F_{TM} of setup H_{TM}.

3. Physical realizations of a computational system

Once an interpretation $I_{DS,H} = \{C_1 \subseteq V(\boldsymbol{M}_1), \dots, C_n \subseteq V(\boldsymbol{M}_n), T = V(\boldsymbol{T})\}$ is given, we define the possible states of the setup $H = (F, B_F)$ as follows.

x is a possible state of H relative to $I_{DS,H}$:= $x \in V(\boldsymbol{M}_1) \times \dots \times V(\boldsymbol{M}_n)$. $V(\boldsymbol{M}_1) \times \dots \times V(\boldsymbol{M}_n)$ is called *the state space of H relative to* $I_{DS,H}$, and is indicated by $\boldsymbol{M}$.

The interpretation $I_{DS,H}$ also allows us to define the instantaneous state of an arbitrary F-realizer *of H*. Let $b_F \in B_F$ be an arbitrary F-realizer of setup H, and $j \in T$ an arbitrary instant. Then:

x is the state of b_F *at instant j relative to* $I_{DS,H}$:= $x = (x_1, \dots, x_n)$, where x_i is the value at instant $j \in T$ of magnitude $\boldsymbol{M}_i$ of b_F (if, at instant j, such a value exists).

[13] Recall that, for any $c \in C$, $c: Z \rightarrow A = \{b, a_1, \dots, a_m\}$.

Obviously, if x is the state of b_F at instant j, then $x \in \boldsymbol{M}$. Note, however, that, depending on the instant j, the value of magnitude $\boldsymbol{M}_i$ of b_F may not exist.[14] If this happens, the state of b_F at instant j relative to $I_{DS,H}$ is not defined.

Now, relative to the interpretation $I_{DS,H}$, we may define the set C_F of all those possible states of H (if any) that *actually* are initial states of H.

C_F := {x : for some $b_F \in B_F$, for some temporal evolution e of b_F, for some $j \in T$, j is the initial instant of e and x is the state of b_F at j relative to $I_{DS,H}$}. C_F is called *the set of all initial states of H, relative to interpretation* $I_{DS,H}$.

Intuitively, the set C_F may be thought as the set of all those states in $\boldsymbol{M}$ that are consistent with the initial conditions specified by the causal scheme CS_F and are in fact initial states of some realizer $b_F \in B_F$. Also note that, depending on the interpretation $I_{DS,H}$, C_F may be empty, or C_F may not be a subset of the state space M of DS.[15] The definition of an *admissible interpretation* (see below) will exclude these somewhat pathological interpretations.

Let $C_F \neq \emptyset$. Let us now define, with respect to interpretation $I_{DS,H}$, the set of all initial instants of the evolutions of a given F-realizer $b_F \in B_F$, whose initial state $x \in C_F$ be fixed. We call this set $J_{b_F,x}$.

$J_{b_F,x} := \{j_{b_F,x} : j_{b_F,x}$ is the initial instant of some evolution of b_F, and x is the state of b_F at instant $j_{b_F,x}\}$. $J_{b_F,x}$ is called *the set of the initial instants of* b_F *whose initial state is x, relative to* $I_{DS,H}$.

Note that, for some $b_F \in B_F$ and $x \in C_F$, $J_{b_F,x}$ may be empty.[16] However, by the definition of C_F, for any $x \in C_F$, there is $b_F \in B_F$ such that $J_{b_F,x} \neq \emptyset$.

As the setup H is usually taken to be deterministic, the existence and identity of the instantaneous state, at any fixed stage of an evolution of any realizer b_F, is not intended to depend on either the initial instant, or the

[14] If, for some reason, b_F no longer exists at instant $j \in T$, then *a fortiori* the value at j of magnitude $\boldsymbol{M}_i$ of b_F does not exist either. Furthermore, we are not making any assumption about the continuous existence of the values of a magnitude during any interval of time. Thus, it is in principle possible that the value of magnitude $\boldsymbol{M}_i$ of b_F exists at some instant j of b_F's existence, but does not exist at some other instant k of its existence.

[15] In fact, by the definition of instantaneous state, C_F is empty if, for any $b_F \in B_F$ and any state evolution e of b_F, some magnitude $\boldsymbol{M}_i$ does not have a value at the initial instant of e. Also recall that, according to interpretation $I_{DS,H}$, each component C_i of the state space M is in general a subset of $V(\boldsymbol{M}_i)$. Thus, if for some $x \in C_F$, its i-th component $x_i \in V(\boldsymbol{M}_i)$ is not a member of C_i, then $C_F \not\subseteq M$.

[16] In fact, $J_{b_F,x}$ is empty if x is not the state of b_F at the initial instant of any of its evolutions.

identity of b_F, but only on the initial state. Thus, any admissible interpretation $I_{DS,H}$ should at least ensure that the condition below holds.

Condition D (Determinism). For any b_F, $d_F \in B_F$, for any $x \in C_F$, for any $j_{b_F,x} \in J_{b_F,x}$, for any $k_{d_F,x} \in J_{d_F,x}$, for any $t \in T$, if $t + j_{b_F,x}$ is an instant of the evolution of b_F that starts at $j_{b_F,x}$ and the state of b_F at instant $t + j_{b_F,x}$ exists, then $t + k_{d_F,x}$ is an instant of the evolution of c_F that starts at $k_{d_F,x}$, the state of c_F at instant $t + k_{d_F,x}$ exists as well, and the state of b_F at instant $t + j_{b_F,x}$ = the state of d_F at instant $t + k_{d_F,x}$.

Let $C_F \neq \emptyset$. For any initial state $x \in C_F$, let us consider the set of all F-realizers whose initial state is x. This set, denoted by B_{F_x}, is in other words the collection of all F-realizers b_F whose set $J_{b_F,x}$ is not empty. Note that also this definition, as the previous ones, depends on the interpretation $I_{DS,H}$.

B_{F_x} := $\{b_F \in B_F$ such that $J_{b_F,x} \neq \emptyset\}$. B_{F_x} is called *the set of all F-realizers whose initial state is x, relative to interpretation* $I_{DS,H}$.

We noticed above that, for any $x \in C_F$, there is $b_F \in B_F$ such that $J_{b_F,x} \neq \emptyset$. Therefore, by the definition just stated, for any $x \in C_F$, $B_{F_x} \neq \emptyset$.

Suppose $C_F \neq \emptyset$. Then, for any $x \in C_F$, for any $b_F \in B_{F_x}$, for any $j_{b_F,x} \in J_{b_F,x}$, we define the following set of durations:

$q_{b_F,j_{b_F,x}}(x)$:= $\{t$: $t \in T$, $t + j_{b_F,x}$ is an instant of the evolution of b_F that starts at $j_{b_F,x}$, and there is $y \in \boldsymbol{M}$ such that y is the state of b_F at $t + j_{b_F,x}$, relative to $I_{DS,H}\}$.

Note that this definition, like the previous ones, is *relative* to the interpretation $I_{DS,H}$. Furthermore, $q_{b_F,j_{b_F,x}}(x) \neq \emptyset$, for $0 \in q_{b_F,j_{b_F,x}}(x)$.

Also note that, whenever Condition D above holds, $q_{b_F,j_{b_F,x}}(x)$ depends on x, but does not depend on either b_F or $j_{b_F,x}$; therefore, if Condition D holds, we simply write "$q_F(x)$" instead of "$q_{b_F,j_{b_F,x}}(x)$".

By Condition D and the previous definition, for any $x \in C_F$, $q_F(x)$ is the set of all durations t that transform the initial state x of an arbitrary F-realizer $b_F \in B_{F_x}$ into some other state of b_F. More briefly, we call $q_F(x)$ *the set of all durations that transform the initial state x of H into some other state*.

As we are not interested in any interpretation $I_{DS,H}$ such that (a) $C_F = \emptyset$, or (b) $C_F \nsubseteq M$, or (c) Condition D does not hold[17], we define:

[17] If either (a), (b), or (c), the interpretation $I_{DS,H}$, is obviously incorrect, for: if (a) holds, no evolution of any F-realizer b_F can be represented by means of the state transition family $(g^t)_{t \in T}$ of $DS = (M, (g^t)_{t \in T})$; if (b) holds, some evolution of some F-realizer b_F cannot be represented by $(g^t)_{t \in T}$; if (c) holds, some evolution of some F-realizer b_F cannot be correctly represented by $(g^t)_{t \in T}$.

$I_{DS,H}$ *is an admissible interpretation of DS on H* := (i) $C_F \neq \emptyset$ and (ii) $C_F \subseteq M$ and (iii) Condition D holds.

We can now precisely state the conditions for an interpretation $I_{DS,H}$ to be correct. The intuitive idea is this. As soon as an interpretation $I_{DS,H}$ is fixed, the dynamical system $DS = (M, (g^t)_{t \in T})$ provides us with a representation of the real systems (F-realizers) in the realization domain of computational setup H. Such a representation is in fact provided by the state transition family $(g^t)_{t \in T}$ of dynamical system DS. The interpretation $I_{DS,H}$ will thus turn out to be correct if the representation, provided by $(g^t)_{t \in T}$, of *all* temporal evolutions of *all* F-realizers of H is correct. This intuitive idea is formally expressed by the definition below.

$I_{DS,H}$ *is a correct interpretation of DS on H* := (i) $I_{DS,H}$ is an admissible interpretation of DS on H and (ii) for any $x \in C_F$, for any $t \in q_F(x)$, for any $b_F \in B_{F_x}$, for any $j_{b_F,x} \in J_{b_F,x}$, $g^t(x)$ = the state of b_F at instant $t + j_{b_F,x}$ relative to $I_{DS,H}$.

Let $\boldsymbol{CS} = (DS, H, I_{DS,H})$ be a computational system, and B_F be the realization domain of H. We can thus finally define:

b is a physical realization of $\boldsymbol{CS}$:= $b \in B_F$ and $I_{DS,H}$ is a correct interpretation of DS on H.

It is now easy to prove that, in the special but important case of an arbitrary Turing machine $\boldsymbol{TM}$, the intended interpretation $I_{DS_{TM},H_{TM}}$ of the Turing machine dynamical system DS_{TM} on the Turing machine setup H_{TM} *is indeed* a correct interpretation of DS_{TM} on H_{TM}, so that any Turing machine realizer $b_{F_{TM}} \in B_{F_{TM}}$ turns out to be a physical realization of $\boldsymbol{TM}$, and conversely.

Theorem

If $\boldsymbol{TM} = (DS_{TM}, H_{TM}, I_{DS_{TM},H_{TM}})$ is a Turing machine, then $I_{DS_{TM},H_{TM}}$ is a correct interpretation of DS_{TM} on H_{TM}.

Proof

The thesis is a straightforward consequence of the definitions of Turing machine and correct interpretation of DS on H, in conjunction with the theoretical part F_{TM} of the Turing machine setup H_{TM}, the specification of DS_{TM}, and the intended interpretation $I_{DS_{TM},H_{TM}}$. *Q.E.D.*

Corollary

For any Turing machine $\boldsymbol{TM}$, b is a physical realization of $\boldsymbol{TM}$ iff $b \in B_{F_{TM}}$.

Proof
By the previous Theorem and the definition of physical realization of a computational system. *Q.E.D.*

4. Concluding remarks

It is my contention that the previous Theorem is not peculiar to Turing machines, but that an analogous theorem holds for each specific type of computational system (for instance, finite automata, register machines, cellular automata, and so on). If this is true, *all* computational systems are then characterized by a form of *a-priori* (or purely theoretical) *interpretation* of the mathematical part on the setup part, for the correctness of the interpretation can be *proved*. The *a-priori* character of the interpretation of a computational system distinguishes this kind of system from ordinary dynamical models of phenomena (Giunti 2010a: sec. 4, 2010b: Appendice, 2014: sec. 4.1, 2016: secs. 3 and 4), as found in empirical science. In fact, for this second kind of dynamical system, the correctness of the interpretation of the mathematical part on the intended *phenomenon* (which is the analog of the *setup* of a computational system) cannot be established *a-priori*—cannot be *proved*—but only *a-posteriori* or empirically.

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Metaphorical Models of The Living and The Theory of Biological Self-organization

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1. Premise

Maintaining as a theoretical horizon of reference contemporary complexity theory[1], this discussion has as its unifying theme the evolution of the metaphorical languages (symbols, metaphors in the strict sense, concepts and analogies) of the scientific models for the explanation of living things. In particular, the work aims to highlight the close relationship that exists, in epistemological terms, between the conceptual representations of the scientific explanation of biological development and the role of metaphor understood not only as an investigative tool (cognitive role) but also as a tool of theoretical development (paradigmatic dimension of scientific practice)[2]. All this by taking into account as a case study not only some recent results of the experimental sciences such as the physics of complex systems and the biology of meaning, but especially the contribution offered by some of the latest research in the field of the self-organization of living systems. Research that has helped to give the initial metaphor of the great

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[1] A theory understood, in agreement with Prigogine and Stengers, as a project aimed at the enrichment of relations with the world and the extension of the boundaries of what can be considered a subject of research and narration. All of this in the light of the construction of a pluralist methodology, epistemology and ontology able to create, moreover, a "natural history of possibilities" in which the concept of "constraint" participates in the construction of an integrated structure, thereupon determining a spectrum of new and intelligible consequences. Cf. Prigogine and Stengers (1979).
[2] For a deeper discussion of the broader issue of the role of metaphor in science, see Gagliasso & Frezza (2010); Frezza & Gagliasso (2014).

dance, which had inspired various scientific explanation models, an accurate constitutive role.

Among the various operational scientific models that from the 1940s until the present day have followed one upon another at the level of investigations into the living, it proves impossible to determine the real ‘metaphorical models of biology’ that have gradually fostered a greater intelligibility of the processes of self-organization proper to biological systems. In particular, an insight is offered into the current state of the art of metaphor in the life sciences, laying out as a problem its role with respect to the standard models and simulations inspired by deterministic and reductionist logics. Particular attention is also dedicated to the fundamental questions of theoretical biology where the themes of chaos, order, and meaningful complexity, as well as of post-genomics and the emergence in living things of teleological structures (at evolutionary and co-evolutionary level)[3], have recently undergone a specific development in virtue of the need to identify new theoretical models and mathematical tools (non-standard models) better suited to understanding vital and cognitive phenomena[4]. Such research is still emblematic for various reasons, especially in regard to the proposed overcoming of the classical ‘certainty/genetic program’ identification (of a reductionist, deterministic and materialistic matrix) quite far from any kind of epistemological characterization of a post-computational nature of the phenomena associated with life (autopoiesis) and thought (morphogenesis in action)[5].

2. Metaphorical models of biological development

All living organisms, from single cells to multicellular entities, can produce their own components, can somehow self-build. Embryonic development is a striking example of this potential. It is an ongoing process of growth and differentiation in which individual events are arranged cascade-like from the first foundational event: fertilization. This term indicates the sperm’s entry into the egg, immediately followed by cytoplasmic activation and, after a few hours, the fusion/reorganization of the two nuclei, the male and the female. The appearance of a completely new cell following the merger of the two sex cells can be considered a special case of endosymbiosis, the cellular mechanism by which, in the course of evolution, the most

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[3] Cf. Dougherty & Bittner (2010); Longo, Montevil, Kauffman (2012).
[4] Cf. Chaitin (2013); Carsetti (2014).
[5] Cf. Di Bernardo & Saccoccioni (2012); Di Bernardo (2014).

significant new traits have appeared. Following the merger of the sperm and egg, such a molecular reorganization takes place that the individual cell derived from it (the zygote) is totally new. In mammals, and hence also in humans, this reorganization is also accompanied by the entry into play of new molecules, but there are many species in which this does not happen and the new element arises solely from a change in the organization of pre-existing molecules.

What is new is the organized structure, not the individual molecules. The form which appears is new. This form, when completed by its genetic heritage, will be identical in all the cells of the embryo, all the way down to the morula, a small mass of stem cells. Unlike fertilization, however, in this case the form does not change, but is maintained and the constituent materials involved are not molecules but cells. In the early stages of ontogeny, embryonic cells are totipotent, then as development proceeds, some genes are switched off, while others remain active: the cells differentiate and are no longer able to turn back. In those circumstances, therefore, the zygote represents simultaneously both a single cell and a single cellular species which, at a later moment, during the course of the roughly fifty events of cell division that separate the zygote from the newborn, will give rise to a multitude of different cell types. Based on recent calculations, at least 265 different types of cells have been identified in the human body[6], each specialized to exert specific functions in the tissues and organs. That being the case, therefore, cell differentiation consists in increasing the variety of cell types while its coordination into organized tissues and organs is called morphogenesis. How then can a single cell give rise to the complexity of a human being? What are the mechanisms that regulate this mysterious self-organization?

In the history of scientific thought, numerous models have been designed in an attempt to explain the mysterious process of continuous autopoiesis proper to every living system. For reasons of space, we will examine only a few that in our opinion appear to be the most significant. The first of these metaphorical models is undoubtedly that of the "aperiodic crystal" contained in the 1944 book *What is life?* by E. Schrödinger, ascribed with the merit of having inspired a generation of physicists and biologists in search of the fundamental nature of living systems. It was Schrödinger, in fact, who brought quantum mechanics, chemistry and the concept of information (especially in the embryo) into biology. He was the forerunner of our conception of DNA and the genetic code, because he

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[6] Cf. Alberts et al. (2002).

translated the idea of saying into the idea of encoding. Since a regular crystal, though ordered, cannot encode a large amount of information, the substance of the gene, according to the great scientist, had to be a form of "aperiodic crystal" and the form of its aperiodicity must have contained, he deduced, a sort of "microscopic code" capable of controlling ontogeny. In addition, the quantum character of the aperiodic solid meant that small discrete changes would have occurred: mutations (Schrödinger, 1967: 63-66).

On February 28, 1953, F. Crick walked into the Eagle pub in Cambridge, England, and declared he had discovered the secret of life. On April 25 of that same year Watson and Crick published an article in the journal Nature in which they presented the model of the double helix structure of the DNA molecule[7]. This model became a kind of icon, a symbol of the scientific revolution that was emerging, because thanks to this breakthrough, it was now possible to understand the role and function performed by this mysterious macro-molecule within the cell. The two scientists, in fact, understood that DNA, as a "repository of information" that resides in the nucleus of the cell, contains the instructions needed to be able to self-replicate. The discovery of the DNA's double helix and its special property of self-replication, therefore, gave birth to the need to arrive at a clarification of the ultimate nature of the genetic code. Various scientists worked on this ambitious project (Watson, Crick, Monod, Gamow, Nirenberg and Wilkins), which, however, was fully realized only in the mid-1960s. At the end of the Sixties, then, it was clear that in biological systems two key mechanisms connect the language of the DNA with that of the proteins: the transcription from DNA to mRNA and the translation from mRNA to the proteins. The original insights of Schrödinger had become reality. Thus the "central dogma of molecular biology" was born, that is, the conception according to which a protein corresponds to each gene: DNA, in fact, encodes the proteins and, subsequently, the proteins make the body.

In light of this, we can make two observations. First, it can be said that with the birth of molecular biology one witnesses the refutation of "naive holism" (the perspective according to which the study of the parts can be left out because the whole is not reducible to the sum of the parts) and the apparent victory of reductionism (the view that the investigation into the whole can be left out as the latter can be reduced to its constituent parts) and of genetic determinism according to which, by knowing the initial

[7] Cf. Watson & Crick (1953).

conditions of a system (in this case, the individual genes of an organism), it is possible to predict the final state (in the case of an embryo it is possible to predict with certainty the characteristics of the adult organism). In the second place, it is helpful to recognize the fact that this vision hides a form of materialism: in certain respects, in fact, living organisms and man are simply the result of the sum of their genes which, inter alia, constitute sequences of nucleic acids contained in the chromosomes (and thus a merely physical reality). DNA, therefore, represents a simple molecule made up of chemical elements present also in non-living matter.

In 1970 the French biologist and 1965 Nobel Prize winner J. Monod published a volume entitled *Chance and Necessity*, a text that would change the face of contemporary biology. In fact, by placing in close relationship J. von Neumann's science of automatons, A. M. Turing's theory of machines, N. Wiener's cybernetics, information theory as developed by Shannon and Weaver, Chomsky's innatistic theory and Darwin's evolutionary theory, the great French biologist gave biology the chance to build a new paradigm and to identify a code for it. The intertwining of these areas of research, therefore, set the stage for the configuration of cybernetics as a science of self-regulation that could provide the first mathematical models able to "interpret" the profound reality of the biological processes of self-organization. In addition, in his book Monod identifies "teleonomy", "autonomous morphogenesis" and "reproductive invariance" as the fundamental properties of living organisms, that is, those features that allow us to distinguish clearly what is alive from what is not. Any artificial object is the product of some activity by a living being that in this way, and particularly clearly, expresses one of the fundamental characteristics of all living beings, without exception: that of being "objects endowed with a purpose or project", shown in "their structures" and at the same time executed "through their performances" like, for example, the making of artificial objects (Monod, 1970: tr. 20).

Thanks to this property or necessary condition for defining living beings, which Monod refers to with the term "teleonomy", "objects endowed with a purpose" are different from the structure of any other system of the universe. Nevertheless, teleonomy is not sufficient to explain the difference between these beings and man-made objects, that is, the products of their activities. The great French scholar then compares the structure and performance of the eye of a vertebrate with those of a camera and concludes that if we take teleonomy alone as the single principle for identifying living beings we cannot but recognize a profound analogy between the two elements. If we limit ourselves, in fact, to studying the structure of an object and features, we can identify "the project, but not its author or source" (Monod, 1970: tr. 20-1). To grasp the author's thesis it is necessary to analyze not only the "object itself", but also its origin and the manner of its construction. At this point it is possible to introduce the second essential property that characterizes a living being: "autonomous morphogenesis". The structure of a living being is the result of a process entirely different from that of an artificial object to the extent that "it owes almost nothing to the action of outside forces", while it owes everything, from its general shape down to its least detail, to "morphogenetic interactions within the object itself" (Monod, 1970: tr. 21).

Autonomous morphogenesis is therefore a kind of determinism interior to living beings that ensures the formation and growth of the organism favoring a 'virtually total freedom' with respect to their external conditions. According to Monod, thanks to this mechanism it is possible to draw such a concrete parallelism between concrete machines and living organisms as to define the latter "machines that build themselves" or "self-constructing machines".

The spontaneous character of the morphogenetic processes of living beings enables them to distinguish themselves both from man-made objects and from natural objects possessing a macroscopic morphology dependent on external factors. There is, however, one exception: crystals. These natural objects are the result of a free interplay between physical forces to which we cannot attribute a project (if one considers as valid the basic principle upon which modern science is based according to which nature is objective and not projective) and have perfectly defined geometric shapes since their macroscopic structure directly reflects their simple and repetitive microscopic structure. Thus, based on the sole criterion of autonomous morphogenesis, crystals would be classified as living beings, while man-made and natural objects would come to be enclosed within another class as they are dependent on external factors. Monod, in the first pages of his book, seeks to define, by means of general criteria, specific macroscopic properties that distinguish living beings from any other system of the universe; thus, he identifies himself with the programmer who ignores biology, dealing exclusively with computer science and information. The complex structures of living things, in fact, have a large amount of information whose source remains unknown.

However, if we admit that, in continuing his investigation, the programmer makes his latest discovery, that is, he becomes aware that the issuer of the information expressed in the structure of a living being is always another object identical to the first, he will be able to identify the source and recognize a third remarkable property of these objects: the power to reproduce and transmit changelessly the information corresponding to their structure. Information that is very rich, as it describes an extraordinarily complex organization which however is preserved integrally from one generation to another. Monod designates this property with the name “invariant reproduction, or simply invariance” (Monod, 1970: tr. 23). The third essential characteristic of living beings is therefore ‘reproductive invariance’, and it is thanks to this property that living organisms and crystalline structures are once again linked. Despite this close similarity, we must consider that the information transmitted over diverse generations in all living beings is many orders of magnitude greater than that contained in crystal structures; this last quantitative criterion allows us to discern living organisms also from crystals.

But let us return to examining the concept of autonomous morphogenesis. According to Monod, this mysterious process highlights the spontaneous origin of the form of the organism, that is, its self-organization.

At this point the question is as follows: what is the nature of the internal forces that gives living beings their microscopic structure? The structures of living organisms represent a significant amount of information in regard to which our sole remaining task is to identify the source. Again, Schrödinger’s metaphorical model proved to be, we could say, “pregnant with the future”. Between life and non-life there is in fact a quantitative and material continuity (cells are made of atoms and molecules); however, there is also a qualitative discontinuity: the “quality” of information makes the difference. The Monodian doctrine of autonomous morphogenesis, therefore, identifies in the morphogenetic mechanism the basis both of teleonomy and of reproductive invariance, (the latter) because it allows living organisms to conserve and propagate their species. The global organization of a complex organism is already contained in the structure of its constitutive parts and becomes actual thanks to their interactions, thus, Monod affirms, the completed structure is not “preformed; but the architectural plan for it was present in its constituents themselves” (Monod, 1970: tr. 87). The completed structure is thus realized without any input of new information since the information is present (but unexpressed) in the constitutive parts and is revealed only during development. The essence of self-organization, then, in the eyes of the great biologist, lies in the metaphorical model of the genetic program (a cybernetic model applied to molecular biology): an invisible guide able to direct the organism and explain its development[8]. The genetic program, therefore, is conceived as a program of cellular development enclosed within the genome. In this program written with the alphabet of nucleotides there reside, for Monod, the source and the apparent purpose of biological development.

According to a certain parallelism, it is then possible to compare the genetic material of an egg to the magnetic tape of a calculator. Following this logic, therefore, the living organism is compared to a machine: the genes constitute the genetic information present in the genome on which the formation of proteins and of the body depends. Immediately after conception, in fact, there exists in essence a complete program of development of a new living being, a program, i.e., which has the peculiarity of being singular and discriminant of each organism. On the one hand, therefore, the metaphor of the programmed computer represents, for Monod, a perfect model of a purposeful machine, unconscious and without intentions, able to accomplish a task in a perfectly deterministic (i.e., predictable) manner. On the other hand, the molecular structure of the DNA and the proteins can be interpreted as a coded message in which the mechanisms of DNA replication and protein synthesis are treated as specific cases of transmitting information along the communication channels by applying Shannon's information theory: just as with a computer, in fact, in a living organism the origin of its purposeful determinations is located in a program inserted into its genes[9].

3. The figure of the great dance as a paradigm of complexity

Although he had shaken the world of culture to which he belonged by recognizing that each organism as such is characterized by a single project which confers upon it some purposes (organization related to an internal purpose), stating in a modern format what Aristotle and Scholasticism had pointed out, that is to say, that in a living being there is a principle of unity and development, Monod, on insisting that life consists of a succession of physicochemical processes governed by statistical determinism chemical changes, does not completely unhinge himself from a deterministic approach of mechanistic inspiration that had guided experimental research since the birth of molecular biology. The elementary processes that ensure the unity and activity of a living organism are – in agreement with what the French biologist writes – chemical reactions between molecules, albeit very

[8] Cf. Jacob & Monod (1961).
[9] Cf. Shannon (1948); Gilbert (1992).

special ones, which give rise to one or more new molecules. While it is a determinism which admits of exceptions, in the sense that in special circumstances a very small number of molecules of an unexpected species may be formed randomly, the molecules involved in a given process are always the same and it is for this reason that, at the level of theoretical modeling, Monod nevertheless makes reference to a deterministic reading of both ontogeny (the formation of an organism) and phylogeny (the formation of a species)[10].

The metaphorical models of biological development sketched above, therefore, do not manage to liberate themselves entirely from the mechanistic influence well represented in the history of scientific thought by the metaphor of the clock, from the era of Galileo and of Newton, according to which the universe is a marvellous clock in which all things are so cleverly thought out that, once the mechanism is set in motion, everything goes according to the creator's plan[11]. This is a point of view that considered the universe purely as a set of systems interacting directly with one another. The internal properties of these systems were considered at least ideally independent from the environment and their behavior was conceived of as completely determined at all times by previous conditions. The deterministic mechanism in effect allowed the great achievements of modern science to occur and came to dominate the scene of scientific research. That is, scientists were convinced that the description of a complex object in terms of its parts and their properties would have said everything there was to know about that subject, although this belief actually rested on the reference to very simple physical systems, such as the solar system. Mechanics thus became the model of authentic science, although at the same time chemistry was laboriously opening the way to understanding the nature of life and the rise of integrationist biology.

In the second half of the twentieth century, in fact, the conception of the physical world that had been gradually developing along the traces of the path set by the modern scientists was called into question by major conceptual advances and new theories – such as deterministic chaos, complex systems and non-equilibrium thermodynamics, as well as the emergence of order, general systems theory and complexity theory in its classic version[12] – that help shape a worldview that points in the opposite

[10] Cf. Monod & Jacob (1961); Monod, Changeux, Jacob (1963).

[11] Cfr. MacKay (1974).

[12] By 'the classic version' we mean that set of complexity theories - in the physical, biological and psychological context - which mainly refer to mathematical tools such as statistical mechanics, the theory of phase transitions and the theory of emergence, ie,

direction by suggesting the putting together of ideas as diverse as the medieval music of spheres, Einsteinian space-time and the inherent historical irreversibility of natural processes, leading eventually, in biology, to a deep revision of the very same metaphorical Monodian model of autonomous morphogenesis. The scholars most representative of this change are first of all the Russian chemist-physicist I. Prigogine who laid the foundations of the explanation of the phenomenon of life in terms of physical and nonlinear laws and L.V. Bertalanffy, who extended the pioneering work of R. Wiener in the cybernetic field to a general theory of living and nonliving systems able to give an account of the constitution and analysis of the properties of systems capable of behaving like active and integrated wholes. Prigogine, in particular, showed that the state of science, with the discovery of the great principles of thermodynamics, relativity and quantum mechanics, needs to overcome the mechanicism of a Cartesian matrix[13]. Just as Kepler renewed astronomy's cognitive ideal, breaking the circle that had led from Ptolemy to Copernicus, Prigogine and other scholars helped to shatter the circle of sufficient reason to create a new mathematical language that can render intelligible the irreversible processes and events that traditional physics had limited itself to saving through phenomenological approximations. Hence the possibility of identifying the time of complexity as the complexity of time: it is time, in fact, that is returning as the undisputed star of phenomena, and therefore of scientific analysis, of observable dynamics and of those not yet covered by a completed measurability[14]. A time that sheds light on the topic of complexity, today a starting point for theorists of nonlinearity and for the search for a type of knowledge that, in the past, was too often simplified and ignored. Complexity theory, despite the difficulty and risks inherent in considering it a theory, first of all highlights the inherent irreversibility of every natural phenomenon, whether molecular, cellular, social or digital. It is the invention of new languages, the opening to new possibilities for thinking and expressing reality[15].

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instruments that have as their basis the theoretical model of deterministic chaos understood as the program of formalization of the reality that has helped produce a critical rethinking of the existing dichotomy between determinism and probability, pointing out that in particular situations many natural phenomena, despite being described by deterministic laws, manifest behaviors which may possibly be predicted only in a probabilistic sense.

[13] Cf. Prigogine (1996), especially ch. 3 and 4.

[14] Cf. Prigogine and Stengers (1979); Nicolis & Prigogine (1989).

[15] Cf. ER. Morin (1993); Gandolfi (2008).

This is how, in all the disciplines of the Sixties and Seventies (in parallel with the studies of Monod), new languages emerged, well-suited to representing the properties of systems with a functional and structural complexity that prevents one from deducing them from those of their components. These languages are based on the inadequacy of reductionism as the only valid scientific method, accepting the irreducibility of the different levels of organization of such systems and the inability to find full explanations of their properties without resorting to historical and evolutionary categories (biological organisms, the mind, social organization, economies). This new way of investigating the reality that has been called by some scholars "the challenge of complexity" leads us to believe that simple phenomena, the manifestations of universal natural laws, which for classical science were the rule, are actually rare exceptions[16]. Unlike Galileo's and his successors' concept of motion, according to which at any given moment the dynamic system is defined as a state that contains the truth of its past as its future, Prigogine's concept of motion offers a thickness to the instant and connects it to becoming, so that each instantaneous state is the memory of a past that allows one to define only a future delimited by an intrinsic temporal horizon. This weft presents itself simultaneously as creation and as revelation. As the continuous creation of new forms of autonomy and, at the same time, as continuing revelation of new levels of generative power: an emergence of novelties able to shape consecutively and in a temporally close fashion the determinations (or schemas) of time, which form, in their turn, according to precise mathematical modules, the varied and bound expression of the language of life[17].

Living systems, then, in agreement with Prigogine, are dissipative structures (complex metabolic vortices). Cells are dissipative structures in nonequilibrium, that is, complex chemical systems that continuously metabolize molecules of nutrients to maintain their internal structure and reproduce, in an attempt to resist the tendency to equilibrium that for living systems corresponds to death. For the Russian scholar, therefore, there is a close link between self-organization and distance from equilibrium; however, life constitutes an extraordinary state of matter, a state of

[16] Cf. Bocchi & Ceruti (2007).

[17] With nonlinear dynamical systems the precedence of information flows over material flows appears evident, and this sanctions the possibility of building non-standard models increasingly adapted to the biological world, a world, that is, in constant free and spontaneous self-organization – the overcoming of determinism and materialism (Cf. Prigogine, 1980; Shaw, 1981).

transition between order and chaos: life emerges right on the very edge of chaos, ie where the matter becomes capable of perceiving and communicating. Living systems find themselves in an intermediate state between the order of the crystal and the disorder of smoke, and it is precisely there that more complex behaviors emerge, processes, that is, whose outcome is not given by generative principles, but from self-organizing forms in action. Hence the possibility of considering nature at the same time as irruption and as emergence, as depth information (meaningful complexity) that hides itself through the emergence of ever new postulates at the semantic level; an emergence that will be matched by the progressive appearance of more and more constraints, forms and rules at the generative level[18].

Life, then, can no longer be explained through the Monodian idea of a compromise between chance and necessity, invariance and metamorphosis, but can be "interpreted" as an order which, emerging from chaos, is able to self-assemble, always in different ways, and producing, moreover, a kind of information no longer measured by Shannon and Weaver 's traditional theory, a theory based on a type of mathematics that is too simple[19]. Unlike what Monod thought, in a complex system the novelty of the information is intrinsic to the dynamic of the process (think for instance of morphogenesis)[20]. In other words, one passes from the deterministic model in which everything is Platonically pre-established (e.g. immutable ideas present in hyperuranium), to the interpretation of DNA as a complex system that can create new meanings (information that is always qualitatively different)[21]. The new vision, then, will be one no longer linked to a deterministic program, but to a bundle of capacities (unpredictable possibilities), that is to say, to rules capable of self-regulating and changing in relation to the environment.

Such an approach, as recognized in recent years by several experts[22], requires the recovery of a holistic view of the universe in which individual events are all in interaction with one another, a vision that suggests associating the complexity of vital and cognitive phenomena with a metaphor at once new and old, a metaphor able to replace the clock's linear and predictable spatiality (complication) with the emergence of a generative temporality in action (complexity) that is necessarily linked to the

[18] Cf. Carsetti (2005).
[19] Cf. Emmeche & Kull (2010).
[20] Cf. Di Bernardo (2007).
[21] Cf. Li et al. (2011).
[22] Cf. Cantor (1998); Ceruti (1994); Del Re (2006); Casadio (2008).

emergence of the next patterns of self-organization and at ever new levels of reality. We are referring here to the figure of the Great Dance[23], led by a symphony that sets the tempo and gives shape to all of material reality in space and time; where, for example, a group of dancers joins another at the right time and place to interpret a new voice in the suite and where the dancers already present make room for new ones while continuing to follow their melodic line, or by retreating into the silence of a voice that is heard no more. In dance, music seems to transform into sounds the regularities of the processes of the universe and, at the same time, the profound communion, though hidden, offers an infinite variety of all that is in becoming, namely emergence and self-organization in action in the continuous irruption of ever-new compressibility which alone can lead to the birth of more sophisticated methods of information processing: at the appearance of new voices, in fact, new dancers come on stage, and complexity and beauty become increasingly conspicuous. Some voices may slowly or suddenly blend with the others, to fade or generate other voices. With respect to the image of the clock, the most distinctive feature is thus the freedom enjoyed by the dancers (allowed both by the music and by the choreography): they always follow the melody and interpret it by taking into account what has come before, so that even repeated musical passages are not always understood in the same way. A feature which highlights the value that can be had by the random fluctuations and spontaneous actions of living (and cognitive) systems in their coherent becoming in a particular environment, as outlined by complexity theory in its extended version[24].

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[23] The dance envisioned here is that of the Three Graces by Sandro Botticelli and not that of a group of savages.

[24] In general complexity theory consists in the interdisciplinary study of complex adaptive systems (natural and biological systems) and the emerging phenomena associated with them. The sense that we refer to in this paper, however, concerns its extended version shared, albeit with different articulations, by Atlan and Carsetti. It no longer refers, that is, to the simple examination of dissipative phenomena of a Markovian mold, but rather one comes to consider the phenomena of processing and of coupled transformation of the information present at the level of the next constitution of a biological system characterized by the processing of the information itself. Living systems, as Atlan and Carsetti claim, are characterized by the fact that what is self-organized in them is the very function that determines these systems along with their meanings. But it is precisely to the extent that the system constitutes itself as an autonomous reality that the origin of meaning related to the self-organization of the system can come to reveal itself objectively as an emergent property. Here we are able to identify with precision that particular interweaving of complexity, self-organization, intentionality and emergence that characterizes the natural forms of cognitive activity of every living system. In this context, therefore, the study of the mechanisms of the transmission of information requires new measures of the complexity,

In light of these statements, it is clear that the progress of science and of scientific research is interwoven with metaphors, that is to say, with images or figures whose deep meanings allow the human mind to grasp or discover unsuspected ideal or material relations between objects. In parallel to the insights of Monod related to the metaphor of the genetic program, in the Seventies, within the scientific literature we have also seen the forward-looking considerations about the dance by the physicist F. Capra who, inspired by Eastern religions, spoke of the existence, at the level of biological systems, of a 'web of life' and the perspective of a real dance of life[25]. In his view, the autopoiesis of living systems is the real secret of life. The boundaries of this enigma are not boundaries of separation, but rather of identity, inasmuch as they are placed at the very root of the constitution of an indivisible totality[26]. In the wake of these insights many studies have followed, one upon the other, over time.

With the analysis of the results obtained by the Human Genome Project (HGP), for example, both reductionism and naive holism (already refuted in 1953[27]) are definitively surpassed by a new theoretical synthesis that, on the basis of the results obtained by the science of complexity, comes to terms with the idea of "emergence of meaning"[28] where the parts and the whole

measures (new axiomatic systems), that is, able not only to address statistical rarity (Shannon) or computational incompressibility (Kolmogorov-Chaitin), but also to take into account the coupled connection between the source and the living (or cognitive) agent, the evolution of this connection, as well as the subsequent constitution of real, continuous reorganization processes at the semantic level. Cf. Carsetti (2009); Atlan (2000).

[25] Cf. Capra (1975, 2010); Capra (1997).

[26] Cf. Carsetti (1982).

[27] Cf. Watson & Crick (1953).

[28] It is necessary to specify that the concept of meaning in the context of complexity theory - in its extended version - is intended as a deep process (of potentially infinite capacity) of the "production of forms" (in the sense that it *cuts out* forms creatively) and, according to Carsetti and Atlan, applies to areas in several disciplines (cf. Carsetti, 2000; Atlan 1998). Biological self-organization, in this sense, is the process of inscription, reconstruction, assimilation and reduction achieved in the conditions of the dual selection and in accordance with sophisticated cognitive procedures. In other words, it appears to be necessarily shaped by the forms and mathematical modules that determine and give form to it. Life (ie cognition), therefore, in the eyes of Carsetti, appears as the embodiment of the method for the process of the canalization of the informational flows-principles in action: if adequate, it truly constitutes the proper way in view of allowing, albeit partially, the actual deployment of the proper content of depth information in accordance with different and successive levels of complexity (cf. Carsetti, 1987). At this level, what really self-organizes in a natural autopoietic system is the function together with its meaning. In the case, for example, of natural language the source of meaning in the complex organization of the system is nothing but an emergent property. Cf. Atlan and Louzoun (2007).

interact reciprocally with each other resulting in a systemic circularity (a new systemic vision that holds together holism and reductionism)[29] that can be considered one of the turning points as far as the metaphor of the dance is concerned. Thus, the Monodian model of the genetic program is replaced by that of the circularity of distributed programs linked to functions of self-programming[30]. What characterizes the bios, therefore, is no longer just teleonomy as conceived by Monod (planning without intention[31]), but rather there begins to take shape the idea that life is inextricably linked to the idea of meaning, memory and intentionality (for example from the cell, to the immune system, to the apparatuses, all the way to the mind).

According to this new metaphorical model that addresses the emerging qualities, the genetic information of the organism does not reside in the initial conditions of the dynamic process of ontogeny, but in distributed programs that govern new information and, given the initial conditions, render impossible the sure prediction of the final state of the organism in question[32]. Today we are aware of the hidden mechanism that allows DNA, through the genetic code, to control the synthesis of proteins: in the dynamics of self-programming, in fact, it is the very functionality of the genome that creates the genetic information. The most important aspect of the phenomena of self-organization is the self-creation of meaning, that is, the creation of new meanings in the information transmitted from one party to another, or from one level of organization to another. Therefore, for a disorganization to be able to produce a reorganization, the meaning of the relationships between the parties must be transformed. This is why the question of the creation of meaning is at the center of the phenomena of self-organization[33]. And this is why the mathematical models (Markov chains and Boolean algebra) which allowed Monod to interpret the stochastic processes of gene expression are no longer sufficient[34]. The notion of "chance", following the Markovian-type model, is equivalent to contemplating a choice not known in advance, between alternatives already established in advance. The contradiction, then, is entirely logical-epistemological, since chance so conceived cannot be sufficient to explain becoming in nature: if the alternatives are already constituted a priori, how can one provide for the self-organization of organisms? In a complex

[29] Cf. Atlan (1990); Di Bernardo (2010).
[30] Cf Fox Keller (2000); Fox Keller (2010).
[31] Cf. Monod (1974).
[32] Cf. Wallace (2014).
[33] Cf. Atlan (2007).
[34] Cf. Landsberg (1978).

system, as we have seen, the newness of the information is inherent in the dynamics of the process. In other words, the system continuously redefines the space of the alternatives[35]. In light of this, H. Atlan and A. Carsetti affirm that "self-organization means allowing chance to take on meaning, a posteriori and in a specific context of observation" (Atlan, 1992: 19-20; Carsetti, 2012: 14-23). Biological systems, in fact, are the result of complex interactions that occur at the level of the immense multiplicity of their components since they are neither equal to the sum of their parts, nor determinable using only the initial conditions. From reductionism and naive holism one thus arrives at a systemic vision according to which life appears as a phenomenon of transaction, that is, the result of a series of compromises that constitute and modify unpredictably the parts of the game itself.

These ideas have found a further experimental confirmation in the results of the 'Encode' project[36], created in 2003 by the *National Human Genome Research Institute* that includes 32 laboratories around the world, published in 2012 in the journal *Nature*[37] and presented to the public in September of the same year at the Science Museum in London as discoveries made by a dance in an installation named: "*Encode: the Dance of DNA*". The initial metaphor of the great dance, which had inspired several models of scientific explanation such as those of circularity (Atlan) and of distributed programs related to self-programming (Fox Keller), has now come to take on a precise scientific connotation: no longer only an object of study or a survey instrument (the cognitive role of metaphorical models of biological knowledge), but also an instrument of theoretical development (a constitutive role). In terms of the results obtained within the 'Encode' project we are no longer faced with an indication of perspective (a set of intuitions) or with a specific and momentary metaphorical model intended as a functional representation, but with a 'living metaphor', that is to say, with the overt birth of a real new scientific paradigm. In confirmation of this, E. Green, director of the NHGR Institute, during a teleconference to present the results of the project, said: "What we learned from ENCODE is how complicated the human genome is, and the incredible choreography that is going on with the immense number of switches that are choreographing how genes are used. [...] We are starting to answer

[35] Cf. Bais, Doyne Farmer (2008).
[36] Cf. The ENCODE Project Consortium (2012).
[37] Cf. Djebali et al. (2012).

fundamental questions like what are the working parts of the human genome, the parts list of the human genome and what those parts do"[38].

According to this new interpretation, also to be found in other works[39], life in general presents itself to us, then, as an amalgamation of the cooperative work done by simultaneous and molecules that can be considered the effective components of a dance; we are referring here to the highly orchestrated game in which DNA, RNA and proteins come to play at the same time the roles of actors and interpreters of a mysterious storyline. DNA is the choreography, the choreographic writing. RNA is the choreographer, that is, the one that interprets the script and then proceeds, where necessary, to make the due alterations. Proteins instead are the physically identified dancers. They are assembled by the RNA, but informed by the DNA[40]. Today, in fact, we know that the membrane at the level of the cell develops combinations of proteins, as a result of the computations carried out, able to modulate the expression of the DNA on the surface level. It thus allows the emergence of hitherto unknown potentials, allowing the DNA to outline new forms of expression at the functional level[41]. From this complex plot a new unity of function and meaning emerges[42]. There is no longer only a hereditary machine on the one side and a meaning external to it enclosed, for example, in a simple selective procedure that occurs on the environmental level, on the other[43]. Now the scientist's gaze is confronted with a complex plot in which meaning comes to work as an immanent guide for the primary expression of life, while at the same time the observer himself comes to be, in turn, determined by the ongoing function.

4. Conclusions

In such a perspective, then, it is possible to interpret in the metaphor of dance as a new paradigm of the science of complexity, the choreography that is given at the level of DNA as a function primarily of the harmony and even the health of a body. At the co-evolutionary level this choreography however cannot but take into account the existence of some other bodies

[38] Cf. http://www.livescience.com/22990-encode-explanation-facts.html.
[39] Cf. Sanyal et al. (2012).
[40] Cf. Gerstein (2012).
[41] Cf. Faulkner (2009); O'Nuallain S (2008).
[42] Cf. Carsetti (2013).
[43] Cf. Jablonka & Lamb (2005).

and minds if it wishes to ensure a real, objective dance of life. A dance that, while giving rise to the realization of a self, will necessarily mediate itself in the other. A dance, that is to say, that can only be articulated at the level of society and its times. According to this interpretation, therefore, it is possible to discover another great metaphor of nature as an intelligible reality that for centuries has accompanied the thought of the West, despite the centuries-old attempts to question it: we are referring here to the metaphor of the book of nature as masterfully summarized by the very words of Galileo: "Philosophy [natural philosophy, i.e. science] is written in this grand book, the universe, which stands continually open to our gaze. But the book cannot be understood unless one first learns to comprehend the language and read the letters of which it is composed" (Galilei 1623: 1995, p. 232)[44]. The main points on which Galileo's attention was focused are the existence of a nature independently of the plurality of perspectives of those who behold it, the limits of the cognitive schemata (to be considered more as a constantly changing working hypothesis) implemented by the scientist, and the comprehensibility of the real understood as the result of the revelation of internal regularities that the human mind perceives as logical rules. In my opinion, these points may be deemed still worthy of attention as they make this metaphor valid not only for all the branches of experimental science, from mechanics to chemistry and biology, but also for humanistic fields such as law, philosophy, anthropology and theology, which after the emergence of the experimental method have been considered by the scientific community as not objective.

These realms of knowledge, in fact, although not formalized in terms of equations of geometric relations, are still attempts to rationalize. Just as in the great dance, in the metaphor of the book, intelligibility comes to be seen as an intrinsic property of nature itself in the sense that the scientific explanation can be decisively interpreted by the philosopher as our mind's realization of actually existing relationships in reality between beings, events and processes in a context of profound harmony. Here is a rationality that unfolds and becomes visible despite an incompressibility of whose constant irruption an original meaning comes to "speak" from within nature. Here is the flowering of an infinitary and never adequate measure of the real complexity of that being that is man, but here also there looms an individuality bearing a logos that is not mere algorithmic computation, but the metaphorical generation of a precise relationship between the emergence

[44] My translation.

of ever new aspects of reality, the renewed growth of the deep roots of pure cognition and rational choice.

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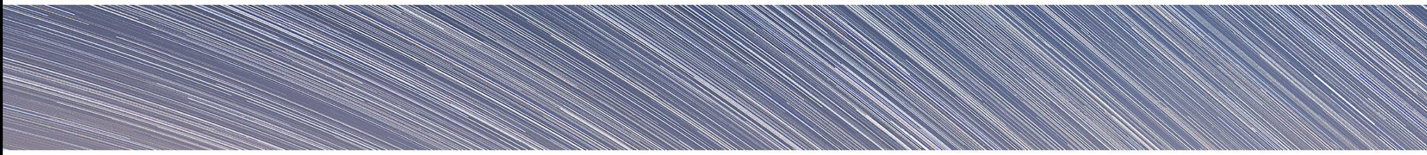

The discursive thought seems very often lacking in adequate expressivity to convey all contents and meanings; not only in poetry and in art, but also in science and philosophy. If something seems to be not completely expressible and clear, it is expressed as if something would be something else that we already understand. This is the reason why, from one hand, we use very often metaphors, and from the other hand, metaphor is a subject with a long and impressive tradition in philosophical and scientific thought. We maintain there is a twofold pattern of usage for metaphors, which we label as "internal" and "external". In the first case, the "internal" one, metaphor assists and urges the formation of new ideas in the inside of science. In the "external" case, from the inside of science to its "outside", metaphor is useful to communicate scientific ideas. Namely, metaphor helps us to express intuitively concepts and contents for the layperson; in other words, science can be explained in layman's terms just by using metaphors. Therefore, metaphors have a social impact as communication tools.
Moving within a multidisciplinary approach, each article of this book analyses these questions from a particular point of view, by discussing a specific problem. This book is composed in two parts: the contributions in first part look into the nature of metaphors and their role in the description of human rationality; the second part inquires the heuristic use of metaphors in science, by drawing on both historical case-studies and theoretical discussion.

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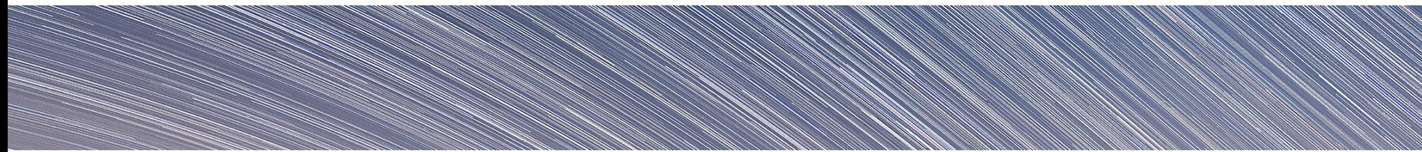

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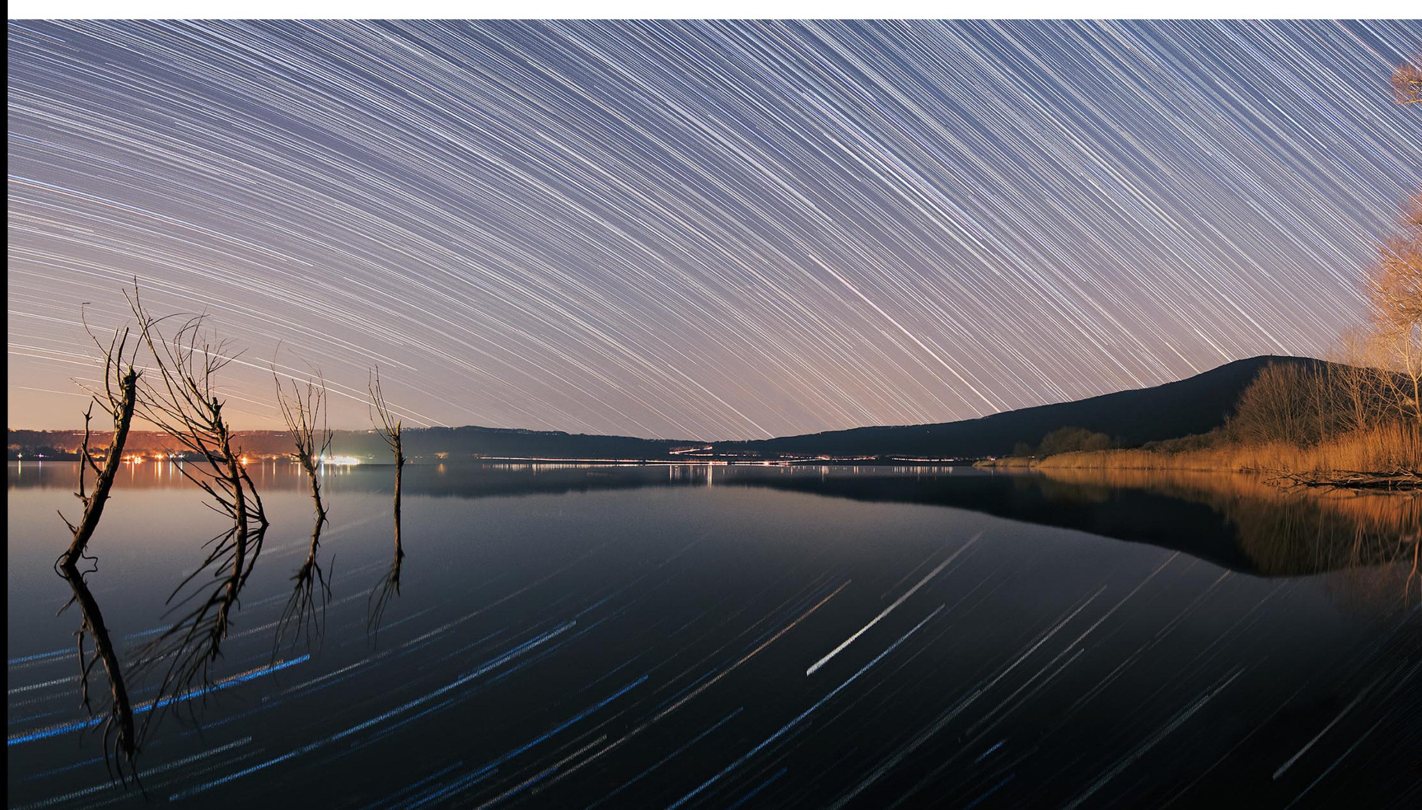

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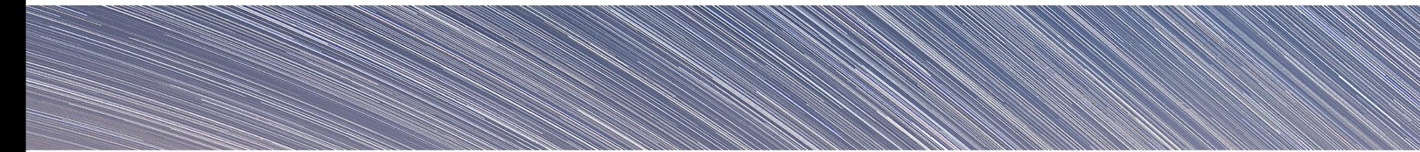

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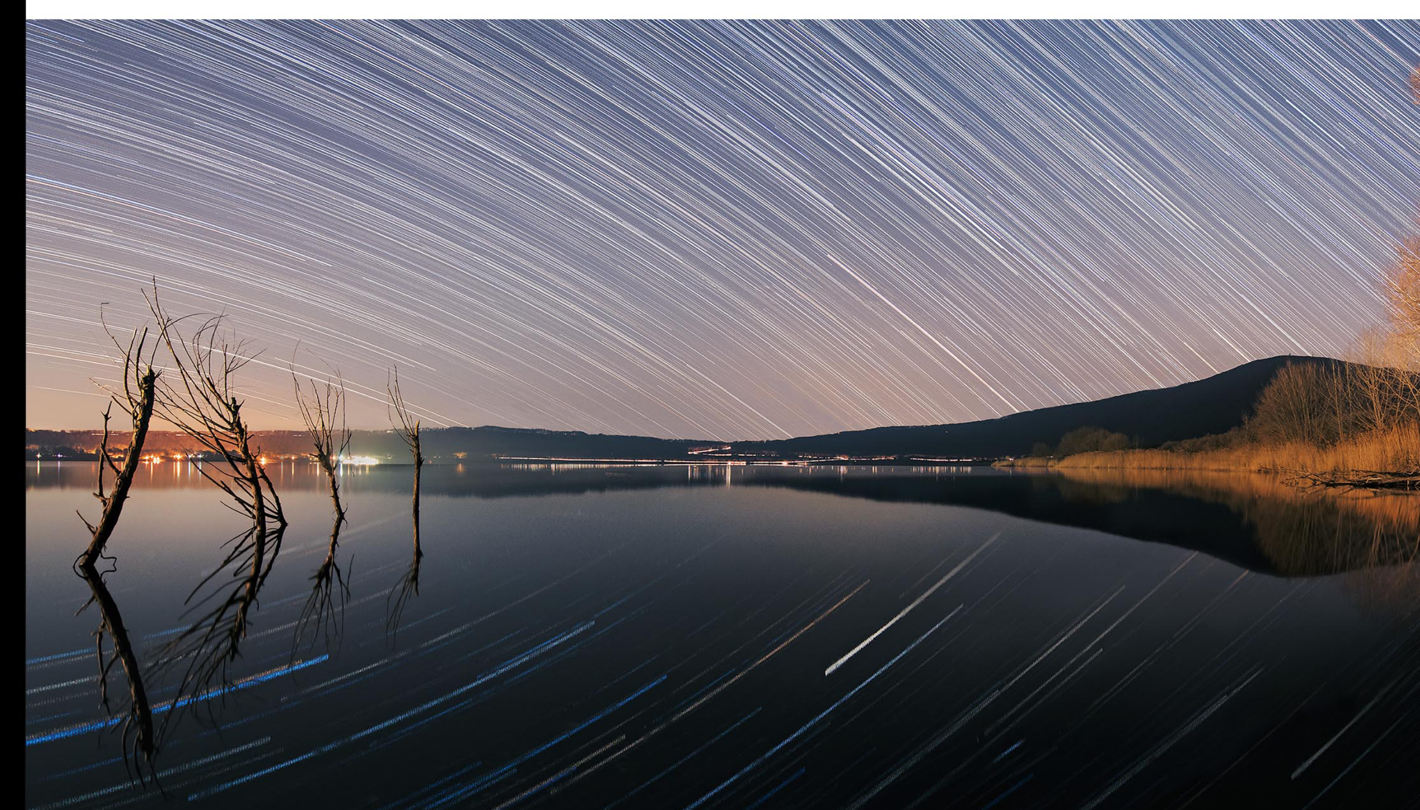

Isonomia *Epistemologica*