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THE USE OF METAPHORS IN SCIENTIFIC DEVELOPMENT: A LOGICAL APPROACH*

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Abstract

In this paper, I argue that the use of multiple metaphors plays an important part in scientific reasoning. It is more powerful in generating new ideas than the use of single metaphors. The aim of this paper is twofold. First I will argue, by means of some historical examples, that the combination of metaphors adds a very specific type of dynamics, that makes them more powerful than single metaphors. Secondly, I will discuss an adaptive logic that grasps the use of multiple metaphors and that increases our insight in the reasoning process.

1. *Introduction*

Most philosophers of science agree that models play an important role in science. Thinking or seeing something in terms of something else is considered to be a major factor in scientific innovations. For instance, in [20], Nersessian discusses the function of model-based reasoning in conceptual change and in [2] Bailer-Jones studies the development of models in science. They both give a thorough analysis of model-based reasoning in science and demonstrate convincingly their importance.

The word "models" is a name for a large group of phenomena that are considered to be similar in some ways. One of these phenomena are metaphors. The idea that metaphors can play an important part in scientific language and even in scientific *reasoning* is quite recent. The classical view on metaphors, inspired by logical positivism, rejected the use of metaphors in the sciences.

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Using a metaphor was considered to be a difficult way of saying something that could be said in an easier way. For instance, the metaphor

(1) Man is a wolf.

was considered to be a more complex and nicer way of saying that men are like wolves in being mean. Adherents to the traditional view saw metaphors as comparisons, encoded in such a way that they seem false at first sight but, nevertheless, obtain a truth value, and hence, are capable of drawing people's attention. In line with this, metaphors were thought to be mere stylistic tools. They could be used in poetry and literature in general, but not in scientific language. The language of science had to be a clear and transparent representation of reality.

The ideas on this topic, however, changed. Philosophers of science got interested in metaphors. One of the first properties of metaphors that drew attention is their capacity of filling gaps in the lexicon — the official name for this capacity is "catachresis". It often happens that when a new concept is developed, there is no way of naming it, other than using a metaphor. A famous example of catachresis is the term "natural selection" Darwin used to indicate the difference with artificial selection (as is shown in [12]). Because of this capacity, metaphors are indispensable elements for naming new concepts. A language without metaphors turns into a static structure, not adapted to capture new ideas. Therefore, metaphors are now considered to be an indispensable element of scientific language.

In addition to this, it became clear that metaphors are capable of causing conceptual innovation, and hence, can actually play a part in scientific *reasoning*. Interesting examples of this are:

(2) Light is a fluid.

(3) Sound is a wave.

(4) The human mind is a clock.

(5) The ocean is a conveyor belt.

The use of these metaphors caused scientists to change their ideas about light (see, for example, [7]), sounds (see, for example, [15]), the human mind (see, for example, [19] and [10]) and the ocean (see, for example, [6]).

Most studies about the use of metaphors in science, however, cannot provide a good explanation for their role in conceptual change. A large group of studies limits itself to a description of the phenomenon, without providing theoretical background. Even the more theoretical approaches cope with a lot of problems. One is that metaphors are often confused with other types of models, and hence, that there is no clear idea about what metaphors are.

Hence, in order to explain the function of metaphors, we first need a theory about their nature. The traditional view that metaphors are encoded comparisons is clearly inadequate in this respect. On this view, the understanding of a metaphor consists in the mere comparison of the pieces of information on its two main elements. Because of this, the traditional view explains the meaning of a metaphor as the information shared by its two main elements. For instance, (1) is interpreted as "men are like wolves in being mean and voracious". However, this view is not capable of explaining why, for instance, (2) to (5) helped scientists to attribute *new* ideas to light, sound, the human mind and oceans. A view that can explain this so-called cognitive function of metaphors is the *interactionist view*.

In the next section, I will explain what an interactionist view on metaphors comes down to. In section 3, I will show that the function of single metaphors in science is somewhat limited. The use of multiple metaphors seems to provide a much more powerful instrument for conceptual innovation. In the last section, I will present an adaptive logic that increases our insight in the use of multiple metaphors in science.

The aim of this article is twofold. On the one hand, I want to prime the study of the role of multiple metaphors in science, a subject that got little or no attention till so far. On the other hand, I want to show that logic can play a key part in understanding creative reasoning processes, such as, for example, the use of metaphors in science.

2. *An interactionist View on Metaphors*

Interactionism was described by Max Black in [4] and further developed in [5]. On this view, a metaphor consists of two parts: a *primary subject* and a *secondary subject*. The primary subject is the central element of the metaphor — what the metaphor is about — and is represented in literal language. The secondary subject modifies the primary subject and is represented in non-literal language. In (1), for instance, the primary subject is "man", and the secondary subject is "wolf".

What happens when we analyse a metaphor — according to Black — is that we consider a "system of associated commonplaces" about the secondary subject and "project" these upon the primary subject. The result is that the primary subject is extended with the commonplaces about the secondary subject.

However, as I explained in [9], the original view still has many shortcomings. A first problem is the *vague terminology* Black used to describe his view. He doesn't define terms like "system of associated commonplaces" or "metaphorical projection". A second and more important one is the so-called *relevance problem*. According to Black, we consider a system of commonplaces associated with the secondary subject and project these upon the primary subject. The problem, however, is that *all* commonplaces are projected. According to Black, (1), for example, allows us to derive that men howl at the moon.

In [9], I presented an alternative version of interactionism that copes with these shortcomings. This modified view is best explained by relying on the common distinction between three different stages in the understanding of metaphors.[1] I will keep the idea of three different stages, but the description of what happens at these stages will differ considerably from the common view.

A first step in the understanding of metaphors is the *recognition*. We have to recognize the metaphor as such and decide what the expression is about. If we know what the expression is about, we also know what the primary and secondary subject of the metaphor are.

The second step is called the actual *analysis*. We first consider a set of common sense information[2] both for the secondary and for the primary subject. Next, we transfer the information we have about the secondary subject to the primary subject. However, when we consider (1), we see that not all pieces of information are transferred, but only those that are *not in contradiction* with information about the primary subject. For instance, we do not conclude from (1) that men howl at the moon because we *know* that they do not. This is the main difference between the original version of interactionism and the modified one. Black thought that only for the secondary subject a set of common sense information is needed and that the latter is transferred entirely to the primary subject. The result is that nonsensical conclusions can be drawn from a metaphor. If we take into account also the information on the primary subject, we can let it operate as a filter for the transfer of information.

The third and last step is the *interpretation*. As a result of the analysis of the metaphor, the primary subject is extended with the information about the secondary subject that is not in contradiction with it.

The modified interactionist view on metaphors offers a good explanation for the role (2) to (5) played in the history of science. (4), for example, caused people to transfer pieces of information about clocks to the concept of the human mind, but only in as far as the former were compatible with the latter. The result was that their view on the human mind was enriched

[1] See, for example, [17] for a description of these stages.

[2] The content of this set can differ from person to person and from context to context.

and even altered: it became more mechanistic. This process opened new research directions and raised new problems scientists had to solve.

There are, however, limits to the innovative power of a *single* metaphor. The idea of a partial transfer, from the secondary subject to the primary subject, implies that the latter is relatively well-known. If it is not, hardly any information about the secondary subject will be excluded, and hence the metaphor will give rise to absurd conclusions and lead the scientist in erroneous directions. Therefore, a single metaphor is only capable of extending and changing *existing* concepts, not of creating new ones.

There is, however, a way to overcome these problems and to use metaphors for the creation of new concepts. As I will show in the next section, multiple metaphors can provide a framework in which underdeveloped primary subjects do not necessarily lead to nonsensical conclusions. The interaction between the subjects of the different metaphors, combined with the interaction between primary and secondary subject, can provide the necessary dynamics.

3. *Metaphors in Scientific Development*

The use of multiple metaphors in scientific reasoning is rarely seen as an important issue. These examples are treated in the same way as single metaphors. There are, however, important reasons to study them separately. Groups of metaphors are very powerful when it comes to developing new ideas, much more than a single metaphor. If we want to obtain a better insight in the cognitive power of metaphors, we should therefore also study the specific dynamics of the *combination* of metaphors and not only these of a single metaphor.

When we have two metaphors, there are — theoretically speaking — four possible relations between the two. A first possibility is that they have the primary subject in common, a second is that they have a common secondary subject, and a third that they are so-called “cross-linked” metaphors (the primary subject of the one metaphor is the secondary subject of the other). The fourth and last possibility is that the metaphors have nothing in common.

For our present purposes, the last possibility is the least interesting one: as these metaphors can hardly be called a cluster, they have to be seen as independent metaphors. Therefore, in what follows, I will only discuss the real clusters of metaphors — those examples where the metaphors have at least one element in common.

Before I move on to the analysis of the different types of clustering, I want to make two preliminary remarks. The first concerns the distinction between the construction and the understanding of a metaphor.

The examples of metaphor use in this section and some of the examples I gave in the previous section have a different function. If we consider (5), for example, we see that it was an existing metaphor, used in oceanography textbooks to point students to certain properties of oceans. Researchers in climatology stumbled on this metaphor and used it to find an explanation for certain temperature changes they measured but could not explain otherwise. The examples I will discuss in this section are different: they do not concern the understanding of a given metaphor, but the *construction* of a new one.

It is commonly accepted that there are important differences between these two processes (see also [8]). For instance, the first step in the construction of a metaphor consists in the active search for a source domain that can be used to structure a given target domain. There are, however, also important similarities between the two. In both cases, we can distinguish two subjects or domains, a source domain and a target domain or a primary and a secondary subject.[3] Moreover, in both cases, there is a transfer of information from the source domain to the target domain, with the exclusion of "unfit" information. Thus, whereas the first step in the construction of a metaphor is clearly different from the first step in the understanding of a metaphor, the second step is quite similar. In what follows, I shall focus on this second step.

A second remark concerns the distinction between metaphors and analogies. It is commonly acknowledged that these are different phenomena, with different functions in science, but there are very few theories available on what these differences are. As a consequence, the examples I discuss in this section will be called metaphors by some and analogies by others.

As I argued in [8], it is impossible to draw a clear distinction between the two phenomena. However, the examples discussed below satisfy the main criteria for metaphors I distinguished in [8]. In all of them, the source domain is represented in non-literal language. Moreover, the information that is transferred is relatively simple and easily accessible: it is immediately associated with the secondary subject and does not involve structural relations.[4] As we shall see below, it is precisely because of these characteristics that the examples can be handled by the same logic as the more traditional examples of metaphors.

[3] In what follows, I will use the terms "source domain" and "target domain" as synonyms for, respectively, "secondary subject" and "primary subject".

[4] The idea that the transfer of complex, structural information is typical of analogies and not of metaphors is also defended in [11].

3.1. *Cross-linked Metaphors*

An example of cross-linked metaphors that was on the news in November 2001, at the time of the bombardments on Afghanistan, is

(6) Tony Blair is the *Winston Churchill* of the 21st century.

(7) *Winston Churchill* was a giant.

In the first metaphor, “Winston Churchill” is the secondary subject, and something is said about Tony Blair. In the second metaphor, “Winston Churchill” is the primary subject, and something is said about Winston Churchill. As both metaphors have a common part, there is a double transfer. The second metaphor causes people to transfer information about giants also to “Tony Blair”. Therefore, the effect of the first metaphor is strengthened.

This type of multiple metaphors is not common in scientific language use. Moreover, in most examples, it is combined with other types of clustering. In the history of optics, however, an example of cross-linked metaphors can be found. Geoffrey Cantor describes in [1, 129-131] that a group of eighteenth-century scientists considered light to be a fluid flowing from the sun towards the stars. That flux of light illuminates the earth and other celestial bodies. At the heart of this theory is the metaphor

(8) Light is a fluid.

According to Cantor, this metaphor connected optical discourse not only with hydrokinetics, but also with theology. It thus allowed people to talk about the behaviour of light in simpler, every-day terms and linked the debate to a theological discourse. The following metaphors, originating from the Bible, connect the ideas of light, fluid and God and played an important part in the development of (8):

(9) God is the fountain of living waters.

(10) God is the sun.

(11) The sun is a fountain of light.

The idea that God is an ultimate *source* and that God emits light led to (9) and (10). These metaphors led in turn to the idea that also the sun can be considered as a source or fountain, and hence, that light can be seen as *flowing* from the sun. The combination of (9) to (11), which displays a mix of cross-linked primary and secondary subjects, thus helped to arrive at (8).

3.2. *Metaphors with a Common Secondary Subject*

An example of metaphors with a common secondary subject can be found in [15, 263-265]. Gerald Holton describes in this paper how the nineteenth-century scientist Thomas Young used the metaphors

(12) Sound is a wave.

(13) Light is a wave.

to explain experimental results. Young had previously formulated the law of superposition that allows one to understand the action of organ pipes in terms of the interference between sound waves, travelling in opposite directions in the pipe. He linked this idea to Newton's description of experiments on thin plates and Newton's rings in the "Optics". The two phenomena could be explained in the same way: the wave properties of sound explain the law of superposition and the wave properties of light the outcome of Newton's experiments described in the "Optics".

Young thus used the concept of waves to explain two different phenomena — sound and light. His ideas became commonly accepted and people started to see both phenomena in terms of waves. As a result, the concept of a "luminiferous aether" found acceptance. Since sound needs a medium to get from one point to another, the idea grew that also light needs a medium. The medium of light waves was considered to be the "aether". Later on, the concept of an "aether" became known as a general medium, also for, for example, electro-magnetic phenomena (see [14]).

Other phenomena too were explained in terms of waves. Macedonio Melloni, for instance, drew an analogy between light and radiant heat (based on his experiments with infrared light), and André Ampère developed a comprehensive theory on the basis of the same analogy (see [13, 34]). Augustin Fresnel stated that light, heat, and electricity could be seen as modifications of a universal aether.

The wave-metaphor also played an important part in the development of thermodynamics. Thomas Kuhn distinguishes in [16, 73] three important developments in the origin of the idea of the conversation of energy: the availability of empirical data about conversion processes, the experiences with engines, and the philosophy of nature, namely the idea that there is an underlying, imperishable force in nature. The wave-metaphor can be added as a fourth element. It caused scientists to focus on common, wave-like properties of, for example, light, heat, and electro-magnetism. Moreover, the idea that they could be seen as manipulations of a common medium, aether, was an important element in developing the idea that they can be converted into each other.

The wave-metaphor thus fulfilled a very important function. It was used to change and structure different concepts, like sound, light, electricity, and magnetism. As a result, people started to focus on the commonalities between these domains, and this led to significant scientific developments.

3.3. *Metaphors with a Common Primary Subject*

The last type of clustering consists of metaphors with a common *primary subject*. This is the most obvious way to create new ideas. In this case, a fairly undeveloped target domain is structured by different source domains. The interplay between the latter enables one to overcome the difficulties the former may otherwise cause. A nice example of this can be found in the work of Charles Lyell (as described, for instance, in [23]).

Lyell wanted to develop a new methodology for geology. At that moment, there were two important approaches to geology, a French one, which used a pure theoretical way of explaining phenomena, and a British one, which concentrated merely on gathering empirical data. Whereas the first approach lacked empirical data to back up its claims, the second consisted of mere data collecting and could not give any explanation for the data. Lyell rejected both approaches. In order to build a new methodology for geology, he used the following metaphors:

(14) Geology is history.

(15) Geology is linguistics.

(16) Geology is demography.

(17) Geology is political economy.

Lyell used ideas and methods of these four sciences to give the concept of geology a new interpretation. As he started with very little and very general information about his primary subject, the latter did not provide an adequate framework to prevent the transfer of senseless information. However, the combination of the different source domains allowed him to exclude the transfer of certain pieces of information.

When we take a closer look at the use of the metaphors, as described in [23], we see that not all information about the source domains was equally important. Only certain elements were considered as *central*[5] pieces of information:

Historiography	Stress on causality and critical scrutiny of fragmentary evidence
Linguistics	Importance of interpretation and the learning process of a language
Demography	Gradual overall change could be the summation of small changes in innumerable discrete units
Political Economy	Innumerable local events can add up to a total system

It seems that Lyell considered these elements so crucial that he wanted to transfer them at any cost. I will say that these pieces of information had a *higher priority*. Those pieces that had a lower priority and that were in contradiction with them were excluded from transfer.

In this type of metaphorical clustering, the higher prioritized information forms a framework in which the lower prioritized information has to fit. In the above example, certain pieces of information about *each* secondary subject are prioritized. In the rest of this section, I will analyse some examples where priorities are assigned in a different way.

In [12] and [24], Michael Ruse and Howard Gruber discussed the process that led Darwin to the formulation of the evolution theory. They were both interested in the metaphors Darwin used to develop the concept of natural selection. Gruber distinguishes six equally important metaphors:

(18) Natural selection is contrivance.

(19) Natural selection is a tangled bank.

(20) Natural selection is an irregular branching tree.

(21) Natural selection is war.

(22) Natural selection is wedging.

(23) Natural selection is artificial selection.

[5] The word "central" must not be interpreted in an essentialistic way. The term is used to indicate certain pieces of information that are crucial in *that* context. What the central information is can change from one context to another.

Michael Ruse, however, stated that only the last metaphor was of crucial importance for the development of “natural selection”. A combination of these two opinions and the idea from the former example shows a way out of this discussion. We can say that all six metaphors played a part in the creation of “natural selection”, but that the information coming from (23) has a higher priority than the information coming from the other metaphors. In that case, the framework is formed by the information about the source domain “artificial selection”, and the information about the other source domains has to fit into this structure.

This example shows us a second way of assigning priorities. In this case, all the information about one specific source domain has the highest priority, instead of specific pieces of information about all the source domains. I will use the term “prioritized source domain” in the former case and “prioritized elements within the source domains” in the latter.

A third and more complex type of priority assignment can be found in [10]. Douwe Draaisma presents in this book a study of the different metaphors that were used for the human brain throughout the history of science. He comes up with a long list of metaphors, of which the following seem to be the most important ones:

(24) The human brain is a labyrinth.

(25) The human brain is a Bologna stone.

(26) The human brain is a clock.

(27) The human brain is a camera.

(28) The human brain is a computer.

This example differs from the previous ones in the sense that (24)–(28) were not used by one single scientist in one era to construct a new concept. Instead, the example offers a range of the different metaphors used through history to form our present concept of the brain.

I will call this type of priority assignment *temporal priority*, since it is determined by the temporal sequence in which the metaphors are used. Each time a new metaphor is used, it is prior to the previous ones. Hence, information about the “old” source domains is transferred only in as far as it is not in contradiction with the information about the new source domain.

These three types of priority seem to cover most of the examples of metaphorical clustering with common primary subjects. The first two types can give us crucial insights in how scientific concepts are constructed. The third type can give us insight in the dynamics between different metaphors throughout the history of science and offers us a tool for studying conceptual dynamics and conceptual change.

4. *An Adaptive Logic for Multiple Metaphors*

In this section, I will sketch the outlines of the logic ALMM that can capture the way in which multiple source domains are used to structure one common target domain. The system I will present is an *adaptive logic*.

As I pointed out in [9], adaptive logics are very well suited to grasp metaphorical reasoning. The reason is that metaphors are *dynamical* reasoning tools. When analysing one or more metaphors, the addition of new information about the subjects may lead to the withdrawal of previously derived conclusions. The same may also happen if a new metaphor is added. This type of dynamics — also called non-monotonicity — is *external*: it is related to the addition of *new* premises. The dynamics may also be *internal*. This is the case when the mere analysis of the available premises leads to the rejection of formerly accepted conclusions. Adaptive logics can grasp these two types of dynamics.

The system I will present in this section is designed to grasp the reasoning involved in the use of multiple metaphors. More specifically, it is adequate for the case in which the different metaphors share their primary subject. As we have seen in the previous section, this type of metaphorical clustering involves reasoning from premises that are more or less prioritized. The importance of the system is that it provides a better insight in the *analysis* of metaphors (the second stage in which information is transferred from one or more source domains to the target domain).

4.1. *The General Idea*

If we want to develop a logic that grasps the way we reason with multiple metaphors, there are three important problems we have to tackle. A first one is representing non-literal expressions, since these cannot be represented in the standard language of classical logic (henceforth CL). A second problem is expressing the idea of higher and lower prioritized information. Finally, we also have to find a way to grasp the idea of a transfer of information after excluding the irrelevant pieces of information.

The first problem can be solved by constructing a formal language $\mathcal{L}^*$ that includes for each so-called literal predicate π, a metaphorical predicate π^*. I will formalize the secondary subject by means of a metaphorical predicate and the primary one by means of an ordinary, literal predicate. (1), for example, can be formalized as $(\forall x)(Mx \supset W^*x)$ — where M stands for "man" and W^* stands for "metaphorical wolf".

The second problem can be tackled by assigning a *priority-index* to each piece of information about each secondary subject. Technically this will be realized by allowing that to descriptive formulas[6] of the form $(\forall x)(Qx \supset C(x))$ an index "$[Q, i]$" is attached in which i is the degree to which the implied formula $C(x)$ is central information about Q. $C(x)$ may be of any complexity. I will follow the convention that the smaller i is, the more important $C(x)$ is for Q. As only one predicate occurs in the "normal" form of the implicans of an indexed formula, the first element of the index of this formula is bound to be either that predicate or its negation.

If we combine these two elements, we can address the last problem. ALMM will allow us to *replace* π with π^* until and unless this substitution leads to unwanted conclusions. ALMM will do this by taking properties that are implied by a literal predicate to be *conditionally* implied by the corresponding metaphorical predicate. Thus, if we have among the premises $(\forall x)(Px \supset Q^*x)$ and $(\forall x)(Qx \supset Rx)_{[Q,2]}$, we will drop the index[7] and replace Q in the latter (descriptive) premise for Q^* on the condition that $(\forall x)(Qx \supset Rx)_{[Q,2]} \wedge {\sim}(\forall x)(Q^* \supset Rx)$ may be taken to be false — see below for more detailed information. Intuitively, we may replace the literal predicate with the corresponding metaphorical predicate in this example, as long as there is neither information about the primary subject nor higher prioritized information about the secondary subject that is in contradiction with the conclusions we can derive from this substitution. In the next section, I will demonstrate how this exactly proceeds in a formal way.

4.2. *The Proof Theory*

The aim of the adaptive logic ALMM is a restricted one. It is developed for grasping the way we reason with metaphors with a *common primary subject*. Expressed more precisely, the logic will be able to handle one or more metaphors of the form $\forall(A \supset B)$ in which (i) $\forall$ abbreviates the universal closure of the subsequent formula, (ii) no constants occur in either A or B, (iii) A, the primary subject, contains a single predicate, and (iv) B, the secondary subject, contains a single predicate that is used metaphorically — formally a starred predicate.

From a formal point of view, a premise set will contain (i) one or more metaphors of the form $\forall(A \supset B)$, (ii) non-metaphorical statements with an

[6] By a descriptive formula, I mean a formula in which no predicate is used metaphorically, in other words, where no predicate carries an asterisk.

[7] This convention is only followed for reasons of simplicity.

index attached to them, and (iii) non-metaphorical statements that have no index attached to them.

All existing adaptive logics consist of three elements.[8] The first is a *lower limit logic* (henceforth LLL) that is always monotonic. The LLL delineates the inference rules that hold without exception. The second is a set of *abnormalities* Ω, which is a set of formulas characterised by a logical form. These formulas are presupposed to be false, unless and until proven otherwise. It is important to note that often a set of premises entails a *disjunction* of abnormalities, without entailing any of its disjuncts. These disjunctions of abnormalities will be called *Dab-formulas* and will be written as *Dab*(Δ), in which Δ is a finite set of formulas. The *Dab*-formulas that are derivable by the LLL from a premise set Γ will be called the *Dab-consequences* of Γ. If *Dab*(Δ) is a *Dab*-consequence of Γ, then so is *Dab*($\Delta \cup \Theta$) for any finite Θ. Therefore it is important to concentrate on the *minimal Dab*-consequences of a premise set. *Dab*(Δ) is a minimal Dab-consequence of Γ iff $\Gamma \vdash_{\mathsf{LLL}}$ *Dab*(Δ) and there is no $\Theta \supset \Delta$ such that $\Gamma \vdash_{\mathsf{LLL}} Dab(\Theta)$. If *Dab*($\Delta$) is a minimal *Dab*-consequence of Γ, we know that some members of Δ behave abnormally, but Γ cannot determine which member of Δ behaves abnormally. One of the central ideas behind an adaptive logic is that it interprets the premises as normally as possible. The *adaptive strategy* decides what the expression "as normally as possible" means. If the LLL is extended with the requirement that no abnormality is logically possible, one obtains a monotonic logic that is called the *upper limit logic* (henceforth ULL). As the ULL presupposes that no abnormality is logically possible, it defines the "'normal" situation.

Intuitively, the LLL of ALMM presupposes that no information can be transferred to the primary subject. In formal terms this means that π can never be replaced with π^*. The LLL is CL^I and its language is $\mathcal{L}^{I*}$. The latter is obtained in two steps. First, where $\mathcal{L}$ is the standard predicative language, and $\mathcal{P}^r$ is a set of predicates of rank r, $\mathcal{L}^*$ is obtained by extending $\mathcal{P}^r$ to $\mathcal{P}^{r*}$ according to the stipulation that $\pi^* \in \mathcal{P}^{r*}$ iff $\pi \in \mathcal{P}^r$. Next, $\mathcal{L}^*$ is extended to $\mathcal{L}^{I*}$. If A is a closed formula of $\mathcal{L}$, B is either a predicate or the negation of a predicate, and $i \in \{1, 2, ...\}$, then $A_{[B,i]}$ is a closed formula of $\mathcal{L}^{I*}$. A subscript as, for example, $[B, i]$ will be called an index and "I" will denote a variable over indexes. Where A and B are wffs of $\mathcal{L}^{I*}$ and Γ is a set of wffs of $\mathcal{L}^{I*}$, CL^I is defined by the following three rules:

R1 If $\Gamma \vdash_{\mathsf{CL}} A$ then $\Gamma \vdash_{\mathsf{CL}^I} A$

[8] As will be shown later in this section, the situation for ALMM is a bit more complex than this, since it is a prioritized system.

R2 If $A \vdash_{\mathsf{CL}} B$ then $A_I \vdash_{\mathsf{CL}^I} B_I$

R3 $A_I \vdash_{\mathsf{CL}^I} A$

It is important to note that in R2 and R3, A and B are wffs of $\mathcal{L}$ because A_I and B_I are wffs of $\mathcal{L}^{I*}$.

Let A^* be the result of attaching an asterisk to the predicate that occurs in A (there will always be one such predicate only), and let $\overline{A}$ be the functional expression obtained by removing the free variables from A. Now we can define the set of abnormalities Ω. It is the set of all formulas of the form $\forall(A \supset B)_{[\overline{A},i]} \wedge {\sim}\forall(A^* \supset B)$ in which A is an open formula containing at most one predicate and containing no individual constants.

The strategy used for ALMM is the *reliability strategy*.[9] Let $U(\Gamma) = \{A \mid A \in \Delta$ for some minimal *Dab*-consequence *Dab*(Δ) of $\Gamma\}$ (the set of formulas that are unreliable with respect to Γ). The reliability strategy considers a formula as behaving abnormally iff it is a member of $U(\Gamma)$. What this amounts to in the case of ALMM will become clear later in this section.

The ULL of ALMM is obtained by extending CL^I with the axiom $\forall(A \supset B)_{[\overline{A},i]} \supset \forall(A^* \supset B)$. The ULL presupposes that all information can be transferred to the primary subject. Formally, the ULL allows us to replace every π with π^*.

The proof format of adaptive logics is a modified version of the Fitch style format. A line in a proof consists of five element: (i) a line number, (ii) a formula A that is derived, (iii) the line numbers of the formulas on which A is derived or a dash in case of a premise, (iv) the rule by which A is derived, (v) a condition. The condition determines which formulas have to behave normally in order for A to be derivable. A wff is said to be derived unconditionally iff it is derived on a line with an empty fifth element. At every stage of a proof, each line is either marked or unmarked. If the line is unmarked at that stage, its formula (second element) is considered as derived at that stage. If it is marked, its formula is considered as not derived at that stage. The generic proof format of adaptive logics consists of three rules — a premise rule, an unconditional rule, and a conditional rule — and a marking definition. The conditional rule is the only rule that introduces non-empty conditions. The unconditional rule is determined by the LLL, and the conditional rule is determined by the ULL. Finally, the marking definition defines which lines are marked at a stage of the proof.

[9] Minimal abnormality can deliver us some more consequences than reliability, but minimal abnormality is more complicated on a proof theoretical level. Since the proof theoretical level is the most important and interesting one for this system, the advantages of using minimal abnormality make no odds against the complications it would cause.

PREM At any stage of a proof one may add a line consisting of (i) an appropriate line number, (ii) a premise, (iii) a dash, (iv) "PREM", and (v) "$\emptyset$".

RU If $A_1, \ldots, A_n \vdash_{\mathsf{CL}^I} B$, and $A_1, \ldots, A_n$ occur in the proof on lines $j_1, \ldots, j_n$ on the conditions $\Delta_1, \ldots, \Delta_n$ respectively, one may add a line with (i) an appropriate line number, (ii) B, (iii) $j_1, \ldots, j_n$, (iv) RU, and (v) $\Delta_1 \cup \ldots \cup \Delta_n$.

RC If A contains one predicate only and $\forall(A \supset B)_{[\overline{A},i]}$ occurs in the proof on a line j that has Δ as its condition, one may add a line comprising the following elements: (i) an appropriate line number, (ii) $\forall(A^* \supset B)$, (iii) j, (iv) RC, and (v) $\Delta \cup \{\forall(A \supset B_{[\overline{A},i]} \wedge {\sim}\forall(A^* \supset B)\}$.

At this point, I would like to make an important remark concerning RC. It is obvious that the formula $(\forall x)(Rx \supset Sx)$ is equivalent to $(\forall x)({\sim}Sx \supset {\sim}Rx)$. Moreover, by R2, a formula A with a certain index entails all CL-consequences of A with the same index. Thus, $(\forall x)(Rx \supset Sx)_{[R,1]}$ is equivalent to $(\forall x)({\sim}Sx \supset {\sim}Rx)_{[R,1]}$ — even in the latter formula, the index indicates that $(\forall x)({\sim}Sx \supset {\sim}Rx)$ expresses the degree to which a certain property is central information about Rx. Nevertheless, the conditional rule RC only refers to such formulas as $(\forall x)(Rx \supset Sx)_{[R,1]}$. This keeps things simple, both formally and intuitively.

Where the above inference rules govern the way in which a proof at a stage may be extended, it depends on the marking definition which lines of a proof at a stage are marked at that stage. The marking definition of ALMM is similar to the one of prioritized adaptive logics — see [3] — except that the role of the iterated modalities is here played by the indices. This requires some explanation.

From now on, abnormalities of the form $\forall(A \supset B)_{[\overline{A},i]} \wedge {\sim}\forall(A^* \supset B)$ will be abbreviated as $!\forall(A \supset B)_{[\overline{A},i]}$. It is easily seen that $C \vee !\forall(A \supset B)_{[\overline{A},i]}$ is derivable on an empty condition just in case C is derivable on the condition $!\forall(A \supset B)_{[\overline{A},i]}$.

An abnormality of the form $!\forall(A \supset B)_{[\overline{A},i]}$ will be called an abnormality of degree i. By a *Dab*^{i}-formula I will mean a disjunction of abnormalities of degree i. A *Dab*^{i}-formula A is a *minimal Dab*^{i}-formula at a stage s iff all disjuncts of A are abnormalities of degree i, and the condition of the line on which A is derived contains only abnormalities (if any) the degree of which is smaller than i. The underlying idea is that, if the line is not marked (see higher), then A is derivable from the premises if the premises are interpreted as normally as possible with respect to all indexed formulas of a degree lower than i. A *Dab*-formula of degree i at stage s will be said to be *minimal* at stage s if the result of dropping one or more disjuncts from A is not a *Dab*-formula of degree i at stage s.

Where Γ is the set of premises, the set of unreliable abnormalities of degree i at stage s of the proof, $U_s^i(\Gamma)$, is the set of the disjuncts of the minimal *Dab*-formulas of degree i at stage s.

The marking definition for reliability is applied stepwise. Where $1, \ldots, n$ are the degrees that occur in the indices, the lines of the proofs are first 1-marked, next 2-marked, etc, up to n. Remark that $U_s^i(\Gamma)$ is well-defined as soon as the lines are $i-1$-marked. For each i $(1 \leq i \leq n)$, i-marking is defined as follows:

Definition 1: *Where Δ is the condition of line j, line j is i-marked at stage s iff $\Delta \cap U_s^i(\Gamma) \neq \emptyset$.*

To complete the proof theory for ALMM, I give the definitions for final derivability:

Definition 2: *A is* finally derived *from Γ on line j of a proof at stage s if (i) A is the second element of line j, (ii) line j is not i-marked for any i at stage s, and (iii) any extension of the proof in which line j is i-marked for any i may be further extended in such a way that line j is unmarked.*

Definition 3: $\Gamma \vdash_{\mathsf{ALMM}} A$ *(A is* finally ALMM-derivable *from Γ) iff A is finally derived on a line of a proof from Γ.*

Since ALMM is a prioritized system, it can easily capture the three forms of priority I distinguished in the previous section. For instance, if we have the following metaphors

1	$(\forall x)(Px \supset Q^*x)$	– ; PREM	$\emptyset$
2	$(\forall x)(Px \supset R^*x)$	– ; PREM	$\emptyset$

we can grasp the first type of priority assignment — with prioritized elements within each source domain — by assigning different levels of priority to the information we have about Q and similarly for R. In case of one prioritized source domain — as in the example used by Charles Darwin — we assign one level of priority to all the information we have about Q and a different level of priority to all the information we have about R. The third example, with temporal priorities, is a bit more complicated. In this case, we start from one metaphor, so all information about Q will have the same priority. Then we add a second metaphor, and as a result of that, the information about Q will get a lower level of priority. The same procedure is repeated when we add a third metaphor. To show how the system works, I will work out a complete example of the first type.

1	$(\forall x)(Px \supset Q^{*}x)$	– ; PREM	$\emptyset$
2	$(\forall x)(Px \supset R^{*}x)$	– ; PREM	$\emptyset$
3	$(\forall x)(Qx \supset Sx)_{[Q,1]}$	– ; PREM	$\emptyset$
4	$(\forall x)(Rx \supset {\sim}Sx)_{[R,2]}$	– ; PREM	$\emptyset$
5	$(\exists x)Px$	– ; PREM	$\emptyset$
6	$(\forall x)(Q^{*}x \supset Sx)$	3; RC	$\{!(\forall x)(Qx \supset Sx)_{[Q,1]}\}$
7	$(\forall x)(R^{*}x \supset {\sim}Sx)$	4; RC	$\{!(\forall x)(Rx \supset {\sim}Sx)_{[R,2]}\}$
8	$(\forall x)(Px \supset Sx)$	1,6; RU	$\{!(\forall x)(Qx \supset Sx)_{[Q,1]}\}$
9	$(\forall x)(Px \supset {\sim}Sx)$	2,7; RU	$\{!(\forall x)(Rx \supset {\sim}Sx)_{[R,2]}\}$
10	$(\forall x)(Px \supset (Q^{*}x \wedge {\sim}Sx))$	1,9; RU	$\{!(\forall x)(Rx \supset {\sim}Sx)_{[R,2]}\}$
11	$(\forall x)(Px \supset (R^{*}x \wedge Sx))$	2,8; RU	$\{!(\forall x)(Qx \supset Sx)_{[Q,1]}\}$
12	$(\exists x)(Q^{*}x \wedge {\sim}Sx)$	5,10 ; RU	$\{!(\forall x)(Rx \supset {\sim}Sx)_{[R,2]}\}$
13	$(\exists x)(Rx \wedge Sx)$	5,11 ; RU	$\{!(\forall x)(Qx \supset Sx)_{[Q,1]}\}$
14	$!(\forall x)(Qx \supset Sx)_{[Q,1]}$	3,12; RU	$\{!(\forall x)(Rx \supset {\sim}Sx)_{[R,2]}\}$
15	$!(\forall x)(Rx \supset {\sim}Sx)_{[R,2]}$	4,13; RU	$\{!(\forall x)(Qx \supset Sx)_{[Q,1]}\}$

On the first five lines we find the premises. The first two premises are metaphors. The premises on lines 3 and 4 contain information about the literal versions of the metaphorical predicates on lines 1 and 2. They carry both an index, the one on line 3 indicates that S has degree 1 of importance for Q, the one on line 4 that ${\sim}S$ has degree 2 of importance for R.

On lines 6 and 7, we apply the conditional rule and replace the literal predicates in 3 and 4 with metaphorical ones. On line 6, we replace Q with Q^{*} on the condition that we cannot derive the fifth element of the line as part of a minimal *Dab*^{1}-formula — a minimal *Dab*-formula with priority index 1. On line 7, we assume we can replace R with R^{*} until and unless we can derive the condition as part of a minimal *Dab*-formula of degree 2 or higher.

If we combine 6 and 7 with lines 1 and 2 respectively, we can derive lines 8 and 9. On these lines, we assume that S and ${\sim}S$ are also implied by P. As soon, however, as the condition is violated, these lines will have to be marked. In that case, the piece of information at issue cannot be transferred to the primary subject.

The conclusions on lines 10 and 11 allow us, in combination with line 5, to derive the lines 12 and 13. If we put these lines into conjunction with 3 and 4 respectively, we can derive the abnormalities on lines 14 and 15 by R1. It is important to note that although the formula on line 14 is an abnormality, it is not a minimal *Dab*-formula, since the degree of the condition is *higher* than the degree of the abnormality (see also the marking rule higher in this section).

On line 15, we can derive a minimal *Dab*^{2}-formula, on a condition with degree 1. The result is that at this stage, all lines that are derived on the condition that $!(\forall x)(Rx \supset \sim Sx)_{[R,2]}$ is not derived as a disjunct of a minimal *Dab*^{2}-formula have to be 2-marked. They will no longer be considered to be derived.

At this stage, we can conclude that $(\forall x)(Px \supset Sx)$, which means that we can transfer the property S to objects that have property P. Let us assume now that we add the information

16	$(\forall x)(Px \supset \sim Sx)$	– ; PREM	$\emptyset$
17	$(\forall x)(Px \supset (Q^*x \wedge \sim Sx))$	1,16; RU	$\emptyset$
18	$(\exists x)(Q^*x \wedge \sim Sx)$	5,17; RU	$\emptyset$
19	$!(\forall x)(Qx \supset Sx)_{[Q,1]}$	3,18; RU	$\emptyset$

On line 19, we can derive a minimal *Dab*^{1}-formula with an empty condition. This forces us to 1-mark all the lines that are derived on the condition that $!(\forall x)(Qx \supset Sx)_{[Q,1]}$ is not derived as a disjunct of a minimal *Dab*^{1}-formula. The marking will proceed stepwise. First all the present marks will be removed and then all the necessary lines are 1-marked. The next step is to 2-mark all the remaining lines that were invalid according to the previously derived minimal *Dab*^{2}-formula. The result is that, at this stage, no conclusions can be derived from the present set of premises.

This example demonstrates the most important properties of ALMM. The use of priority indices allows us to express the idea of "central" information about a certain source domain. ALMM allows us also to grasp the different types of dynamics that are crucial in metaphorical reasoning. The dynamics is caused by the tension between different secondary subjects and between a primary subject and the different secondary subjects. The internal dynamics is demonstrated when certain previously valid conclusions are withdrawn in view of the further analysis of the available information. The external one is illustrated on line 16 where the addition of a new premise leads to the withdrawal of previously valid conclusions.

5. *Conclusion and Open Problems*

In this article, I showed that multiple metaphors are powerful instruments in scientific innovation. They are capable of creating new concepts or ideas. They can help in problem solving by providing a solution to the problem — as, for example, in the case of Charles Lyell — or by changing the context of the problem.

I started from the possible combinations of metaphors and studied some examples from the history of science in detail. However, further research is needed to gain a better insight in how these combinations of metaphors function. It is very likely, for example, that in most examples a combination of different types of metaphorical clustering is used. At the moment, however, it is still unclear what the impact of these combinations is, and also if they fulfill a specific function in scientific reasoning. Another open problem is how the source domains are chosen. It is unclear what the motives are for preferring one particular source domain to another.

In the last part of this paper, I presented an adaptive logic that is capable of grasping the second step in the understanding of multiple metaphors. It is clear that the system should be completed with a semantics and the metatheoretical proofs.

ALMM could also be extended to handle more complex examples of multiple metaphors. It is possible that also for the information about the primary subject, we can make a distinction between more and less important information. Therefore, we could assign priorities also to the information about the primary subject. The implications of this extension for the proof theory, however, need to be carefully studied.

A final open question concerns the extension of ALMM to handling the other two types of metaphorical clustering. However, before this problem can be addressed, a more detailed study of these types of metaphorical clustering is needed.

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