THE MECHANICAL VIEW[1]

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Abstract: I introduce and characterise the Mechanical view as a third view on scientific theories besides the Syntactic and the Semantic views. Currently, there is no such term and category which unifies the work philosophers of science such as Norman Campbell, Mary Hesse, Rom Harré, Nancy Cartwright, and Ronald Giere. Currently the work of these and other related philosophers is either placed as part of the Semantic view, or it remains an orphan with no family and no generic name or characterisation. Each philosopher is therefore treated separately, or is regarded as unrelated or weakly related to others. The introduction of the Mechanical view as a comprehensive position within the philosophy of science has at least three advantages: First, it unifies apparently dissimilar and unrelated positions economising and enhancing both analysis and understanding as well as helping the reappraisal of the work done by forerunners. Second, it helps to correct the wrong characterisation of the work from philosophers like Ronald Giere, whose work is placed as part of the Semantic view. Third, along with the Syntactic and the Semantic views, the Mechanical view exhausts virtually all philosophical research done on models, and in other areas in the philosophy of science. A unified characterisation can bring benefits to the Mechanical view itself, by systematising and empowering its own view and future research.

1. SYNTACTIC AND SEMANTIC GEOMETRY

Rudolf Carnap distinguishes among three scientific 'word-languages': arithmetic, axiomatic and physical. He uses geometry to illustrate the differences between them.[2] The use of geometry is particularly relevant because, if there is a place where the importance of graphics and graphic reasoning should be acknowledged, it is in geometry. Carnap highly praised the metamathematical method of arithmetisation

[1] This paper was for the first time delivered at the Instituto de Investigaciones Filosóficas, UNAM, México, in September 2016.
[2] R. Carnap (1934), p. 78-82, §25.

developed by Kurt Gödel. With it, Gödel intended to exhibit the structure and order of mathematical propositions using natural numbers as a language of translation, by establishing a one-to-one correspondence between natural numbers and those mathematical propositions. René Descartes proceeded in a similar fashion by using pairs of numbers on a Euclidian plane as an algebraic translation of any geometrical shape. In an important basic sense, arithmetisation is a syntactical translation—an *explication* in Carnap's own terms—which serves as a method of *logical proof* when mathematical expressions can be deduced from the so constructed metalanguage of natural numbers.

In the case of geometry, all shapes are arithmetised by assigning ordered triads of real numbers, and the linear equations constructed with them: 'a point is interpreted in the usual way as a triad of real numbers, a plane as a class of such triads which satisfy a linear equation, and so on.'[3] By doing this, all shapes in geometry disappear by being arithmetised through the assignment of ordered triads of real numbers, and the linear equations constructed with them: 'a point is interpreted in the usual way as a triad of real numbers, a plane as a class of such triads which satisfy a linear equation, and so on.'[4] Therefore, arithmetisation becomes an *eliminative method,* where all shapes and graphic models disappear. The graphical proof of Pythagoras theorem or the law of cotangents using triangles, square and circles is replaced with a syntactical proof produced using natural numbers as a metalanguage.[5]

[3] *Ibid.*, p. 274, §71e.
[4] *Ibid.*, p. 274, §71e.
[5] Carnap explains that unlike Wittgenstein he wanted to do more than just *showing* the syntax of scientific language; he wanted to *express* it using a formal language. Arithmetisation, therefore, becomes an *explication* of the syntax of in geometry; see R. Carnap (1934), p. 53, §18,; and (1962), pp. 1-18.

Physical geometry comprises the set of 'definite synthetic sentences which state the empirical (namely the geometrical or graphical) properties of certain physical objects', for instance, 'these three objects A, B, C are light-rays in a vacuum each one of which intersects the other two at different points.'[6] Carnap argues that besides producing physical descriptions, scientists must also axiomatise their own theories. In the case of Euclidian geometry, such axioms were produced by David Hilbert, i.e. axiom of parallels, axiom of continuity and so on. Hilbert's axiomatic geometry contains twenty-one axioms, which any physical sentence can be related to by using 'correlative definitions'. The philosophical task is again syntactic and logical, which consists of *explicating* the order and kinds of words of physical or empirical sentences, equations and axioms by using a metalanguage, and *proving* the deductive order of sentences, equations, axioms, theorems, and any other scientific proposition.[7]

For reasons of exactness, clarity and simplicity; axioms were selected by Carnap as the standard canonical way of expressing the terms and propositions contained in scientific theories. Following Gottlob Frege,[8] he criticised the inexact and often hazardous expression of scientific terms and propositions published by scientists in articles and books. Hence, his aim was to render these concepts and propositions exact and closed under the relation of logical consequence, having axioms as a foundation. Inexact physical descriptions with loose ends were and still are common in science. In contrast, axioms are scarcely used to express the basic terms and propositions of scientific theories.

[6] R. Carnap, (1934) p. 81, §25.

[7] Carnap explains that besides first-order predicate logic, arithmetisation is also needed in some cases, so it must be considered as an explication method, see R. Carnap (1934), pp. 57–58, §19.

[8] See G. Frege (1879), pp. 5–8, and (1979), pp. 12-13.

The logical explication consists of making explicit the syntax of three different sets of scientific propositions, namely equations, axioms and definite empirical sentences by identifying features such as extension: existential or universal; size: atomic or molecular; composition: conjunctive, disjunctive or conditional as well as the sequences of reasoning performed with these elements, leading to normative patterns with the form of a modus tollens, a destructive dilemma and so on.

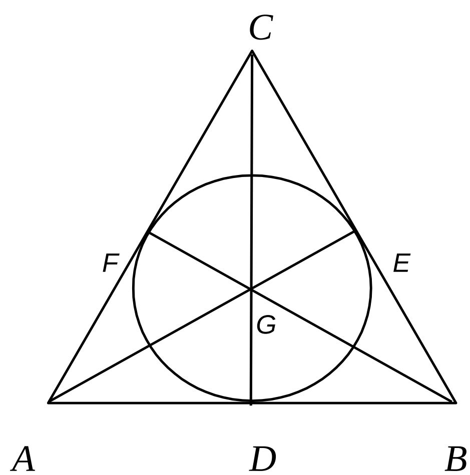
By doing this, philosophy becomes concerned only with sentences and their logical syntax. Any geometrical shape is reduced to triads of real numbers and equations for each physical dimension. Geometry, a basic candidate for graphic reasoning, vanishes by being reduced to sentential descriptions. Inference from graphics, a cognitive activity so crucial to geometricians, simply disappears. The same *eliminative method* could, in principle, be extended to any model and any other graphic means used in science such as diagrams, photos, engravings and blueprints.

Bas van Fraassen offers an alternative to Carnap's syntactic geometry. Following Alfred Tarski, he argues for *models* as the standard for expressing the content and truth-value of scientific theories, with the ultimate task of identifying isomorphic structural relations among those models and data from the world. Within the Semantic view, models comprise both set-theoretic mathematical and graphic models such as Niels Bohr's model of the atom. Accordingly, van Fraassen uses a Fano plane, also called Seven Point Geometry, as a model for the following four axioms:

A1. For any two lines, there is at most one point that lies on both.
A2. For any two points, there is exactly one line that lies on both.
A3. On every line there lie at least two points.
A4. There are only finitely many points.

Van Fraassen argues that ‘logical claims, formulated in purely syntactical terms, can nevertheless often be demonstrated more simply by a detour via a look at models’,[9] therefore the four axioms can be proven not by using a logical metalanguage but *by reasoning from a graphic model*, namely the Fano plane below, which consists of a geometry of the seven points *A* to *D*.

Figure 1.1. Fano plane.



Such a visual demonstration, however, still requires the help of the following set of sentences for the interpretation of the image: “In this structure only seven things are called ‘points’, namely A, B, C, D, E, F, G. And equally, there are only seven ‘lines’, namely, the three sides of the triangle, the three perpendiculars, and the inscribed circle. The first four axioms are easily seen to be true of this structure: the line DEF (i.e. the inscribed circle) has exactly three points on it, namely D, E, and F; the points F and E have exactly one line lying on both, namely DEF; lines DEF and BEC have exactly one point in common, namely E; and so forth.”[10]

[9] Van Fraassen (1980), p. 43; Seven Point Geometry in p. 42.
[10] *Ibid.,* p. 43.

Unlike Carnap's syntax of word-languages, van Fraassen's semantics keeps geometrical shapes as models for demonstrating axioms. Philosophically, this is a very important choice. First, because it lays out some common grounds with the Mechanical view, where graphic models are taken as fundamental in science. Second, because it supports graphic reasoning, that is, it accepts that scientific inference can be based on models and other graphics means. By doing this, philosophical research is not anymore constrained to word-languages. This is a very important step for a methodology of design and engineering, where blueprints are fundamental.

Despite its prominence in science, inference from models has received scarce attention from philosophers of science and, more specifically, from logicians. Most of the philosophical research has been concerned with ontological and metaphysical aspects of models as well as their function as suppliers of truth conditions, and further empirical content of scientific theories. Despite its interest in models, the Semantical view is not in a better position because virtually no further attention has been paid to inference from models. Because of the main interest of this thesis on blueprints, I concentrate on graphic models depicting mechanisms. Therefore, I do not discuss mathematical model-theory or any graphic means used in mathematics such as Euler or Venn diagrams or any Cartesian plane.

2. THE MECHANICAL VIEW

Besides the Syntactic and the Semantic views there is the *Mechanical view*. This is a term and a description I am introducing covering a number of contemporary philosophers with closely related arguments and proposals. I place the physicist and philosopher of science Norman Robert Campbell as the founder of this view.

Besides Campbell, the Mechanical view encompasses the work of Rom Harré, Mary Hesse, Nancy Cartwright, and Ronald Giere among others. This view emerged with a more defined shape in 1960s through the work of Mary Hesse and Rom Harré, who were inspired by the work of Campbell.

Norman Campbell argued against the methodological reduction of physics to mathematics as it had been pursued by scientists such as Ernest March and Henry Poincaré, who 'were primarily mathematicians and not experimenters.' Campbell drew a distinction between 'mechanical theories' and 'mathematical theories' in physics rejecting 'the view that theories of the second kind are in any manner superior in value or certainty to those of the first […] it is simply asserted that such [mechanical] theories alone can attain the ultimate end of science and give perfect intellectual satisfaction.'[11] This was his main thesis; he wanted to restore the value of mechanical theories in physics, which he claimed are supported on models depicting analogies between events from different domains.

Currently, entries and articles on models in encyclopaedias of philosophy and edited volumes do not register the Mechanical view as a unifying position, and they do not use either any other term identifying this position in the philosophy of science. Usually, the Syntactic and Semantic views are discussed as the only systematic unified positions, and then a number of main authors and problems are listed separately and discussed as unrelated, or as weakly or randomly related with one another, which all belong to the Mechanical view as I present it here. Moreover, from those female and male philosophers belonging to the Mechanical view, there are comparatively fewer systematic books with a comprehensive treatment than in the Syntactic and the Semantic views. The explications and discussions in main

[11] N. Campbell (1920), pp. 8, 154-155.

sources of reference such encyclopaedias and handbooks are no doubt relevant and philosophically rigorous, but they become too dispersed and somehow cumbersome, when they addressed the work of philosophers belonging to this view. See for instance the entries on models in the Stanford and the Rutledge Encyclopaedias of Philosophy, the volume edited by Mary Morgan and Margaret Morrison, and the comprehensive survey on models written by Daniela Bailer-Jones.[12]

Back in the early twentieth century, Pierre Duhem drew a methodological distinction between the 'abstract mind' of French and German scientists, and the 'visualising mind' of the English scientists. The abstract mind produces axioms and equations associated to perfect geometrical shapes representing real objects, and it performs all inferences through rigorous deductive steps.[13] In contrast, the visualising mind relies on mechanical models picturing imperfect real objects: axioms are not required while equations often have an instrumental role by being epistemically less important than graphic models. Models do the ultimate and more fundamental epistemic job by exhibiting and demonstrating the mechanisms through which nature operates. Duhem points out that rigorous deduction is replaced with 'rough analogies', which are 'a regular feature of the English treatises on physics. Here it is a book intended to expound the modern theories of electricity and to expound a new theory. In it there are nothing but strings which move around pulleys, which roll around drums, which go through pearl beads, which carry weights; and tubes which pump water while others swell and contract; toothed wheels which are geared to one another and engage hooks. We thought we were

[12] M. Morgan and M. Morrison (1999), D. Bailer-Jones (2009); see also R. Frigg (2006a).

[13] A representative criticism from the Mechanical view on deductive rigour and formalisation in economic models can be read in N. Cartwright 'The Vanity of rigour in Economics: Theoretical models and Galilean experiments', in her (2007) *Hunting Causes and Using Them*.

entering the tranquil neatly ordered abode of reason, but we find ourselves in a factory.'[14]

Indeed, we enter into a factory not only by opening that book from the nineteenth century English physicist Oliver Lodge, but we also do by opening the books from current philosophers of science such as Rom Harré, Nancy Cartwright or Ronald Giere, where images, diagrams, and other graphic means play a main role.

The introduction of the Mechanical view as a comprehensive position within the philosophy of science has at least three advantages. First, it unifies apparently dissimilar and unrelated positions economising and enhancing both analysis and understanding, as well as helping the reappraisal of the work done by forerunners.[15] That is, it allows the reappraisal and unification of the early work from Norman Campbell, Mary Hesse and Rom Harré with the most recent one from Nancy Cartwright, Ronald Giere, Margaret Morrison, Nancy Nersessian, David Gooding and others. Second, it helps to correct the wrong classification of the work from philosophers like Ronald Giere, whose work is placed as part of the Semantic view.[16] Third, along with the Syntactic and the Semantic views, the Mechanical view exhausts virtually all philosophical research done on models, and in other areas in the philosophy of science.

Among the female and male philosophers and historians just named as part of the Mechanical view there are of course differences. For instance, for some induction and logic play a crucial part, while for others reasoning from analogy and

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[14] P. Duhem (1906), pp. 70-71, 56-57; the book Duhem is referring to is by Oliver Lodge (1889) *Modern Views of Electricity*.

[15] Unlike the Syntactic and the Semantic views, the Mechanical view did not have a continuous and more cohesive and systematic development; some aspects and authors from this view are discussed D. Bailer-Jones (2009).

[16] See R. Frigg (2006b), p. 52; N. da Costa and S. Frech (2000), p. S119; and M. Morgan and M. Morrison (1999), p. 3-4.

cognition are a fundamental part of science. In spite on these and other differences, the prominent place given by all of them to mechanical model is, I believe, strong enough to support this classification. In sum, I argue that the addition of the Mechanical view is insightful and general enough by allowing a quick and comprehensive look into the current debate on models, and more generally, in the philosophy of science.

Against the Syntactic view,[17] the Mechanical view rejects the elimination of models and causal powers, and it also rejects the idea that scientific language provides a literal description of the world. It argues instead for the use of models, especially those depicting theoretical mechanisms and entities, which involve the vindication of causal powers. It also highlights the constitutive role of analogy and metaphor in those models, and the explanations and predictions made with them. Its own defence of inference from analogy is supported on single cases,[18] in contrast to a large number of cases, which is typical of induction and laws as defined by the Syntactic view. Because of its defence of mechanisms, causal powers and theoretical models, the Mechanical view is largely realist in opposition to the empiricism of the Syntactic and the Semantic views.

Graphic models like the Fano Plane are a common ground for the Semantic and Mechanical views; this explains why the work of philosophers such as Ronald Giere is mistakenly placed as being part of the Semantic view. Unlike this view, models in the Mechanical view are not used as means for establishing isomorphic structures among models and data from the world, nor for the interpretation of

[17] See C. Hempel (1965), pp. 433-447, and R. Carnap (1939), who argues that when 'Maxwell's equations of electromagnetism, were proposed as new axioms, physicists endeavoured to make them "intuitive" by constructing a "model"… It is important to realize that the discovery of a model has no more than an aesthetic value or didactic or at best a heuristic value, but it is not at all essential for a successful application of the physical theory', pp. 67-68.

[18] See N. Cartwright (1989), p. 56ff; and (1992), p. 51.

axioms or any other formalisation in a scientific theory. In the Mechanical view, knowledge of mechanisms is placed at the core of scientific models and scientific labour, such knowledge is the ultimate aim of science. In this view models are graphic representations of causal mechanisms; they are the means to expose those mechanisms. A mechanism is a cohesive arrangement of causes regularly producing an effect. Within this view, models are used for at least three outstanding purposes:

- As means for justifying new theories as well as for expanding and refining current ones
- As means for rendering scientific claims true
- As means for improving scientific and technological intervention in the world.

With the term ‘models as mediators’ Morgan and Morrison tried to grasp and summarise much of the work done by philosophers working in the Mechanical view since 1980s. Such mediation between theories and the world is exposed mainly in two ways. The first one concerning the truthvalue of scientific claims; the second one concerning scientific intervention into the world.

In the first one, models are the real providers of any empirical content in science, that is to say, when laws and theories are taken at face value ‘they lie’—to use Cartwright’s phrase—only models tell us the truth. Particularly, what she calls ‘representative models’, which contain a detailed description of the empirical domain of concern, often described as ‘target system’. Cartwright asserts that ‘theories in physics do not generally represent what happens in the world; only models represent in this way, and the models that do so are not already part of any theory.'[19] Morgan and Morrison hold almost the same thesis by criticising the conception of models as mere derivations from theories, or as simplifications of them. They argue that 'models should no longer be treated as subordinate to theory and data in the production of knowledge' but as independent and autonomous.[20] Models are autonomous because they actually help produce new causal explanations and new measurements, which cannot be derived from the theory or the data themselves.[21]

The centrality of models is also held by Ronald Giere, who claims that scientific theories comprise 'a population of models' and 'various hypotheses linking those models with systems in the real world'.[22] Such models are not set-theoretic but they are mechanical models. His preference for graphic mechanical models clearly places him into the mechanical tradition, and away from the Semantic view, which he actually criticises. He rejects isomorphism as the hypothesis explaining the relationship between scientific models and the world, and he argues instead for a relation of similarity. Also, against the Semantic view, he rejects van Fraassen's empiricism, arguing instead for a variety of realism.[23] A realist position is also shared by Harré and Cartwright.

The second aspect concerning scientific and technological intervention is one of the most recent developments within the Mechanical view. Nancy Cartwright has produced the first work and analysis with a clear focus on the implementation of social and economic policies. In particular, she has focused on blueprints regarded as a particular type of model.

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[19] In M. Morgan and M. Morrison (1999), p. 242.
[20] *Ibid.*, p. 36.
[21] *Ibid.*, pp. 13, 21; also there see article by M. Suarez in pp. 168-196.
[22] R. Giere (1988), p. 85.
[23] *Ibid.*, p. 80-82, 92-106.

The pioneering work of Mary Hesse and Rom Harré on models is largely addressed to the production and justification of new scientific theories. Instead of using terms like ‘normal’ and ‘revolutionary science’, or ‘progressive’ and ‘degenerative research programmes’, Harré and Hesse use the term ‘theory construction’ as a description covering the creation of the new theories, their refinement and expansion. Such a term was a response to the distinction made by Logical Positivist philosophers between the contexts of discovery and justification. The term theory construction is also associated to the cognitive foundations of science adopted by the Mechanical view in contrast to the logical foundations pursued by Logical Positivism. Philosophers like Rom Harré and Ronald Giere explicitly state their methodological commitment to the cognitive approach, while others like Morgan and Morrison use the term ‘learning’ instead.

The Mechanical view can be summarised in the following six components:

i. Graphic models as central to science

ii. Vindication of causal powers and mechanisms

iii. Key role of single case inference with and without analogy

iv. Realism predominates

v. Metaphorical terms as important part of scientific language

vi. A concern with the use of models for intervention

The first four are the most widely shared aspects, while the last two are less widespread. In article, I only discuss numbers one, three and five.

3. ANALOGY

I argue that the opposition between the supertypes '*mechanical aether*' and '*force field*' in nineteenth century physics, illustrate the contrast between minimal and maximal analogies as rules guiding scientific research. I claim that minimal analogies represent a necessary and progressive method needed for building up type-hierarchies, and I also hold the view that maximal analogies are conservative, and that they can even have recessive or regressive effects in scientific progress. The differences between maximal and minimal analogies and their effects, are illustrated with the models of James Maxwell and Michael Faraday on the magnetic lines of force.

In 1852, Michael Faraday published his strongest defence of the separate ontological status of the magnetic lines of force as continuous physical entities distinct from matter.[24] His argument challenged the idea of action at distance by arguing instead for a non-mechanical and physical continuum as the explanation for the magnetic forces of attraction and repulsion. Following the Newtonian paradigm, James Maxwell wanted instead to produce a mechanical explanation of such an unobservable physical continuum: 'I propose now to examine magnetic phenomena from a mechanical point of view, and to determine what tensions in, or motions of, a medium are capable of producing the mechanical phenomena observed.'[25] The leading idea for such an explanation was that of long vortices parallel to each other created by small particles revolving on their axes. The position and direction of such vortices coincided with those of the lines of force observed around a magnet. Hence,

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[24] M. Faraday (1852) 'On the physical character of the lines of magnetic force'; the same year Faraday published a second article complementing this one with the title, 'On the Lines of Magnetic Force: Their definite character; and their distribution within a magnet and through space'.
[25] J. C. Maxwell (1861-1862), p. 162.

the lines of magnetic force observed on the iron powder scattered around a magnet, were explained as the observable effect of such vortices.

The creation of a full mechanical model was not an easy task. An important problem was to think of a mechanism which could allow all vortices to move in the same direction when an electrical current is induced. If we imagine vortices as pipes placed next to each other, they all would get stuck and stop if each of them moves in the same direction. This is how Maxwell explains the solution to this important problem:

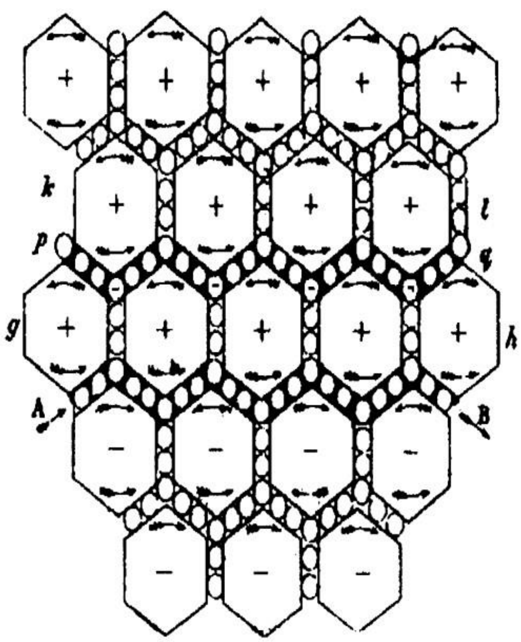
> ‘I have found great difficulty in conceiving of the existence of vortices in a medium, side by side, revolving in the same direction about parallel axes. The contiguous portions of consecutive vortices must be moving in opposite directions; and it is difficult to understand how the motion of one part of the medium can coexist with, and even produce, an opposite motion of a part in contact with it. The only conception which has at all aided me in conceiving of this kind of motion is that of the vortices separated by a layer of particles, revolving each on its own axis in the opposite direction to that of the vortices, so that the contiguous surfaces of the particles and of the vortices have the same motion. In mechanism, when two wheels are intended to revolve in the same direction, a wheel is placed between them so as to be in gear with both, and this wheel is called an `idle wheel’’ [26]

The postulation of some kind of particle functioning as an idle wheel was a clever mechanical solution to the problem of how to make both electricity and magnetism work together. It combines mechanics of fluids and the mechanics of solids with an analogy and a metaphor taken from natural phenomena, like cyclones or tornados and metallic wheels as they operate in a machine. Maxwell’s model relies on a mechanical analogy from the action of natural phenomena and the mechanics of a machine creating a full mechanical explanation, which turns into a maximal analogy

[26] C. Maxwell (1861 1862), p. 283.

within the dominant Newtonian view. This is the graphic model he produced of such a mixed mechanism:

Figure 1.5. Maxwell's vortex-idle wheel model:[27]



'Let the current from left to right commence in AB. The row of vortices *kl* still at rest, then the layer of particles between these rows will be acted on by the row *gh* on their lower sides and will be at rest above. If they are free to move, they will rotate in the negative direction, and will at the same time move from right to left, or in the opposite direction from the current, and also form and induced electric current.' [28]

The model actually resembles the schematic diagram of a mechanism inside a machine. If we magnified the image, or if we relate it to an actual physical macroscopic model, we can actually appreciate the metaphor in its full dimension. By magnifying it, we can obtain an even more mechanical impression similar to that of tornadoes in an electrical storm, or an image of a hybrid machine such as a hydroelectric power plant, which combines technology with the mechanical force

[27] For more on the explicit use on this analogy see also M. Hesse (1961), pp. 206-212; and N. Nersessian (1984), pp. 69-93.
[28] J. C. Maxwell (1861 62), p, 291.

of a natural phenomenon such as a river. This was the kind of model Duhem criticised as distinctive of the English mind, in which one feels like entering into a factory with ‘tubes which pump water while others swell and contract; toothed wheels which are geared to one another and engage hooks’.[29] This model almost works as a form of figurative language.

Maxwell created this model following the *method of physical analogy*, which anticipates the work Norman Campbell and Mary Hesse did on the topic. Maxwell borrowed this method from the physicist William Thomson, who had produced successful analogies between different observable phenomena and their theoretical explanations, for the purpose of developing common mathematical solutions. For instance, he drew a fruitful analogy between the electric and magnetic forces by arguing that both were ‘distortions’ caused by ‘the absolute displacement’ and ‘the angular displacement’ of a particle.[30]

Maxwell explains that ‘by a physical analogy I mean the partial similarity between the laws of one science and those of another which makes each of them illustrate the other […] [a] method of investigation which allows the mind at every step to lay hold at a clear physical conception, without being committed to any theory founded on the physical science from which that conception is borrowed, so that it is neither drawn aside from the object in pursuit of analytical subtleties, nor carried beyond the truth by a favourite hypothesis.’[31] Note that a physical analogy is not necessarily false; there is just no definite answer yet on its truth-value.

Instead of using only the terms ‘force’ or ‘energy’ in his analogy, Maxwell used the term ‘aether’ as a description for the unobservable magnetic fluid depicted

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[29] P. Duhem (1906), pp. 70-71, 56-57

[30] W. Thomson (1847), p. 62.

[31] J.C. Maxwell (1855 1856), p. 156.

in his model. The aether was still matter just of a subtle kind. Over two centuries the aether was a well-established natural kind in physics, which can be described as a supertype with several types and subtypes such as the luminiferous aether introduced by Newton, the stationary and gravitational aether postulated by Christian Huygens, the elastic and solid aether suggested by George Stokes, and the electromagnetic aether depicted in Maxwell's model. By maximising similarity with the predominant supertype, the electromagnetic aether simply became another subtype in the Newtonian semantic mask, where all types of aether were mechanical. Once a new subtype is added, properties are just inferred as inherited traits. There is no meaning shift; the mask virtually covers all aspects inheriting properties from a supertype to different types and subtypes. The main scientific task consists only of figuring out how a new mechanism would look like and how it would operate, which is what Maxwell did following the rule of maximal similarity.

Because of this, Maxwell's model was methodologically conservative, and it later became recessive and regressive. Ontologically there was no big leap, no significant gain for nearly a century, until Albert Einstein in 1905 and 1920 rejected the need for an aether and established the concept of a field.[32] In contrast, Faraday throughout his investigations and in his exchange with Thomson was reluctant to accept a mechanical explanation of the lines of force; he explicitly wanted to de-mechanise them.

For more than three decades, Faraday tried different analogies and theoretical explanations of magnetism and electricity, which finally led him in 1855 to the

[32] A. Einstein (1905), p. 2; (1920), pp. 13, 16; see P. M. Brown (2002) for the differences between Einstein's concept of a field and current views, which Brown claims are closer to those of Faraday than Einstein's [32] Historical accounts with different explanations of Faraday's creation of the concept of a magnetic force field can be found in B. G. Doran (1975), and D. Gooding (1980).

postulation of a magnetic force field distinct from matter.[33] This ontological distinction anticipated the current distinction we draw between the two supertypes energy and matter. The whole discovery was an *ad hoc* process, during which different hypotheses were entertained by Faraday, who increasingly became aware of the limitations of the dominant Newtonian paradigm. His research and findings show he was working at the semantic boundaries of the Newtonian paradigm trying to make sense of phenomena such as diamagnetism, which remained anomalous within the mechanical view.

Faraday's search for an explanation of the magnetic lines of force started in 1820, when he rejected André Marie Ampère's hypothesis of an undulating fluid with two electric effluvia as the explanation of magnetism. Ampère believed magnetism was not a new phenomenon but mere electricity in motion. In 1830, Faraday studied Augustin-Jean Fresnel's undulatory theory of light, which didn't need Ampere's electric effluvia, and rested instead on an analogy between the vibrations of the sound and the waves of light. Fresnel rejected the idea of aether as a fluid, and postulated instead an elastic solid aether able to transport both longitudinal and transverse waves.

Faraday used this idea of an elastic solid aether, and he placed the locus of magnetic action in the 'inductive lines of force'. Then in 1845 he met William Thomson; the exchange between the two gave rise to the non-Newtonian concept of a magnetic field.

Thomson's main interest was to produce a mathematical theory of magnetism with a method based on metaphors and analogies that he created by relating different phenomena. He first suggested an analogy between heat and magnetism assuming

[33] In Martin, T. (1932-1936), Vol. V, #10834; see also B. G. Doran (1975), p. 174.

that the inductive lines of force acted like heat waves. Faraday had rejected action at distance as an explanation of magnetism, so his main challenge was to find a satisfactory explanation of the continuity of magnetism in space. The analogy with the waves provided a model for such continuous action. A constant problem Faraday saw with this and other analogies and models, was the need for a surrounding substance—an aether—which would serve as the medium allowing the travel and action of magnetic forces. This implied an ontology with three elements: magnetism, matter and aether. The alternative hypothesis consisted of eliminating the aether by assuming an empty space, but he just could not make full sense of the lines of magnetic force acting in a vacuum. This was a problem that persisted for a century in the theories of James Maxwell, Hendrik Lorentz and Albert Einstein.[34]

Stimulated by Thomson's analogy, Faraday developed in 1846 a new model where forces form a plenum filling up all space such that no aether was needed. This plenum was made up by atoms acting as the centres of forces around them; he explains that 'the point intended to be set forth for consideration of the hearers was whether it was not possible that the vibrations, which in a certain theory are assumed to account for radiation and radiant phenomena, may not occur in the lines of force which connect particles, and consequently masses of matter together; a notion which as far as it is admitted, will dispense with the aether, which, in another view is supposed to be the medium in which these vibrations take place.'[35] A model with atoms and forces was only closer to the current conception of fields derived from the work of Einstein.

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[34] Further historical details of this problem from Faraday and Einstein can be found in N. Nersessian (1984).

[35] Faraday (1846) 'Thoughts on ray-vibrations'; the idea of centre-atoms and forces is similar to that of R. J. Boscovich, whose work was known to Faraday, although it is controversial the extent to which Faraday took this idea from him; see B. G. Doran (1975), p. 166

But there was no lineal progress in Faraday's search for the best model and hypothesis explaining the nature and operation of the magnetism. By 1850 he abandoned the dualism atomsforces by reconsidering again aether as a medium. This time as a fluid whose action was described with the analogy of a stretched spring transmitting the magnetic forces. He acknowledges that the idea of the lines of force acting in an empty space without a medium 'is difficult to comprehend according to the Ampere theory [...] or with any other generally acknowledged, or even any proposed view or even any trial speculation that I am aware of.'[36] One year later he goes back to an explanation with no aether: 'we have to consider the true character and relation of space free from any material substance. Though one cannot procure a space perfectly free from matter, one can make a close approximation to it in a carefully prepared Torricellian vacuum [...] Mere space cannot act as matter acts, even though the utmost latitude be allowed to the hypothesis of an ether; and admitting that hypothesis, it would be a large additional assumption to suppose that the lines of magnetic force are vibrations carried on by it.'[37]

By 1851 new doubts and hesitation appeared, when he writes that 'how the magnetic forces is transferred through bodies or through space we know not; whether the result is merely action at a distance, as in the case of gravity; or by some intermediate agency, as in the case of light, heat, the electric current, and (as I believe) electric static action.'[38] In 1852, he finally converted to the field concept Thomson had originally suggested it to him. Faraday explains that 'I conceive that when a magnet is in free space, there is such a medium (magnetically speaking) around it. That a vacuum has its own magnetic relations of attraction and repulsion

[36] In Martin, T. (1932-1936), Vol. V, #10834; see also B. G. Doran (1975), p. 174.
[37] M. Faraday (1851), p. 194; #2787.
[38] M. Faraday (1852), p. 330; #3075.

is manifest from former experimental results; and these place the vacuum in relation to material bodies, not at either extremity of the list, but in the *midst* of them […] What that surrounding magnetic medium, deprived of all material substance, may be, I cannot tell, perhaps the aether.'[39] In his last statement from 1855, he fully abandons the hypothesis of an aether, which he now considers to be inadequate and old:

> My physico-hypothetical notion […] views these lines as *physical* lines of power […] Those who entertain in any degree the aether notion might consider these lines as currents, or progressive vibrations, or as stationary undulations, or as a state of tension […]It was always my intention to *avoid* substituting anything in place of these fluids or currents, that the mind might be delivered from the bondage of preconceived notions; but for those who desire an idea to rest upon, there is the old principle of the aethers.[40]

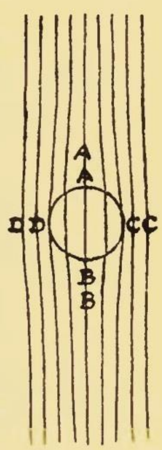
As we know, a few years later Maxwell would go back to the 'old principle of the aethers' with his vortex-idle wheel model. Jointly Faraday and Thomson produced the concept of a force field after ten years of collaboration. Like Faraday, Thomson also thought that magnetism was distinct from matter by claiming that 'this imaginary substance possesses none of the primary qualities of ordinary matter, and it would be wrong to call it either a solid, or the "magnetic fluid", or "fluids"'[41] Although, he was more interested in developing a mathematical theory than investigating the 'physical nature of magnetism', he nonetheless produced the idea

[39] *Ibid*., p. 425; #3277.
[40] M. Faraday (1855), pp. 529-530; #3301-3302.
[41] W. Thomson (1851), p. 251.

of a ‘field of force’ supported on a basic graphic model, which he communicated to Faraday for the first time in a letter from 19th June 1849:

Figure 1.6. First basic model of a magnetic field:[42]

Let the diagram represent a field of force naturally uniform, but influenced by the presence of a ball of diamagnetic substance. It is clear that in the localities A and B the lines of force will be less densely arranged, and in the localities D and C they will be more densely arranged than in the undisturbed field. Hence a second ball placed at A or at B would meet and disturb fewer lines than if the first ball were removed; but a second ball placed at D or C would meet and disturb more lines of force than if the first ball were removed. It follows that two equal balls of diamagnetic substance would produce more disturbance on the lines of force of the field if the line joining their centres is perpendicular to the lines of force than if it is parallel to them.



Thomson represented the magnetic field as naturally uniform affected by a ball of diamagnetic matter. In his later work he refined this basic model showing the different effects different spherical bodies produced, namely a ball with no intrinsic magnetism, and a ball inductively magnetised. Such models were the support of the sophisticated mathematics he developed with a number of equations, values and descriptions of regular effects. Some of those values and graphic sophistication can be appreciated in the following three models:

[42] S. P. Thompson (1910), p. 215; see also B. G. Doran (1975), p. 175.

Figure 1.7. Model of a magnetic field 'with an inductively magnetized globe'[43]

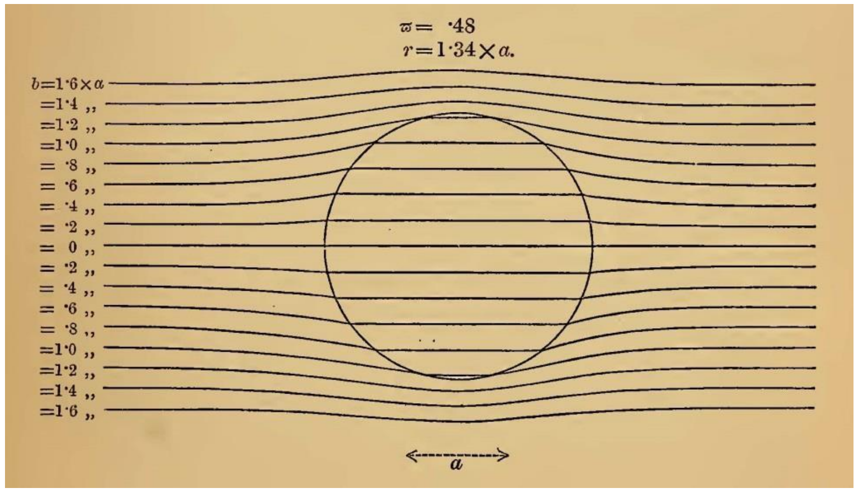
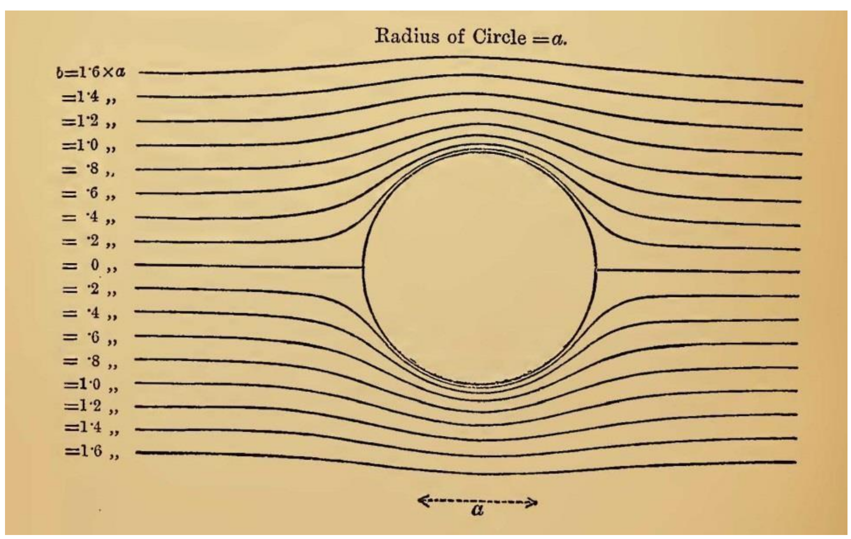


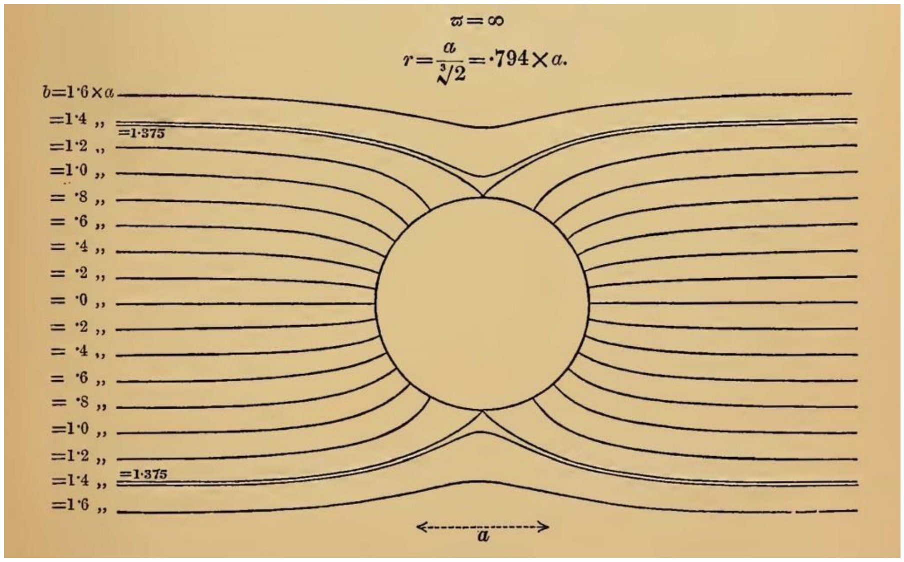
Figure 1.8. Model of a magnetic field representing 'the lines of magnetic force in the neighbourhood of a solid globe of any ferromagnetic or diamagnetic homogeneous material destitute of intrinsic magnetism, put into a uniform magnetic field':[44]



[43] W. Thomson (1872), p. 493.

[44] *Ibid.*, p. 491.

Figure 1.9. Model of a magnetic field representing ‘the lines of magnetic force in the neighbourhood of a globe of soft iron in a uniform magnetic field’[45]



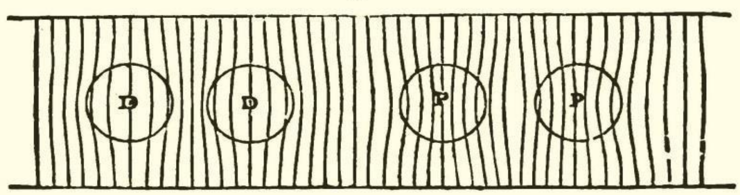
By 1850, Faraday was using the same graphic model for representing similar magnetic phenomena, namely the opposite effects diamagnetic and iron balls have on a magnetic field as it can be appreciated in the figure 1.20 below.

[45] *Ibid*., p. 491.

Figure 1.10. Model of a magnetic field affected by iron and diamagnetic ball[46]

The diamagnetics ought to separate, for the field is stronger in lines of magnetic force between them than on the outsides, as may easily be seen by considering the two spheres D D in fig. 6; and therefore this motion is consistent, and is in accordance generally with the opening or set equatorially, either of separate portions or of a continuous mass of such substances (2829.), in their tendency

Fig. 6.



to go from stronger to weaker places of action. On the other hand, the two balls of iron, P P, have weaker lines of force between them than on the outside; and as their tendency is to pass from weaker to stronger places of action, they also separate to fulfil the requisite condition of equilibrium of forces.

By comparing Maxwell's vortex-idle wheel model (Figure 1.5.) to the magnetic field models of Faraday and Thomson, it is possible to appreciate a sharp and clear meaning shift from a semantics of contiguous action based on the mechanical action of subtle matter, to a semantics of contiguous action based on the non-mechanical action of force fields. Faraday was aware of this for he expressed how difficult it was to make sense of distinct nature of the lines of force, and how they would act without a medium.

Faraday and Thomson's models are examples of *minimal analogies*, where the similarities with the Newtonian mask are minor; they relied on a minimal mechanical analogy represented mainly by presence of balls of different kind affecting the field. The remaining part of the models is nonmechanical, and therefore

[46] M. Faraday (1851), pp. 211-212; #2831; see also p. 208; #2831; p.204; #2807 for more examples of the same kind of model.

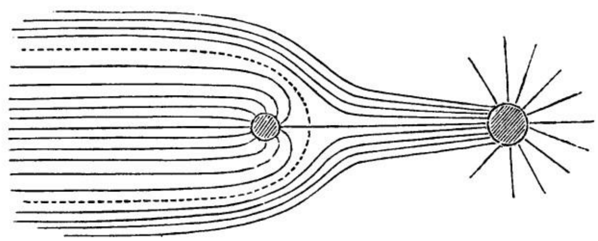
it constitutes a disanalogy. The minimal analogy was a road to scientific progress in the construction of a new supertype and its respective hierarchy with types and subtypes. In contrast, Maxwell's model is mechanical it all its details, and therefore it exemplifies a maximal analogy. In spite of the mathematical progress Maxwell made using the vortex-idle wheel model, it was ontologically regressive because it relied on an ontology of aethers already superseded by Faraday. Maxwell knew Faraday's work but he decided to continue working within the Newtonian paradigm, and he actually tried to reconcile the magnetic lines of force with the action of a gravitational aether.

On 9th November 1857, Maxwell wrote a letter to Faraday, where he put forward a definition of gravitational force as a 'pushing force' stemming from the sun and from each planet. The crucial difference between the two was the status of force fields as extended non-mechanical separate entities, where massive bodies are *placed into* versus extended non-separate mechanical entities being *emitted* by those bodies. In his letter, Maxwell drafted the following basic graphic model:

Figure 1.11. Lines of force of gravitational aether:[47]

> The lines of Force from the Sun spread out from him, and when they come near a planet *curve out from it,* so that every planet diverts a number depending on its mass from their course, and substitutes a system of its own so as to become something like a comet, *if lines of force were visible*.

[47] P. M. Harman (1990), pp. 548-552. In Queries 21 and 22 (*Opticks*, 1717, pp. 325-327), Isaac Newton had speculated on the composition and operation of the gravitational aether, which he thought was made of small particles; the impulses of a stream of these particles bombarding the planets would cause gravitation. This gravitational aether would be denser in empty space than in the vicinity of planets or any other massive body. Hence, the Earth moves towards the Sun under the pressure of the aether, like a cork rising from the depths of the sea.



> The lines of the planet are separated from those of the Sun by the dotted line. Now conceive every one of these lines (which never interfere but proceed from sun and planet to infinity) to have a *pushing* force instead of a *pulling* one, and then sun and planet will be pushed together with a force which comes out as it ought, proportional to the product of the masses and the inverse square of the distance.
>
> The difference between this case and that of the dipolar forces is, that instead of each body catching the lines of force from the rest, all the lines keep as clear of other bodies as they can, and go off to the infinite sphere against which I have supposed then to push.

Compare this model to Faraday's model above (Figure 1.10). The lines of force in both act in a similar fashion by expanding and contracting, but the explanation of such effects and the nature of those lines, makes the difference between a Newtonian model and Faraday's model. Faraday responded rapidly to Maxwell, first in a letter written on 13th November, and later in an addendum he published in June 1858, where he criticised him for turning magnetism into a 'mechanical force'.[48] He makes a clear statement writing that 'I do not use the word "force" as you define it, "the tendency of a body to pass from one place to another" […] such a thought, if accepted, pledged them [experimental physicists] to a very limited and probably erroneous view of the cause of the force, and to ask them to consider whether they should not look (for a time, at least), to a source in part external to the particles.'[49]

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[48] M. Faraday (1858), p. 460.

[49] B. Jones (1870), pp. 390-391; letter from Faraday to Maxell from 13th November 1857.

Maxwell's model of the lines of gravitational force and his vortex idle-wheel model actually complement each other. The first model makes the lines of gravitational force visible by zooming into the actual shape and pathways followed by those lines, the second model zooms in even further to make the actual micro-composition and operation of the lines of magnetic force visible. In both cases mechanisms described with different degrees of detail are offered as explanations of gravitational and magnetic forces. We can assume that a Maxwellian microscopic model of the gravitational aether would be similar to the vortex idle-wheel model, perhaps also with wheels and vortices or similar mechanical parts.

The contrast shown between the models of Faraday and Thomson, and those of Maxwell demonstrates the need for a mixed methodology with both kinds of analogy, namely minimal and maximal analogies. Hesse's inference from analogy is a case of maximal analogy because it prescribes a choice for models with greater similarity; this type of inference can therefore be renamed as *inference from maximal analogy*. I am arguing for a second type, which can be called *inference from minimal analogy*. The same half-Bayesian justification Hesse produced for the inference from maximal analogy could be used for the inference from minimal analogy, which is best represented here by the Faraday's models of force fields and the ontology underpinning them.

I argue that mixed methodology responds better to the demands from type-hierarchies and meaning shifts as they are advanced by Eileen Way. On the one hand, a methodology relying on maximal analogies like that of Hesse is at risk of becoming not only conservative but also regressive, or at least recessive, like Maxwell's models of the electromagnetic and gravitational aether show. A methodology that also includes inference from minimal analogies provides the grounds for scientific progress as it has shown with Faraday and Thomson's models.

On the other hand, there is a greater risk of failing with any inference from a minimal analogy; progressive rules often carry greater risk. Conservative inferences from maximal analogies are less risky. Hence, only the use of both analogies along different scientific communities or individuals provides both protection against failure building up a type-hierarchy and protection against ontological regression, where new semantic masks and new supertypes are not developed further and more rapidly. The exclusive use of one kind of analogy would be a methodological mistake just as it would also be a mistake to use both undermining the advance of one of them; the right science policy should ensure opportunities of equal progress.

For nearly a century, the scientific labour and the theories produced by Faraday, Thomson and Maxwell show how *de facto* scientists on the whole were following a mixed methodology pursuing minimal and maximal analogies. This thesis can be extended to the work of Lorentz and Einstein. A philosophical justification provides such labour and its products with *de jure* grounds, not only to episodes from the past but also to current scientific research. It meets the needs for the construction of type-hierarchies both in normal and revolutionary science. Only the justification of a mixed strategy can provide both protection and progress as well as guidance on science policy.

4. METAPHOR

Currently, there is only a thin bridge connecting the Mechanical view with the social sciences, and there is no comprehensive account either on how this view can be applied to those sciences. The main aim of this work is to enlarge the bridge and lay some initial grounds for such an account. I introduce the machine metaphor by relying on the work from Nancy Cartwright on socioeconomic machines. I use the term ‘social machines’ instead of ‘socioeconomic machines’ for referring to any state institution, firm or farm. I show how the machine metaphor is an escalation from a mechanical metaphor based on natural forces to a mechanical metaphor based on artefacts, which implies an ontology of artefactual institutions and artefactual behaviour brought about by design and engineering. This is in contrast to an ontology of traditional institutions and traditional or customary behaviour. Besides this distinction, three methodological principles of blueprint making are discussed as well as two related ontological theses on realism of capacities and individualism. Such principles and theses belong to the work from Cartwright on socioeconomic machines; they are illustrated with a game theory model on debt contracts produced by the economists Oliver Hart and John Moore. The main aim of this section is to introduce and build up an insightful and fruitful discussion of the machine metaphor to be used as the foundation for a methodology of design and engineering in the social sciences.

- Mechanism design theory
- Analytical sociology
- Institutional design

The knowledge and postulation of mechanisms are distinctive of the Mechanical view. All mechanical models theoretical or observable describe a causal mechanism responsible for certain effects. There are two fundamental features of mechanisms as they are introduced by the Mechanical view. The first one requires continuous physical contact between all the entities and effects involved. That is to say, action at distance is avoided. Newtonian mechanics is a canonical example of this, where theoretical entities and mechanisms such as the luminiferous aether and the corpuscular theory of light were postulated. The second one is a widely shared realist belief in causal powers.

The Mechanical view is itself a metaphor, which has expanded into scientific and philosophical domains where causes and mechanisms are used metaphorically. The work of Donald Davidson in the philosophy of mind and action, and that of Daniel Little in explanation in the social sciences are examples.[50] In the social sciences, mechanism design theory, an important branch in game theory, constitutes another outstanding example, where the term ‘mechanism’ has been introduced with a clear metaphorical sense. Mechanism designers devise specific rules, incentives and penalties, which together bring about certain behaviour. However, it is not entirely clear the kind of physical interaction existing between the presumed causes, the mind and the observed behaviour. In spite of this, the work of Davidson and mechanism design theory is a clear example of the success of metaphors in philosophy of mind and science.

Other terms such as inflation, deflation, depression and boom used in economics also have a metaphorical meaning. Besides mechanisms, functionalism is an example of another successful metaphor widely used in anthropology and sociology. Evolutionary game theory represents another well-established twofold metaphor in the social sciences, where among others terms like ‘dove’ and ‘hawk’ are widely used describing the profiles of different individuals portrayed as players. These examples show that metaphors are not a few only having an accessory character; there are many of them playing a fundamental role also in the social sciences.

[50] D. Davidson (2001); D. Little (1991).

In contrast, in the natural sciences the use of mechanisms is often considered to be literal and real. It is believed that nature is composed of mechanisms, that is, of causes responsible for all things we see happening. This seems obvious and in principle difficult to challenge; the many successes of science predicting and intervening in nature seem to prove the reality of causes and mechanisms as well as the literality of the related descriptions. However, even here metaphors can be found in some of the most fundamental concepts.

The use and the role of metaphor in science has been a very important contribution made by Rom Harré to the Mechanical view. He explains that models, metaphors and analogies are needed when 'we have reached the limits of discernible mechanisms'.[51] While some analogies and models can be built using literal language, metaphorical terms are often required when no adequate concept or description is available. Thus metaphorical terms and analogies meet in a model at the borders of scientific discovery, conceptual change and scientific revolutions. James Maxwell's vortex-idle wheel model of magnetic force, and the billiard balls model of gas molecules are examples of such models.

In Positivism, the meaning of any theoretical terms could only be decided upon by the observable effects; no speculation on the specific nature and inner workings of unobservable mechanism and entities was otherwise acceptable. Harré demonstrates how the observational language accepted by Positivism actually contains metaphorical terms, whose meaning ultimately relies on the terms and procedures taken from another scientific branch. For example the term 'current' in electro-dynamics pictured as a flow of electrons cannot be fully defined with reference to the different readings observed on an ammeter from a simple circuit,

[51] R. Harré (1960), p. 105.

‘because as it is used in electro-dynamics it carries with it an accretion of meaning derived from its use in hydro-dynamics, where it could be effectively taught before a flowing or running stream. Hence the term 'current' is metaphorical carrying with it into the description of the phenomena encountered in electrical circuits some of the force it had in its original p.c.p.’[52]

Besides the term ‘current’ other fundamental terms in physics are also metaphorical such as ‘force’, ‘field’, ‘repulsion’, ‘conductor’, ‘wave’, ‘packing fraction’ and ‘strangeness’. Generally, the metaphorical meaning of scientific terms goes unnoticed because ‘the tradition in philosophy of language and science is that language is intrinsically literal in nature. Literal meaning is considered to be the standard and normal use of words, and it is the meaning that words possess independently of when and how they are used.’[53] This is an important observation, without it the widely shared belief that science provides literal descriptions of nature and society would persist and remain unchallenged. In science metaphorical terms ‘are *picture-carrying expressions*. When we describe an electrical discharge ('discharge' is an M-term too) in a gas as the passage from a current, we are inviting ourselves to picture something flowing of which incandescence, for instance, is an effect.’[54] Therefore, figurative language is not anymore exclusive to art but it also is a systematic component of science.

The *comparison view* of metaphor explains figurative meaning by relating it to a primary literal meaning. For instance, the term ‘electrical current’ is metaphorical because it can be related to the literal description of clusters of

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[52] R. Harré (1960), p.112; he explains that ‘a term has been defined with reference to a *paradigm case* (p.c.) if it *could have* been introduced by ostension. The paradigm case will be that to which we could have pointed in introducing the term, and the whole method of introduction I shall call a *paradigm-case procedure* (p.c.p.)’, p. 111.

[53] R. Harré, J. L. Aronson, E. C. Way (1995), p. 96.

[54] R. Harré (1960), p. 112.

molecules of a fluid like water moving along a canal. Harré criticises Norman Campbell and Ronald Giere for implicitly holding this view, when they use analogy and similarity in their philosophical accounts of models and scientific theories. He argues instead for the *interactive view* put forward by Max Black with an application to language in general, that is to say, without a special focus on science. Unlike the comparative view, this view does not assume that literal meaning remains as the fixed foundation upon which metaphor is explained. The introduction of metaphors rather shakes those foundations by creating new meanings, which affect any related literal meaning; Black points out that 'it would be more illuminating… to say that the metaphor creates the similarity than to say that it formulates some similarity antecedently existing.'[55]

Mary Hesse also criticised the comparison view and adopted the interactive view of metaphor, applying it to science. She explains that the interactive view accounts for the mutual affectation of both literal and the metaphorical language producing a 'shift in meaning', and a 'postmetaphoric' sense. For instance, with the metaphor 'Man is a wolf', 'men are seen to be more like wolves after the wolf-metaphor is used, and wolves seem to be more human.' And with any mechanical metaphor 'nature becomes more like a machine in the mechanical philosophy, and actual concrete machines themselves are seen as if stripped down to their essential qualities of mass and motion.'[56]

Harré agrees with this mutual affectation and believes similarity is created by choosing to relate two or more objects, rather than being there preceding the metaphor. However, he holds that the comparative view remains 'vague', at least in its application to scientific language, because 'it is not clear how the interaction or

[55] M. Black (1962), p. 37; see also (1993), p. 35.
[56] M. Hesse (1965), p. 254.

filtering is to occur, nor how similarity can be created where none was seen to exist before.' [57] He calls this 'the problem of principled filtering of positive from negative analogies.' And he also rejects Hesse's thesis on the logical priority of metaphor, which states that 'metaphor properly understood has a logical priority over the literal, and hence that natural language is fundamentally metaphorical, with the "literal" occurring as a kind of limiting case'[58] In other words, she inverts the order by placing metaphor as a more fundamental form of speech.

Besides these two problems, Harré also identifies another problem with the use of bare similarity as the kind of relationship models hold with the world, and as the criterion to be used for defining metaphor. Ronald Giere places bare similarity as the criterion needed for evaluating the empirical significance of models by claiming that 'the notion of similarity between models and the real system provides a much needed resource for understanding approximation in science. For one thing, it eliminates the need for a bastard semantical relationship—approximate true.'[59] Giere says that such a basic notion could be refined by adding 'degrees' and 'respects' of similarity, however he does elaborate this claim further showing how this can actually be done. Harré believes this notion of similarity is too basic for models because it does not tell us if it is a symmetric or a transitive, and also because it 'is not rich enough to give us a ranking of models in terms of which are better approximations […] The notion of similarity is doing too much of the work in Giere's theory; and similarity is too complex and difficult a notion to leave as unanalysed primitive.'[60]

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[57] R. Harré, J. L. Aronson, E. C. Way (1995), pp. 105, 96-97.
[58] M. Hesse (1993), p. 56.
[59] Giere (1988), p. 106
[60] R. Harré, J. L. Aronson, E. C. Way (1995), pp. 94-95.

In sum, Harré identifies three outstanding related problems on metaphor and analogy; and I am adding the fourth on the list, which is the logical problem of analogy discussed in the previous section:

1) *Priority*: the problem of establishing the logical priority of metaphorical or literal language.
2) *Salience*: the problem of filtering positive from negative analogies
3) *Triviality*: the problem of distinguishing trivial from non-trivial analogies
4) *Inference*: the problem of justifying the likelihood of a prediction or an explanation based on an analogy.

Harré argues that an ontology of types organised in hierarchies can provide a solution to the first three problems, and I am also evaluating such hierarchies against the inference from analogy.

5. THE MACHINE METAPHOR

James Maxwell produced a fully mechanical model of magnetic force mainly based on natural forces adding one component only from a machine, namely an idle wheel. Nancy Cartwright extends this view creating a *machine metaphor* of both nature and society. Nature and society are seen as an array of steady machines producing regular outcomes, and each of these machines consists of an array of separate parts assembled into mechanisms under the guidance of a blueprint.

Maxwell described the solar system as fully mechanical with no fields but with gravitation conceived as a pushing force, whose microscopic model would have contained parts similar to the wheels and vortices of the electromagnetic aether. Natural mechanical forces largely define his models and, in spite of having an important role, artefactual mechanical effects are small in proportion. Cartwright also sees the solar system as mechanical but she escalates the Mechanical view by creating a metaphor entirely based on artefacts, that is to say, on machines, which she calls *nomological machines*. A nomological machines is 'a fixed (enough) arrangement of components, or factors, with stable (enough) capacities that in the right sort of stable (enough) environment will, with repeated operation, give rise to the kind of regular behaviour that we represent in our scientific laws.'[61] Using the laws of Kepler, she explains how the nomological machine metaphor works.

Based on the astronomical data on Mars gathered by Tycho Brahe, Johannes Kepler established the following three laws of planetary motion: i.) The orbit of every planet is an ellipse with the Sun at one of the two foci, ii.) The line joining a planet and the Sun sweeps out equal areas during equal intervals of time, and iii.) The square of the orbital period of a planet is proportional to the cube of the semimajor axis of its orbit. Later, Isaac Newton postulated a gravitational force and established the magnitude of such force required to keep a planet in such elliptical orbit with a constant speed. Generally, the laws of Kepler and Newton are presented as examples of regularities with no further explanation on how they arise. The machine metaphor provides an answer to this question by postulating *capacities*. This is done by figuring out 'the nomological machine that is responsible for Kepler's laws—with the added assumption that the operation of the machine depends entirely on the mechanical features and their capacities. This means that we have to establish the arrangement and capacities of mechanical elements, and the

[61] N. Cartwright (1999), p. 50.

right shielding conditions that keep the machines running properly, so that it gives rise to the Kepler regularities.'[62]

Hence, the machines that give rise to natural laws like those of Kepler consist of three main parts, namely capacities, the specific assembling of them, and the provision of a shield for protection. More specifically, this means a realist belief in a gravitational force as a capacity or causal power existing in each planet and other massive bodies in the solar system; knowledge of the joint effects of this capacity from massive bodies of different size placed in different positions; and knowledge of events which can affect or prevent isolated or joint effects of the gravitational forces in operation. The philosophical choice for capacities constitutes a radical departure from empiricist standards, which ultimately relies on the cogency of a realist argument.[63]

The joint effects of gravitation for any set of known planets and massive bodies can be calculated reliably by using Newton's laws and equations. Knowledge of the presence of new planets or potential colliding objects such as asteroids and comets, which can affect the running of the solar system as a machine, can only be obtained gradually and normally *a posteriori* when a distortion has already been observed. This affects the scope and power of the shielding conditions. Cartwright accepts this limitation explaining how the discovery of a new planet as an 'observed irregularity points to a failure of description of the specific circumstances that characterise the Newtonian planetary machine. The discovery of Neptune results

[62] Ibid., p. 50.

[63] In *Nature's Capacities and Their Measurement* (1989), Nancy Cartwright has produced such a realist argument for capacities.

from a revision of the shielding conditions that are necessary to ensure the stability of the original Newtonian machine.'[64]

In this way, the nomological machine metaphor is employed also for philosophical purposes. It works as a mask, exhibiting new features of scientific theories and scientific explanation, which remain hidden under the Syntactic view. Under this technological metaphor, any scientific laws only holds relative to the operation of a nomological machine, which comprises a number of parts assembled under the right plan or blueprint as well as a protective shield, and further ceteris paribus conditions. All these elements remain unnoticed under the regularity view of scientific laws. With the Mechanical view, Kepler's laws and any other natural law arise as the product of different nomological machines. Scientific explanation ceases to be guided by the covering-law model, and theories become collections of models of nomological machines. Nature consists of a big array of nomological machines.

The metaphor also extends to the state, markets and society. Economic and political institutions as well as contracts among individuals are also seeing as technological artefacts. Society as a whole becomes an array of nomological machines, which Cartwright calls *socioeconomic machines*, while theories in the social sciences become collections of models on those socioeconomic machines. This is the Mechanical view escalated from natural mechanical forces to artefactual ones now being extended to society and theories in the social sciences.

As Nancy Cartwright advances it, the Mechanical view applied to the social sciences consists of five explicit methodological principles, and three ontological theses. In this section, only the first three principles and the first two theses are

[64] N. Cartwright (1999), pp. 52-53.

discussed, the remaining two principles and single thesis are discussed in the next section. The first three principles establish that any model of a socioeconomic machine must show:[65]

i) The parts that make up the machine, their properties and the separate capacities.

ii) How the parts are to be assembled.

iii) The rules for calculating the outcome from the joint operation of the assembled
parts.

To illustrate these methodological principles, Cartwright uses an example from game theory applied to long-term debt contracts. In particular, the model of a 'repudiation-proof contract' produced by the economists Oliver Hart and John Moore. Seen as socioeconomic machines, investment contacts must function steadily by producing regular outcomes, which depend on the knowledge game theorists have on the individual players and their capacities as well as knowledge of the different expected outcomes from their mutual interaction. In this case, the regular expected outcome consists of a timely delivery of credits from the investor, and the accomplishment of business targets by the entrepreneur until the full completion of the project.

In the model, Hart and Moore describe the parts of the machine and the capacities of those parts, namely two individual players an investor and an entrepreneur, both displaying specific psychological capacities. These consists of

[65] *Ibid.*, p. 146.

self-interest, greed, perfect and costless calculation, and full rationality. It is also assumed that the entrepreneur has a special capacity consisting of particular skills relevant to the project, which are not easily and costlessly replaceable. Because of this, he enjoys greater bargaining power. Other parts are structural or external to both players such as identical discount rates, certainty in all operations, rules for renegotiation, and the existence of a frictionless second-hand market for the physical assets of the project.[66] The structural parts and the players are assembled in one game in two main stages, one with an initial negotiation and agreement on a certain distribution of the surplus, and a second one when repudiation of the contract occurs and the surplus is now divided in equal parts of 50% each.

Long-term debt contracts pose particular challenges. One of these challenges arises from the opposite repayment preferences between the investor, who prefers a fast repayment, and the entrepreneur, who prefers a slow repayment. This tension increases when opportunities for outside investment of capital or skills exceed the returns of the current project. This leads to greed, selfinterest and defection from each player a real possibility. From a social perspective, Hart and Moore wanted to prevent these contracts from failing because of the social losses and inefficiencies that failure creates. The challenge consisted of reversing the repudiation of the contract by devising a set of new rules, which would create opportunities for negotiations available to both players, so that the project is not abandoned but completed. Easy and costless defection must be prevented, while the conditions for renegotiation must keep returns attractive to both players.

[66] O. Hart and J. Moore (1994); the analysis from Cartwright is based on an earlier version of this article published in 1991 as Discussion Paper No. 129 by the LSE Financial Markets Group.

They devised a mechanism by relying on the assumptions of certainty and a continuum of optimal points during the renegotiation period, they explain that 'the assumption of perfect certainty, combined with that of renegotiation, implies that there is a continuum of optimal debt contracts', which implies that ' the parties can write a succession of short-term contracts that are renegotiated, or a long-term contract that is never renegotiated along the equilibrium path', and therefore 'a debt contract can be agreed to such that in equilibrium *D* [debtor/ entrepreneur] never repudiates.[67] Recall that in the model the entrepreneur enjoys greater bargaining power. With those two assumptions, the calculation of the joint effects after repudiation is made by using equilibrium theory using specific rules for renegotiation, and by relaxing the assumption of a common discount rate, while the capacities of self-interest, greed and rationality remain the same for each player. In this way, Hart and Moore's repudiation-proof contact illustrates the three methodological principles any model of a socioeconomic machine should follow.

Besides those three principles, Cartwright adds two important ontological theses on socioeconomic machines:

i) Realism of capacities.
ii) Ontology of individuals.

Against empiricist standards, Cartwright argues for a realist belief in unobservable capacities, which she also called 'natures' following Aristotle. Natures or capacities of individuals cannot be reduced to the constant conjunction of two or more episodes of observable behaviour. We should also add that they should not either be considered as having the instrumental status of convenient fictions used only for explaining observable behaviour, nor should they be

[67] Hart and J. Moore (1994) pp. 842, 849.

considered as the product of an inference to the best explanation of observable behaviour in the absence of alternative better explanation. The realist thesis is stronger than instrumentalism and the inference to the best explanation because it holds 'natures as primary and behaviours, even very regular behaviours, as derivative.'[68]

Although, the realism of capacities or natures enjoys better prospects in experimental and behavioural economics, Cartwright argues for it using models and examples from game theory. The contrast between realist and antirealist standards in the social sciences can be clearly observed in the controversy between cognitive psychology and behaviouristic psychology, and between utility theory and preference revealed theory in economics. Adopted as a thesis for socioeconomic machines, the realism of capacities justifies and prescribes the use of psychological capacities as the ultimate explanation for any expected or any observed behaviour.

Against a holism of social facts or social structures, Cartwright argues for individuals and their capacities as the ultimate grounds for explanation in the social sciences. Using the science of economics as an example, she explains that this thesis 'is based on the hope that we can understand aspects of the economy separately and then piece the lessons together at a second stage.'[69] This thesis is both ontological and methodological for she explains that 'the analytic method works in physics: to understand what happens in the world, we take things apart into their fundamental pieces, to control a situation we reassemble the pieces, we reorder them so they will work together to make things happen as we will.'[70]

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[68] N. Cartwright (1999), p. 149; earlier (1989, p. 9) she chose the term 'capacities' over 'causal powers', currently she believes 'natures' is a better term: 'most of my arguments about capacities could have been put in terms of natures had I recognised soon enough how similar capacities, as I see them, are to Aristotelian natures.' (1999, p. 85); see also N. Cartwright and J. Pemberton (2013).
[69] N. Cartwright (1999), pp. 149-150.
[70] *Ibid*, p. 83

Ontologically and methodologically, individualism is widely accepted, and used in economics and all branches of game theory including mechanism design theory. In contrast, individualism has been abandoned in political science, particularly in institutional design, while it has been strongly vindicated in analytical sociology. Mechanism design theory, institutional design and analytical sociology are discussed later.

The machine metaphor helps to meet two important scientific tasks, namely the explanation of actual states of the world and the design of new ones. The work of Cartwright addresses both: first through the ontological description of the components of actual socioeconomic machines, and second through the establishment of methodological principles for the blueprints of those machines. The machine metaphor implies a transition from natural systems, natural laws and traditional institutions to constructed laws, systems and institutions. Thus, the solar system, the Roman Senate and the International Monetary Fund become machines just like a bulldozer, a microprocessor or a blender. Natural laws like those of Kepler and economic relations of trade are seen as artefactual just as the flow of electrical currents in a microprocessor. Cartwright writes, 'here it is my strong claim: look at any case where there is a regularity in the world (whether natural or constructed) that we judge to be highly reliable and which we feel that we understand […] what you fill find is a nomological machine.'[71]

Therefore, the three principles and the two ontological theses, which have just been discussed, apply to both traditional and constructed institutions as well as traditional and constructed social relations. Game theory models can be models of any traditional institution or social relationship but they can also be models of

[71] *Ibid.*, p. 58.

constructed institutions and social interactions. Unlike Cartwright, I use the term 'constructed' exclusively for artefacts produced with the help from scientific designers and engineers, and I use the term 'traditional' instead of the term 'natural' for any institution or social relation, where no scientific design or engineering has be used. Unlike the term 'natural', the term 'traditional' in the social sciences seems to be accurate, and it also creates a sharper contrast with 'constructed' or 'designed'.

The model from Hart and Moore belongs to those models describing a constructed regularity, that is to say, the model is a blueprint for replacing a traditional or customary type of behaviour, namely the repudiation of debt contacts with a new constructed or artefactual behaviour, namely the ability to renegotiate contracts until the completion of a project. In this way the metaphor of the socioeconomic machine, and the related principles and ontological theses, apply to constructed or designed contracts and institutions. In contrast, debt contracts with no design rely on trade traditions inherited through generations of bankers and traders, so the rules of those contracts are the product of learning across generations without the help from game theorists or social scientists in general.

The repudiation of contracts certainly is an important social problem, and a lasting efficient solution that can benefit all parties involved without creating social losses is not easy to find. Traders and bankers can continue relying of their own means and experience for solving the problem but they can also seek help from social scientists. The use of science is what distinguishes tradition from construction, traditional from designed and natural from artefactual. More precisely, the science to be used is a science of design, whose main task is the production of blueprints.

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