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Technological metaphors and history of science

(1) Introduction

Although metaphors have been studied for over 2000 years, a precise definition of the word has been notoriously difficult to do. Bailer-Jones has defined it as follows:

> A metaphor is a linguistic expression in which at least one part of the expression is transferred [...] from one domain of application (source domain), where it is common, to another (target domain) in which it is unusual, or was probably unusual at an earlier time when it might have been new. [1]

However, the definition does not specify the relationship between the source domain and the target domain. Gentner has distinguished between three possibilities. First, metaphors can be relational comparisons, that is, they convey that source domain and target domain share a common relational structure. For example, "atom is a solar system". Second, metaphors can be attribute comparisons, for example, "Mike is a giraffe" is used to convey that Mike and giraffe share the attribute "tall". Third class of metaphors consists of such complex metaphors as "the voice of your eyes is deeper than all the roses". These metaphors are characterised by many cross-weaving connections without a clear way of deciding exactly how the source predicates should attach to the target.[2]

According to traditional view, metaphors are rhetorical or poetic devices. However, nowadays it is widely accepted that some metaphors can be employed as "cognitive instruments". In particular, relational metaphors can present insight into, so to speak, "how things are". In this respect, they are closely linked to models and analogies.

When we use metaphors as cognitive instruments, we attempt to understand and explain the unknown (i.e. target domain) with the known (i.e. source domain). These metaphors can be classified with the help of their source domain.

First, the source domain can be the physical world, that is, living organisms and nonliving material objects. This kind of metaphor is very common in philosophy and science. For example, "electron is a wave" in physics or "tree of life" in the theory of evolution.

Second, the source domain can be the world of mental states, that is, the world of subjective or personal experiences. This kind of metaphor is uncommon. For example, pre-Socratic philosopher Empedocles believed that all matter in the cosmos is made of the four elements, but he added two diametrically opposed cosmic principles. "Love" is the uniting force that attracts all things, thereby creating something new. "Strife" is the dividing force that separates and destroys things. In contemporary particle physics, quark has a "colour".

Third, the source domain can be the realm of social relations, institutions, and structures. For example, in Plato's *Theatetus*-dialogue Socrates presents himself as a sort of "intellectual" midwife. In the same way as an ordinary midwife guides the soon-to-be mother through a complicated process of childbirth, a "philosophical midwife" directs the pupil through the difficult process of philosophical education. Both processes involve crucial moments at which all can be lost without the intervention of the midwife. A chaperone is a person who accompanies and supervises a young woman or gatherings

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[1] D. Bailer-Jones, "Models, Metaphors, and Analogies", in: P. Machamer and M. Silberstein (eds.), *Guide to the Philosophy of Science* (Oxford: 2001), p. 114.

[2] D. Gentner, "Viewing Metaphor as Analogy", in: D.H. Helman (ed.), *Analogical Reasoning* (Dordrecht: 1988), pp. 171–173.

of young people. In modern biology, “molecular chaperone” is a protein whose function is to ensure that the folding of certain other proteins occurs correctly.

Next, the source domain can be the abstract product of the human mind, for example, scientific concepts and theories. In *Timaeus*, Plato attempts to explain the interaction between four elements with the help of geometrical metaphors. He argues that the particles of air, water, earth, and fire are constructed from regular solids. A particle of fire is a tetrahedron, a particle of air an octahedron, a particle of water an icosahedron, and a particle of earth a cube. The shapes and sizes of these geometrical figures are linked with their physical qualities: for example, the destructive power of a fire pyramid is connected to its sharp angles and sides. The notion “DNA is a code” changed fundamentally the way life was understood in the latter part of the 20th century. Finally, the source domain can be technology, for example, “mind is a digital computer”.

According to Max Black, metaphors can be employed as instruments for drawing implications grounded in analogies of structure between two subjects belonging to different domains.[3] Consequently, metaphors have two important roles in scientific thought. First, they introduce terminology where none previously existed. It is noteworthy that concepts are not introduced one at a time but as frameworks of concepts. It is a question of analogical transfer of vocabulary from the source domain to the target domain. In other words, metaphors provide a structured framework for interpreting and understanding a domain of unfamiliar or novel phenomena.

At the same time, metaphors can sometimes contribute to the substance and structure of philosophical and scientific theories. When we employ metaphors, we are attempting to understand and explain the unknown with the known. One could say that the unknown is “seen through” the known. According to Black, a metaphor suppresses some details, emphasizes others — in short, it organizes our view of the unknown thing or phenomenon.[4] In this respect, the choice of source domain matters. Metaphors derived from different source domains provide different kinds of conceptual frameworks.

The second role of metaphor is to produce new topics for research. In other words, statements concerning the source domain can be translated into hypothesis concerning the target domain. With the help of metaphors, scientists can formulate hypotheses, which can be tested empirically and experimentally. This has been characteristic of the use of metaphors in modern experimental science.

Technology has been one of the most important source domains of “insightful” metaphors. In particular, I want to emphasise the role of artefacts, that is, any object made, modified, or used by people. First, we have a very thorough knowledge of artefacts, that is, a maker’s knowledge. As a result, they are very useful in the attempt to explain the unknown with the known. Second, the struc-ture and function of artefacts is unambiguous. Thus, they provide a clearly structured conceptual framework for the interpretation of unknown phenomena. Third, as technology advances, new artefacts are constantly invented. These artefacts can be employed as new and possibly insightful metaphors in science. As a result, scientists have used different kinds of technological metaphors in different ages.

The level of technological development has imposed limitations on the use of technological metaphors. The level of technology has made possible certain kind of artefacts, which, in turn, have created the possibility to employ these artefacts as metaphors. Many different kinds of artefacts exist. Mitcham has distinguished between utensils (e.g., baskets and pots), clothes, structures (e.g., houses), apparatus (e.g., dye vats and brick kilns), utilities (e.g., roads and reservoirs), toys, tools of doing or performing (e.g., numbers and musical instruments), objects of art or religion, tools, machines, and automata.[5] In the history of science, some of these artefacts have been more important as metaphors than others have been. In particular, I want to emphasise the importance of machines and automata. That is to say, both machines and automata can be described in terms of mathematical relations among their component parts. When using a machine or automaton metaphor, these mathematical relations can be transferred from the source domain of technology to the target domain of physical world. As a result, the unknown natural phenomena can be subjected to quantitative description.

[3] M. Black, “More About Metaphor”, in: A. Ortony (ed.), *Metaphor and Thought* (Cambridge: 1979), p. 39.

[4] M. Black, “Metaphor”, in: M. Black, *Models and Metaphors* (Ithaca: 1962), p. 41.

[5] C. Mitcham, *Thinking Through Technology: The Path Between Engineering and Philosophy* (Chicago – London: 1994), pp. 162–163.

It was no accident that the rise of the mechanical philosophy was closely associated with the rise of experimental science and the so-called “quantitative method”. The observable phenomena of the natural world were to be explained in terms of hidden mechanisms, and the structure and function of these mechanisms could be described in a quantitative manner.[6]

(2) William Harvey’s use of metaphors

Next, I shall discuss William Harvey’s (1578–1647) use of metaphor in two of his works. The first, the *Exercitatio anatomica de motu cordis et sanguinis* (1628) is one of the greatest contributions to physiology, for it introduces the theory of the circulation of the blood. The second is *De motu locali animalium* (c. 1627), that is, Harvey’s incomplete manuscript on animal movement and the structure of muscle in general. Harvey’s work on animal movement has received little attention among historians of science. It contains little that can be called original. It is mostly a compilation of the views of Aristotle, Galen and Harvey’s teacher Fabricius. Moreover, it was a failure. Harvey never published the manuscript.

However, I still believe that the study of the *De motu locali* can provide some interesting historical insights. In particular, it provides further information about Harvey’s use of metaphors. Moreover, I believe that the failure of the *De motu locali* throws some additional light on the success of the *De motu cordis*, that is, on the discovery of the circulation of blood. I shall argue that Harvey’s choice of source domain of metaphor was critical to his success in the *De motu cordis* and failure in the *De motu locali*.

There have been two main trends in Harvey scholarship. On the one hand, Harvey has been seen in the context of mechanical philosophy. On other hand, it has been argued that Harvey’s research was guided by the Aristotelian tradition, and, furthermore, Harvey’s thought was influenced to some degree by the Renaissance natural magic tradition. The latter view is nowadays the dominant one, and the difference of opinion concerns the exact nature of Harvey’s Aristotelianism.

One aspect of the influence of the Aristotelian tradition and the Renaissance magical tradition is Harvey’s use of notions of microcosm and macrocosm. The idea connected with the notions of microcosm and macrocosm is the ancient Greek belief that an identity exists between the universe and the individual human being. The macrocosm is the universe as a whole whose parts are thought of as analogous to the parts of a human being. The microcosm is an individual human being whose parts are thought of as analogous to the parts of the larger universe.[7] The microcosm metaphor amounts to antropomorphism, that is, the attribution of human characteristics to nonhuman organisms and nonliving objects. In the macrocosm metaphor the source domain is the nonliving physical world and the target domain an individual organism.

(3) The macrocosm metaphor

Harvey uses the macrocosm metaphor both in the *De motu cordis* and the *De motu locali*. In the *De motu locali* he compares the animal body to the Pythagorean concept of the universe:

> Nature performs her works in animals by the power of the muscles and attains her end by means of rhythm and harmony. Thus Aristotle says. It will appear that through godlike power truly in the heaven there is a pursuit of the delectable and the lovable by harmony and rhythm of movement of which we have no more perception than a dog has of music.[8]

The main concepts of the “cosmic harmony” metaphor are rhythm and harmony. According to the Pythagorean concept of cosmic harmony, the cosmos is put together by means of laws of musical harmony. Thus, the cosmos produces, through the motion of celestial bodies, harmony and rhythm. Harvey claims that, similarly, the diverse movements of muscles produce the harmonious action of the animal body:

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[6] C. Craver C., L. Darden, “Introduction”, *Studies in History and Philosophy of Biological and Biomedical Sciences*, vol. 36 (2005), p. 236.

[7] G. Boas, “Macrocosm and Microcosm”, in: P. Wiener (ed.) *The Dictionary of the History of Ideas: Studies of Selected Pivotal Ideas*, vol. 3 (New York: 1973), p. 126.

[8] W. Harvey, *De motu locali animalium* (1627). Edited, translated and introduced by G. Whitteridge (Cambridge: 1959), p. 143.

> Just as divine Nature pursues an architectonic end making of diverse things one, of different things the same, by composing discords and making opposition to harmonize, so through diverse movements and uses and employments of the muscles are effected the works and actions of the body and of the parts. And so the actions are performed to effect movement by using the operations of the muscles in two ways: harmony and rhythm.[9]

In the *De motu cordis* Harvey compares the cardiovascular system to the weather cycle:

> We may call this motion [i.e. the movement of blood] circular in the same way in which Aristotle says that the air and the rain imitate the circular motion of the heavens. For the earth being wet evaporates by the heat of the sun; the vapours being drawn upwards condense and being condensed descend again in raindrops and wet the earth.[10]

The scheme of correspondence is as follows:

Sun	Heart
Earth	Body
Air	Arterial blood
Water	Venous blood
------	Arteries
------	Veins
------	Valves
Clouds	-------

The importance of the "weather cycle" metaphor has been emphasised in Harvey scholarship. It has been argued that Harvey used the conceptual framework provided by the "weather cycle" metaphor to interpret his complex anatomical observations. In other words, Harvey discovered the circulation of blood by drawing implications grounded in analogies of structure between the cardio-vascular system and the weather cycle.

However, if we start to draw the implications, it becomes apparent that this cannot be the case. The analogies between the macrocosm of weather cycle and the microcosm of animal body break down at a superficial level. First, the metaphor suggests that the heart does not cause the motion of blood, because the sun does not cause the motion of air and water. According to Aristotle, each element has its natural place in the universe. Starting from the center of the cosmos, the order of the four elements is as follows: earth, water, air, and fire. If an element is out of its natural place, it will move toward that place, requiring no external cause. Thus, air rises up and water falls down as a rain. However, the main point of Harvey's investigations is that the movement of blood is caused by the impulse of the heart.

Second, the sun is not part of the earth whereas the heart is a part of the body. In consequence, the evaporation of water into air happens outside the sun whereas the conversion of blood takes place inside the heart. In this respect, the cloud would be a better counterpart for the heart, because, in Aristotle's terminology, the coldness of the cloud condenses air into water. However, Harvey's point is that the heat of the heart converts venous blood into arterial blood in the same way as the heat of the sun evaporates water into air. Finally, counterparts for the blood vessels and the valves do not exist in the weather cycle. Thus, in my view, the weather cycle metaphor cannot be the origin of Harvey's discovery of the circulation of blood.

However, Harvey uses this metaphor as a cognitive instrument in another respect. With its help, Harvey explains the conversion of the venous blood into the arterial blood. According to his vitalistic explanation, the "heat" of the heart impregnates the blood again with spirit.[11]

[9] *Ibid.*.

[10] W. Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures*, translated with an introduction and notes by Gweneth Whitteridge (Oxford: 1976), p. 75.

[11] W. Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures*, translated with an introduction and notes by Gweneth Whitteridge (Oxford: 1976), p. 76.

(4) Harvey's use of technological and social metaphors

The role of mechanistic ideas, that is, technological metaphors in Harvey's scientific work have been a matter of considerable debate. Harvey was not a mechanical philosopher. This is shown, for example, by his later dispute with Descartes. Descartes and Harvey had fundamentally opposed views on the validity of vitalistic explanations in physiology.[12] However, there are mechanistic elements in Harvey's thought. In the *De motu locali* Harvey refers to Aristotle's the *De motu animalium* in which Aristotle compares the movements of animals with those of automatic puppets:

> The movements of animals may be compared with those of automatic puppets, which are set going on the occasion of a tiny movement; the levers are released, and strike the twisted strings against one another; or with a toy wagon. For the child mounts on it and moves it straight forward, and then again it is moved in a circle owing to its wheels being of unequal diameter, the smaller acting like a centre. Animals have parts of a similar kind, their organs, the sinewy tendons to wit and the bones; the bones are like the wooden levers in the automaton, and the iron; the tendons are like the strings, etc.[13]

However, although Aristotle compares the movement of animals to the movement of automatic puppets, he is not a "mechanical" philosopher. In the same way as Aristotle, Harvey does not follow through on the automaton metaphor. Harvey does not base his investigations on the automaton metaphor or any other mechanism of muscular movement. Instead, he relies on metaphors derived from the social domain. Harvey's *De motu locali* ends with a long list of metaphors from the social domain:

> Is the brain the general? The nerves carry the commands, sergeant major. The spinal medulla the lieutenant-comet. The branches of the nerves which give the signal to the muscles, the captains. The muscles, the soldiers.
>
> Or is the brain the ruler of the senate for the purpose of deciding what useful things are present? The nerves, the magistrates. The branches of the nerves, the officials. The muscles, the citizens, the populace.
>
> Or again, is the brain the choir-master? The nerves, the time-keepers and prompters, dancers. The muscles, the actors, singers, dancers.
>
> Or is the brain the architect? The nerves, the overseers, surveyors. The branches of the nerves, the clerks of every work. The muscles, the workmen.
>
> Or is the brain the master? The spinal medulla, his mate. The nerves, boatswains. The muscles, sailors.[14]

For example, muscles are like "separate living creatures" which have to be directed in harmony by the choirmaster of the brain.[15] It is noteworthy that this metaphor is based on the same two notions than the earlier macrocosm metaphor, that is, harmony and rhythm. Harvey emphasises the importance rhythm and harmony in muscular coordination. Each muscle has its own rhythm of tension and relaxation in the same way as the beat of the heart has its systole and diastole. Harvey's choirmaster metaphor is unsuccessful. It does not provide a satisfactory conceptual framework for the analysis of animal movement. Harvey's remarks stay on a general level. For example, he says that chickens with their heads cut off still move, as do also men in delirium and drunkards, but they move with a disorderly action and not with the harmony and rhythm necessary for work.[16]

In the *De motu cordis* Harvey employs a mechanistic metaphor, which can be called a "hydraulic mechanism" metaphor. I shall not call it the "pump metaphor", because Harvey never compared the heart to a pump in the *De motu cordis*. The comparison can be found only in later works. However,

[12] G. Gorham, "Mind-Body Dualism and Harvey – Descartes Controversy", *Journal of the History of Ideas*, vol. 55 (1994), pp. 211–234.

[13] W. Harvey, *De motu locali animalium 1627*, edited, translated and introduced by G. Whitteridge (Cambridge: 1959), pp. 73 and 97–98.

[14] *Idem*., p. 151.

[15] *Idem*., p. 111.

[16] *Idem*., p. 111.

although Harvey does not call the heart a pump in the *De motu cordis*, it functions like a pump as a part of the cardiovascular system. According to Harvey, one of the actions of the heart is the very transmission of the blood and its propulsion to the extremities by way of arteries.[17] The scheme of correspondence between the cardiovascular system and a hydraulic mechanism is as follows:

------	Body
Fluid	Arterial blood
Fluid	Venous blood
Pipes	Arteries
Pipes with valves	Veins
------	Heart

The "hydraulic mechanism" metaphor is the structured framework that Harvey employed to interpret and explain his anatomical observations. It was the "cognitive instrument" behind the discovery of the circulation of blood. Harvey's train of thought can be reconstructed as follows. The auricle of the heart is the cistern, which supplies the blood for the ventricle. In the same way as a pump propels the fluid into the pipes, the ventricle of the heart propels the blood into the arteries. After this, Harvey was faced with a difficult problem. The amount of blood that passes out of the heart is so large as to cause problems. The arteries would rupture from the overflow of blood. Harvey's solution was the reinterpretation of the notion of "valve". He noticed that all the valves in the veins point to the heart. They were so placed that they gave free passage to the blood toward the heart, but opposed the passage of the blood to the outer limbs. In other words, the motion of blood in the arteries was from the heart to the extremities, and in the veins from the extremities to the heart. This resulted to the discovery of the circulation of blood.

The failure of the *De motu locali* throws some light on the success of the *De motu cordis*. In the *De motu locali*, the use of social metaphors hindered decisively Harvey's investigations of the animal movement, because there are crucial differences between social and technological metaphors. First, the structure and function of a social relation or institution is often a bit vague. Thus, it does not present a clearly defined conceptual framework for the interpretation of unfamiliar phenomena. Second, social relations and institutions cannot usually be described in terms of mathematical relations among their component parts. "Hydraulic mechanism" metaphor has both of these advantages. It presents a clearly defined conceptual framework for the interpretation of the cardiovascular system. Moreover, hydraulic mechanism can be described in terms of mathematical relations among its moving and stationary parts. When Harvey saw the cardiovascular system as a hydraulic mechanism, he could transfer these mathematical relations from the source domain of technology to the target domain of the cardiovascular system. Harvey's famous quantitative argument for the circulation of the blood can be understood against this background. He measured the amount of blood heart sends out to the body in a given time and showed that it is more than can possibly be either supplied by the food we eat or contained at one time in the veins.[18] That is to say, the only possibility was that the blood circulates.

[17] W. Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures*, translated with an introduction and notes by Gweneth Whitteridge (Oxford: 1976), pp. 51–52.

[18] *Idem.*, pp. 79–80.