RESEARCH PAPER

Metaphor and theory: a case study of astronomy

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ABSTRACT

Metaphors enable the understanding of one thing in terms of another. Although central to reasoning and theorizing, there is limited understanding about their role in theory development. This paper presents a process of metaphorical reasoning that addresses the question of how metaphors support theory development. The process is applied to the case of astronomy, which helps explain why metaphors create reality and why their reality-creating side cannot be separated from their creative side. The paradoxical nature of metaphors means that metaphorical reasoning is an open-ended process. The paper also shows that emergence – a fundamental property of metaphors – explains their paradoxical nature. This same property makes metaphor a compressed interpretation of the world, characterized by the discarding of information. Finally, it is argued that metaphors are abstract intermediaries between senses and experiences. Given that metaphors are central to reasoning and theorizing, it is not surprising that these findings are consonant with what we know about theory (creative, reality-creating, sparse, abstract and open-ended). What is surprising, though, is that the discarding of information seems to be essential for the building of theory. The paper concludes by exploring what this entails for our understanding of theory.

Introduction

Metaphors enable understanding by allowing the experiencing one thing in terms of another. There is a growing recognition in cognitive sciences about the significance of metaphors for reasoning and understanding (Lakoff and Johnson, 1980, 1999; Fauconnier and Turner, 2003). That metaphors play an essential part in theorizing is widely acknowledged and studied in many disciplines; for example, management (Morgan, 1980, 1983, 2006; Weick, 1989; Tsoukas, 1991), physics (Lightman, 1989; Dyson, 2008; Bohm and Peat, 2010) and artificial intelligence (Watson, 2019).

Although essential for reasoning and theorizing, there is limited understanding of how metaphors actually support theory development. A majority of research has focused on what metaphors do rather than how they support theory development. This paper first reviews the key theories about metaphors. Building on the review findings, the paper proposes a process of metaphorical reasoning that might underpin theory development, and then explains the methodology devised to test the process. The results of applying the process in the case of astronomy are presented and their implications for our understanding of how metaphors support theory development are considered. The paper concludes by exploring what the implications entail for our understanding of theory.

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Three theories of metaphor

The most frequently used metaphor theories are comparison theory, interaction theory and conceptual metaphor theory. Here, the aim is to identify what is known about how metaphors work and what is still missing in that knowledge.

Comparison theory

Originating with Aristotle, comparison theory treats metaphors as similes equivalent to the assertion that A is like B in certain definite respects (Johnson, 1990). To process the metaphor means to see that the A domain (target) shares certain properties and relations with the B domain (source). The whole emphasis is on the similarities. The distinctive feature of comparison theory is its insistence that similarities revealed through the metaphorical transfer exist objectively in the world and are expressible in literal propositions (Johnson, 1990). Aristotle's view was that metaphor had to be (1) a mere use of words and not a matter of concepts, and (2) a deviant use of words since they are applied to things to which they do not properly apply. If a metaphor had a meaning at all, there would have to be some consistent basis for determining what the appropriate literal sense was. For this, Aristotle chose similarity (Lakoff and Johnson, 1999).

Interaction theory

Created by Black (1955), interaction theory offers two improvements over comparison theory. First, it recognizes that metaphor is not a matter of language, but of cognition. Second, it argues that metaphorical meaning is created or generated and is emergent in nature. Black (1955, pp.284–5) says: 'It would be more illuminating in some of these cases to say that the metaphor *creates* [original emphasis] the similarity than to say that it formulates some similarity antecedently existing'. Richards (1936), who argues that thought is irreducibly metaphorical and that linguistic metaphors are manifestations of these underlying metaphoric thought processes, inspired Black. However, Richards fails to provide an account of metaphorical creativity. Black (1955) argues that some metaphors have irreducible meaning beyond any statement of similarities of two objects. The meaning of the metaphor depends on thought processes in which an entire system of implications from the target domain interacts with the system from the source domain in a cognitive act of 'seeing-as' or 'conceiving-as'. According to Black, the comparison theory misses this interactive process by which an emergent structured meaning is generated in such a way that it cannot be broken into parts without destroying crucial meaning relations. That is, comparison theory of metaphor is too reductionist and atomistic in its account of metaphorical meaning.

Conceptual metaphor theory

Lakoff and Johnson (1980, 1999) are the key proponents of conceptual metaphor theory. Their account of how metaphors work in generating understanding builds on three findings of cognitive sciences: (1) the mind is inherently embodied, (2) thought is mostly unconscious and (3) abstract concepts are largely metaphorical. The first states that our conceptual system neurally makes use of, and is shaped by, our sensory and motor systems. That is, understanding is framed in terms of concepts shaped by our embodied experiences. The second finding argues that our thought is mostly unconscious and that we do not have much control over how we conceptualize situations and reason about them. For abstract thought, metaphorical reasoning in the form of conceptual or complex metaphors is used. Built on these three findings, the theory of conceptual metaphor consists of four parts (Lakoff and Johnson, 1999): (1) theory of conflation, (2) theory of primary metaphor, (3) neural theory of metaphor and (4) theory of conceptual blending.

The theory of conflation (Johnson, 1997) states that, for young children, subjective (non-sensorimotor) experiences and judgements, on the one hand, and sensorimotor experiences on the other, are regularly conflated. They are so undifferentiated in experience that for a time children do not distinguish between the two when they occur together. The theory of neural metaphor (Narayanan, 1997) then claims that the associations made in conflation are realized neurally in simultaneous activations that result in permanent neural connections made across neural networks. These neural connections form the basis for source-to-target activations that constitute metaphorical entailments. The theory of primary metaphor (Grady, 1997) argues that most complex metaphors consist of atomic metaphorical parts called 'primary' metaphors. A primary metaphor, an activation of neural connections, allows sensorimotor inference to structure the conceptualization of subjective experience and judgements. Complex metaphors are then formed by conceptual blending (Fauconnier and Turner, 2003), a mechanism by which two or more primary metaphors are brought together to form a larger complex metaphor or blend. Such blends may be either conventional or wholly original. There are different types of conceptual blends. Though metaphor involves blending, not all blending involves metaphor (Fauconnier and Turner, 2003).

Summary

Our review agrees with Way (1994) who notes that each metaphorical theory has something important to say about how metaphor operates. However, each also has specific difficulties in accounting for the full range and power of metaphors. Before we present the drawbacks or limitations common to all three metaphorical theories, we will summarize the key points revealed in each theory.

By stressing the importance of similarities, the comparison theory points to an essential aspect of metaphor, but it also assumes that similarities exist between two concepts before the metaphor is used. This assumption is invalidated by many examples where metaphorical understanding results in creative and emergent meaning with the basic mechanism in metaphorical understanding involving the generation and creation of new meaning beyond an existing similarity (e.g., see Cornelissen, 2004, 2005, 2006).

Interaction theory draws our attention to the creative aspects of metaphor and sees metaphorical creativity as more than antecedently existing similarities between the source and target domains. Metaphorical creativity creates as much as it reveals the existing similarities; i.e., metaphorical creativity is emergent in nature. However, as is argued by Johnson (1990) and Way (1994), Black's account of metaphorical creativity is vague.

The proponents of the conceptual metaphor theory argue that to explain metaphorical creativity we need to accept that the mind is inherently embodied and thought is mostly unconscious. This is at odds with both comparison theory and interaction theory, which view metaphor as either linguistic (comparison theory) or cognitive instrument (interaction theory). Neither theory takes seriously the idea that a metaphor is primarily rooted in, shaped by, and shaping the embodied experience.

Moving to the limitations of metaphorical theories, the notion that metaphor works because of the dynamics between similarities and differences is overlooked by all three theories. Hausman (1989) argues that a metaphor is effective because of dissimilarities rather than similarities. Ricoeur (1978) states that the reason metaphor works is because it creates a tension between sameness and difference. Morgan (1980, 1983) claims that metaphor is based on partial truth in which certain features are emphasized and others suppressed in a selective comparison. Bohm and Peat (2010) argue that the use of metaphor involves a paradox, a simultaneous equating and negating of two domains, where the metaphor urges one to acknowledge both similarities and differences. Oswick *et al*. (2002, 2011) state that both similarities and differences are essential for theory development. They claim that metaphor, metonymy and synecdoche work on the basis of similarities, while anomaly, irony and paradox work on the basis of dissimilarities. They call for less emphasis on similarities and more emphasis on dissimilarities.

Furthermore, the central idea behind interaction theory is that metaphors create similarities and do not just report on pre-existing objective similarities (Cornelissen, 2004, 2006). This implies that metaphors have two roles – creative and reality creating:

> For such reasons as this I still wish to contend that some metaphors enable us to see aspects of reality that the metaphor's production helps to constitute. But that is no longer surprising if one believes that the 'world' is necessarily a world *under a certain description* [original emphasis] – or a world seen from a certain perspective. Some metaphors can create such a perspective. (Black, 1977, p.454)

Others have also recognized this reality-creating aspect of metaphor:

> . . . the processes of metaphor in language, the exchanges between the meanings of words which we study in explicit verbal metaphors, are superimposed upon a perceived world which is itself a product of earlier or unwitting metaphor. (Richards, 1936, pp.108–9)

Pinder and Bourgeois (1982) argue that the point at which a metaphor stops being of positive heuristic value and starts to be misleading is difficult to detect. Weick (1989) recognizes that metaphors are not just catchy phrases, but an integral part of how reality is constructed. Similarly, Tsoukas (1991) argues that metaphors do not simply describe an external reality; they also help constitute that reality and prescribe how it ought to be viewed and evaluated. Although a view that metaphors can create reality is recognized in the literature, the three theories provide no explanation of how it is that metaphor can have such a central ontological function. To summarise, two aspects of metaphors are unexplained: (1) the relationship between similarities and differences, and (2) how metaphor creates reality. Both are widely recognized in the literature, but unexplained by the three theories of metaphor.

From differences to similarities and back: the process of metaphorical reasoning

The process of metaphorical reasoning is an attempt to address the two drawbacks identified above. Its key assumption is that the use of a metaphor involves a paradox whereby the metaphor both enables and constrains our reasoning. Shedding light on this paradoxical nature of metaphor is necessary to understand its role in theory development. To realize this, the relationship between similarities and differences inherent in metaphors was investigated. The investigation led to the following process of metaphorical reasoning underpinning theory development: $T \neq S_1$ leads to $T = S_2$ leads to $T \neq S_2$ ... where: T is studied phenomenon or target domain, S_1 is source domain of the metaphor commonly used to understand T and S_2 is new source domain providing a new metaphorical understanding of T. The '...' implies that metaphorical reasoning is an open-ended process.

$T \neq S_1$

One of the major findings about human neurophysiology is a realization that what we experience has acquired meaning before we become conscious of it. Consciousness presents us with sensory data that have already been processed, compressed and interpreted (Nørretranders, 1999). The capacity of consciousness is less than 40 bits/s, which is incredibly small compared with the volume of information we take in through our senses, which estimated to be more than 11 million bits/s (Zimmermann, 1986). The key task, done entirely by cognitive unconscious, is to reduce 11 million bits/s to fewer than 40 bits/s so that the latter can be used as a map for the former. So, every second million of bits of information is discarded and compressed into just a few bits. This process is not random but is somehow meaningful to us. What we consciously experience is not the raw sensory data, but an interpretation of the sensation (Nørretranders, 1999). It is proposed here that this sparse and highly compressed interpretation of the world is provided by metaphor. Our consciousness presents us with a metaphor that provides an interpretation of the sensation about the world rather than the raw sensory data. This is the starting point of our process.

The creative process, which will eventually result in a different metaphorical interpretation of the studied phenomenon (T) unlocked by a new domain of experience (S_2), starts with the realization that there are some significant differences ($T \neq S_1$) between the interpretation provided by the prevailing metaphor, characterized by the domain of experience S_1, and the studied phenomenon. The first step towards creating a fresh metaphorical understanding of T is the awareness of some aspects of the phenomenon that have either been ignored or hidden by the habitual application of S_1. To understand how this may happen, we need to understand how our senses can deprive us of a capacity to sense. Sensory studies (Ratliff, 1965) have found that our senses respond to the difference, to relative, not absolute, values. To sense is to sense a difference. Without an ability to sense a difference, we are not able to sense at all.

Morgan (2006) says that, although a metaphor allows us to see new similarities, the seeing is, at the same time, based on not seeing the differences. Through creating new ways of seeing, metaphors at the same time create ways of not seeing. Consequently, metaphors not only interpret reality but are also able to create reality. The first step of the creative process is to break away from such reality by restoring the senses numbed by the habitual, and largely unconscious, use of the established metaphor. This will allow us to sense the differences between the studied phenomenon and the understanding enabled by the prevailing metaphor.

$T=S_2$

Once aware of the significant differences ($T \neq S_1$) and the need for a fresh way of organizing understanding, the search for a more revealing metaphor can begin. The search will end once we realize that the differences in some other domains of experience (S_2) are similar to those that are, at first sight, unrelated domains of our study (T). This will urge one to apply known ideas in a new context. Therefore, the process is driven by a search for similar differences ($T=S_2$). The resonance with Aristotle's view on metaphor is evident:

> But the greatest thing by far is to be a master of metaphor. It is the one thing that cannot be learnt from others; and it is also a sign of a genius, since a good metaphor implies an intuitive perception of the similarity in dissimilars. (Lakoff and Johnson, 1999, p.384)

With source-to-target ($S_2 \rightarrow T$) mapping, the primary function of a metaphor is to reason about the target domain by using the inferential structure of the source domain. The notion of vital relations proposed by Fauconnier and Turner (2003) may provide a clue to what is being mapped between the two domains, and elaborated in the metaphor. Vital relations are a small set of relations established between two mental spaces. Table S1 in this paper's supplementary material gives an overview of key vital relations.

The metaphorical mappings established between the two domains via the vital relations help to highlight and elaborate similarities, thus enabling insight. This is the essence of creativity, which, according to Koestler (1964, p.35) is 'the perceiving of a situation or idea … in two self-consistent but habitually incompatible frames of reference'. The definition is almost identical to single-scope and double-scope conceptual blends that, according to Fauconnier and Turner (2003), underpin metaphorical integrations.

A single-scope blend consists of two input spaces with different organizing frames, one of which organizes the metaphorical blend. The organizing frame of the blend is an extension of the organizing frame of one of the inputs, but not the other. A double-scope blend consists of inputs with different organizing frames (often clashing) and a metaphorical blend with an organizing frame that includes parts of each of those frames and has emergent structure. In both blends, the elaboration of similarities ($T=S_2$) via the vital relations is an unconscious process. Koestler (1964, p.201) argues that the essence of creativity is 'that unlikely marriage of cabbages and kings … but the ultimate matchmaker is the unconscious'. Similarly, Fauconnier and Turner (2003, p.44) say that the creative act 'seems magical precisely because the elaborate imaginative work is all unconscious'. In addition, the elaboration of vital relations established in the metaphorical blend happens all at once. Lakoff and Johnson (1980) say that we categorize experiences in structured wholes or experiential gestalts. In gestalts, we experience a wholeness before we perceive the parts; we see a configuration before we see the elements. Gestalt theorists maintain that the whole is distinct from the sum of its parts; the whole has emergent properties (Rock and Palmer, 1990). So, metaphorical understanding 'takes place in terms of entire domains of experience and not in terms of isolated concepts' (Lakoff and Johnson, 1980, p.117). This has important consequences for the last stage of the process.

$T \neq S_2$

According to Matte-Blanco (1975, p.1988), there is an unconscious and inevitable tendency for humans to frame their experiences in a binarizing and polarizing way, focusing on similarities and obliterating the differences. He describes this process as symmetric/asymmetric logic. When categorizing an experience, we locate similarity within the category and thereby obliterate differences between experiences in that category (symmetric logic). Between categories, the differences are emphasized and similarities between them are obliterated (asymmetric logic). Therefore, we unconsciously organize experience in symmetrical patterns in which similarities within a category are emphasized and differences are obliterated. This way the paradox of simultaneous similarity and difference within and between categories is lost, explaining why some view metaphors as primarily about similarity rather than paradox (e.g., Oswick *et al*., 2002, 2011). The loss also explains why Lakoff and Johnson (1980) argue that metaphorically understanding a situation as being an instance of an experiential gestalt involves emphasizing only those aspects of the situation as fitting the gestalt and downplaying aspects that do not fit the gestalt. Namely, metaphorically understanding situation T involves imposing the experiential gestalt S_2 on it, implying that the creative act is as much about highlighting similarities ($T=S_2$) as about obliterating the differences ($T \neq S_2$).

The elaboration of similarities and the obliteration of differences are all unconscious. Fauconnier and Turner (2003, p.57) say: 'In the case of blending, the effects of the unconscious imaginative work are apprehended in consciousness, but not the operations that produce it'. Blending, which they call a compression tool *par excellence*, compresses vital relations between the two domains established in metaphorical mappings. The result is a metaphorical blend in which meaning is densely packed to achieve global insight and understanding at human scale (Fauconnier and Turner, 2003). Without being aware, the blend compresses one or more vital relations into another. Table S1 introduces the most commonly encountered patterns of compression of vital relations.

Being a compression tool *par excellence* and a central engine of human insight and understanding (Fauconnier and Turner, 2003), a metaphorical blend compresses vital relations between the two domains, thus creating compact experiential gestalt packed with meaning. This is what Lakoff and Johnson (1980) mean when they say that metaphors enable us to understand and experience one kind of thing in terms of another. By elaborating the similarities ($T=S_2$), the compression of vital relations is crucial for achieving new insights and understanding. However, this occurs at the expense of obliterating the differences ($T \neq S_2$). Unconsciously, we seem to push similarities to the forefront at the expense of obliterating the differences. The result is an interpretation of the world according to the metaphor. This is characterized by compression (blending) and discarding of information (differences) so the interpretation of sensory inputs has taken place before it reaches consciousness. This may explain why metaphors not only describe reality, but also create reality. It also provides a possible explanation for how our senses are numbed and deprives us of a capacity to sense. Thus is the loop closed by taking us back to where we started and making metaphorical reasoning an open-ended process. Table 1 summarizes the process of metaphorical reasoning together with the key assumptions underpinning it and propositions resulting from its logic.

Table 1. Process of metaphorical reasoning, assumptions, and propositions

Assumptions:

a. Metaphors are essential for reasoning and understanding. A metaphor has a source domain (S), a target domain (T), and a source-to-target (S → T) mapping. Use of a metaphor involves a paradox whereby the metaphor both enables and constrains our reasoning.
b. A metaphor enables us to understand and experience a studied phenomenon (T) in terms of some familiar domain of experience (S). This is achieved via vital relations that map similarities (T=S) between S and T (S → T).
c. A domain of experience is a structured whole or an experiential gestalt whereby parts make no sense without the whole. Metaphorical reasoning takes place in terms of entire domains of experience and not in terms of isolated concepts.
d. Metaphors are products of conceptual blending and can be either single-scope or double-scope conceptual blends. They are compression tools *par excellence*.
e. Our senses respond to the difference; to sense is to sense a difference. Without an ability to sense a difference, we are not able to sense at all.
f. Due to the limited bandwidth of consciousness, every second million of bits of sensory information are discarded and compressed into just a few. This sparse and highly-compressed interpretation is provided by a metaphor.
g. Humans categorize experience by focusing on similarities and obliterating the differences. Understanding a phenomenon (T) as being an instance of an experiential gestalt (S) involves emphasising aspects of the phenomenon fitting the gestalt (T=S) and obliterating aspects that do not fit the gestalt (T≠S).
h. Cognitive unconscious is essential for metaphorical reasoning. Categorization, elaboration of similarities (T=S), obliteration of differences (T≠S), and an interpretation of what we sense provided by the metaphor all happen via the cognitive unconscious.

Process of metaphorical reasoning:

i. By restoring the senses numbed by the habitual and unconscious use of S_1 to understand T, the first step in the process of metaphorical reasoning involves the realization of significant differences ($T \neq S_1$).
ii. Once aware of significant differences ($T \neq S_1$), the next step involves the realization of similar differences ($T=S_2$), which allow us to see the similarities between a new domain of experience (S_2) thus providing a new metaphorical understanding of T.
iii. In the creative act (ii), similarities ($T=S_2$) are pushed to the forefront at the expense of obliterating the differences ($T \neq S_2$). Without an intentional introspection, the obliterated differences ($T \neq S_2$) may deprive us of a capacity to sense.

Propositions:

1. Metaphorically understanding T via S_1 entails imposing the experiential gestalt S_1 on T, which, unless one is aware, may result in an inability to sense significant differences ($T \neq S_1$). Not being able to sense the differences is a result of placing emphasis on the similarities ($T=S_1$).
2. The creative aspect of a metaphor, which allows us to see and elaborate similarities ($T=S_2$) between a new domain of experience (S_2) and the studied phenomenon (T) established via the vital relations, cannot be separated from its reality-creating aspect.
3. By elaborating the similarities ($T=S_2$), the compression of vital relations in the metaphorical blend is crucial for achieving new insights and understanding. The creative aspect of a metaphor is in its emergent structure.
4. Metaphorical reasoning is an open-ended process. No matter how insightful a metaphor is, the process of metaphorical reasoning ‘predicts’ that the obliterated differences ($T \neq S_2$) will eventually form a starting point in the next round.
5. A metaphor is a compressed interpretation of the world characterized by discarding of information. These features explain why metaphors are not only potent ways to describe reality, but also able to create realities.

Methodology

To test the process of metaphorical reasoning, a methodology consisting of four steps was devised.

Identify case study

When looking for the relevant case study, two criteria were used. A case study had to be (1) well researched and documented, and (2) have importance that goes beyond its immediate domain. It was decided to investigate astronomy. This is a well-documented domain providing plenty of the information necessary for this kind of analysis. Furthermore, astronomy is the oldest science and has the longest history (Dyson, 2008), making it a forerunner to physics (Feynman *et al*., 2011).

Reconstruct key metaphors

The accounts by Koestler (1989) were used as the main source of evidence. Covering distinct periods in the history of astronomy, three metaphors were identified:

- The Universe as onion, originated with Aristotle and used by Ptolemy and Copernicus. This metaphor characterized astronomy for almost 2,000 years.
- Heavens as the epitome of the Holy Trinity, originated with Kepler, enabling him to formulate the three laws of planetary motion (Table 2), which make sense only in the light of what Newton achieved based on these laws.
- The Moon as an apple, from which Newton may have formulated the three laws of motion and the law of universal gravitation.

Heavens as the epitome of the Holy Trinity metaphor was the explicit creation of Kepler. The other two metaphors were formulated to provide the best fit with the accounts of Koestler (1989).

Detect metaphorical blend

To analyse the identified metaphors the theory of conceptual blending (Fauconnier and Turner, 2003) was employed. The theory was used first to detect and then to map the three metaphors. The two steps are interdependent and overlapping, but are here presented in a sequential manner. According to Fauconnier and Turner (2003), metaphors are typically either single-scope or double-scope conceptual blends. To detect the type of conceptual blend behind each of the three metaphors, the key features from Table S2 in the supplementary material were used. The result was:

- The Universe as an onion, single-scope metaphorical blend.
- The Heavens as the epitome of the Holy Trinity, double-scope metaphorical blend.
- The Moon as an apple, double-scope metaphorical blend.

Table 2. Galileo's principles of inertia, laws of Kepler and Newton

Galileo's principles of inertia	If an object is left alone, and no forces are applied to it, then its state of motion is unchanged.
	If an object is moving, then it continues to move with the same velocity.
	If an object is standing still, then it continues to do so.
Kepler's three laws of planetary motion	Planets travel round the Sun not in circles, but in elliptical orbits.
	A planet moves in its orbit not at uniform speed, but in a manner that a line drawn from the planet to the Sun always sweeps over equal areas in equal times.
	The squares of the sidereal periods (of revolution) of the planets are directly proportional to the cubes of their mean distances from the Sun.
Newton's three laws of motion and the law of universal gravitation	If a body is at rest or moving at a constant speed in a straight line, it will remain at rest or keep moving in a straight line at constant speed unless a force acts upon it (law of inertia).
	The vector sum of the forces F on an object is equal to the mass *m* of that object multiplied by the acceleration *a* of the object: $F = m \cdot a$ (law of acceleration).
	When two bodies interact, they apply forces to one another that are equal in magnitude and opposite in direction (law of reciprocal action and reaction).
	The force of attraction is proportionate to the attracting masses and diminishes with the square of the distance (law of universal gravitation).

Map metaphorical blend

Once the type of a conceptual blend behind each of the three metaphors was detected, the final step involved their mapping. The following method was used (Figure 1):

- A complete metaphorical blend consists of input spaces (typically two input spaces), a blend, and connections between these spaces. Input spaces are often blends themselves.
- Inputs and blend are mental spaces. A mental space is an experiential gestalt, which works with the entire domain of experience and not in terms of isolated concepts. In neural interpretation, mental spaces are sets of activated neural assemblies and the lines between elements correspond to co-activation bindings.
- All mental spaces are represented by ovals. Elements of mental spaces are represented by points in the ovals and connections between elements in different spaces by lines.
- Vital relations link input spaces and this forms cross-space mappings. A cross-space mapping connects counterparts in the input spaces.
- Structures in the inputs and vital relations between them are selectively compressed within the blended space. A vital relation between input spaces is compressed into a structure inside the blend. One of the most important things about blending is the compressions it

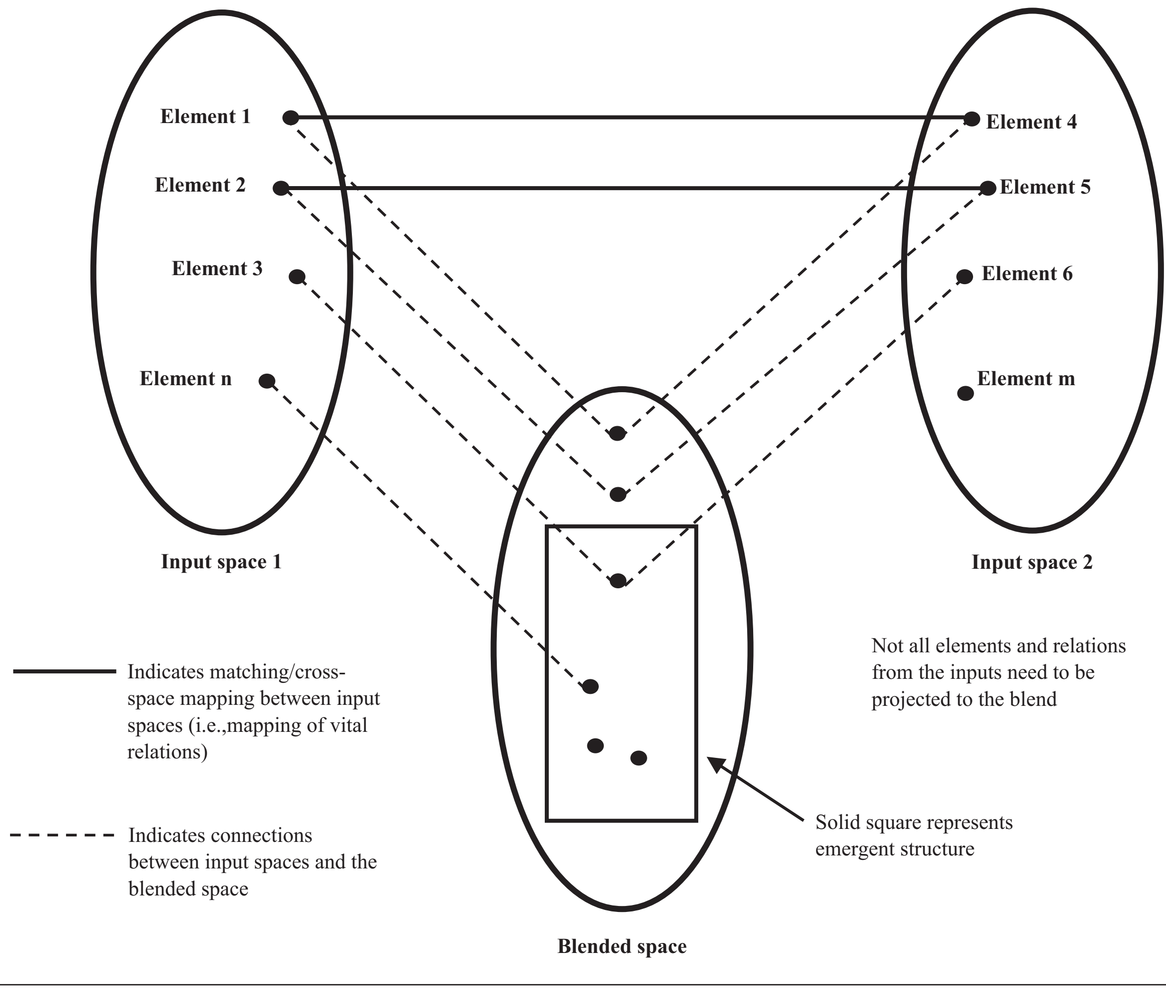

Figure 1. Metaphorical blend – map and description

Source: adapted from Fauconnier and Turner, 2003 achieves. The blend is a compressed version of the entire network; the compressions hold information about input spaces and all cross-space mappings.

- Blend has some characteristics of input spaces and may have some of its own (i.e., emergent structure). The creative aspects of metaphors are in the latter.

The result is a map of the metaphorical blend, which includes the input spaces, the blend and all the vital relations and their compressions. This allowed detailed analysis of each of the three metaphors and of their implications. From this, it was possible to reconstruct the reality ensuing from the metaphor and its similar and significant differences.

Metaphorical analysis of astronomy

Table 3, together with Figures 2, 3, and 4, presents the results from applying the process of metaphorical reasoning.

The Universe as onion

This was not the first model of the Universe, but it was significant because it shaped astronomy for almost 2,000 years. Aristotle's model was a mixture of ideas produced by Pythagoras and Plato. Pythagoreans were first to propose that mathematical relations hold the secrets to the Universe. Their cosmology held that the Earth is a sphere floating in air and around it Sun, Moon, planets and stars revolve in concentric spheres. Herakleides and Aristarchus, some of the last Pythagoreans, were first to propose that the Sun, not the Earth, was the centre of our world.

Plato believed that visible world of stars was merely an illusion and that the only world worthy of investigation is the world of eternal ideas and forms. He considered mathematics key for this. Plato took change to be not only an illusion, but virtually synonymous with degeneration. His vision of creation is a story of successive emergence of ever-lower forms of being. Everything starts with the prime mover, next is the world of reality that consists of forms and ideas, and finally there is a world of appearances that are only copies or shadows of forms and ideas. The appearances deceive men. Following the Pythagoreans, Plato concluded that the shape of the world is a perfect sphere and that all celestial motions occur in perfect circles at uniform speed.

Building on the ideas of Pythagoras and Plato, Aristotle created a model of the Universe that can be described with the Universe as onion metaphor. In this model, Earth is at the centre, immobile, and surrounded by nine concentric spheres. The innermost is the sphere of the Moon, following are the seven spheres (of the Sun, five planets, and stars), and the last is the sphere of the prime mover, who moves the whole thing. The prime mover is outside the world of humans and furthest from them. This meant that humans are the lowliest in the Universe. Their sphere is completely deprived of the divine presence and is cursed with constant change. Beyond it, everything is eternal and unchanging.

Figure 2 and Table 3 present the map and analysis of the Universe as onion metaphorical blend. The reality ensuing from this blend is an emotionally powerful one as all theologically motivated ideas are. It consists in a belief in the Universe stratified into two realms. Each realm has different properties and obeys different cause-effect laws. One is eternal, unchanging and imbued with the presence of the prime mover. The realm of the Earth is furthest from the prime mover and cursed with constant change. Both Ptolemy and Copernicus seem to commit to this reality.

The Universe as ferris wheel

The chief empirical problem of the Universe as onion metaphor is the movement of Sun, Moon and five planets. The belief is that this happens in uniform circular motions. Therefore, astronomy is reduced to application of Euclidean geometry. To describe the movement of a celestial body,

Table 3. Key metaphors and metaphorical blends in astronomy

Metaphor	Input space 1 (IS1)	Input space 2 (IS2)	Cross-space mappings between IS1 and IS2	Blended space or metaphorical blend
Universe as onion Author: Aristotle Influence: Pythagoras and Plato Timeline: 4th century BC	Domain: theology and metaphysics Type of blend: single-scope Elements and compressions: blend has three elements and one pre-existing compression: 1) Heavenly things – eternal and unchanging, made of aether, move in circles at uniform speed, and imbued with the prime mover's presence. 2) Earthly things – made only of four elements, constantly changing one another, move in straight lines, devoid of the prime mover's presence. 3) Intentionality - two different frames exist to explain events: (1) frame of the prime mover in which events are scripted, and (2) natural frame in which events are not scripted. In supra-lunar region, events are scripted. All events here (movement of heavenly things) are actions of the prime mover. However, power of prime mover gradually diminishes, disappearing completely when it reaches the centre of the Universe (Earth). In sub-lunar region where Earth belongs, all events are natural and not scripted. Explanation for events on Earth is in activities and properties of the earthly things themselves and not in the actions of the prime mover. 4) Cause-effect compression – Intentionality is added to cause-effect (see Table S1). The resulting cause-effect compression argues that the cause of change in earthly things is natural and not scripted. It is in the activities and properties of the earthly things themselves. Because they are eternal and unchanging, the only thing left to explain is movement across the heavens. This happens in uniform circular motions, which are caused by the prime mover. In short, heavenly and earthly things obey two different cause-effect mechanisms. The mechanisms are entirely a result of the presence or absence of the prime mover.	Domain: movement of Sun, Moon and five planets Type of blend: unknown, hence the use of IS1 to shed light on this domain. Elements and compressions: 1) Supra-lunar region – Sun, Moon, the five planets (Mercury, Venus, Mars, Jupiter and Saturn), comets, and stars. Other planets in our system (Uranus and Neptune) were discovered after Newton. 2) Sub-lunar region - Earth and everything on it; people, birds, apples, projectiles, stones etc.	Two vital relations are mapped (see Table S1) between IS1 and IS2: 1) Category heavenly things to category supra-lunar region. 2) Category earthly things to category sub-lunar region.	Type of blend: single-scope metaphorical blend because (see Table S2) (1) there is no emergent structure in this blend, and (2) the organizing frame of the blend is an extension of the organizing frame of IS1. Elements and compressions: 1) On Earth, change is constant and caused by other earthly things. This element results from the compression of cause-effect into category (see Table S1). The same process produces the second element. 2) Sun, Moon and the five planets move across the heavens in uniform circular motions.

Metaphor	Input space 1 (IS1)	Input space 2 (IS2)	Cross-space mappings between IS1 and IS2	Blended space or metaphorical blend
Heavens as epitome of the Holy Trinity Author: Kepler Influence: Copernicus, Pythagoras, Brahe Timeline: 16th century AD	Domain: Holy Trinity Type of blend: single-scope Elements and compressions: This blend has three elements and two pre-existing compressions: 1) Father (God). 2) Son (Jesus Christ). 3) Holy Spirit. 4) Cause-effect compression –the Father (God) acts through his Son (Jesus Christ) *via* the Holy Spirit. 5) Part-whole compression – This is about omnipresent God. The Father (God or whole) is manifested in his Son (Jesus Christ or part) and in the Holy Spirit (part). That is, all three are only different manifestations or emanations of the same entity (God). The result is a holographic idea that the whole is in the part and the part is the whole.	Domain: movement of Earth and five planets Type of blend: unknown, hence the use of IS1 to shed light on this domain. Elements and compressions: 1) Sun 2) planets 3) force	Two vital relations are mapped between IS1 and IS2: 1) Role-value: Father is the Sun, a planet is its Son, and the force is the Holy Spirit. 2) Based on the role-value mapping, an analogy relation is established between elements of the two input spaces (see Table S1).	Type of blend: This is a double-scope metaphorical blend because there is an emergent structure in this blend. In addition, the organizing frame of the blend can be seen as an extension of the organizing frame of IS1 (see Table S2). Elements and compressions: Three elements appear in this blend, two of which have emergent qualities: 1) Sun has force that acts on the planets – this element is projected from both input spaces, which is because of the analogy relation established between those spaces *via* the role-value vital relation. To this, cause-effect compression from IS1 is then added (see Table S1). 2) Sun is equivalent to a planet – this is the first emergent element resulting from projecting the part-whole compression from IS1, which has established that the whole (Sun) is in the part (a planet) and that the part is the whole. Hence, there is equivalence between Sun and a planet.

(Continued)

(Continued)

Metaphor	Input space 1 (IS1)	Input space 2 (IS2)	Cross-space mappings between IS1 and IS2	Blended space or metaphorical blend
				3) Heavenly bodies have a force by which they act on other heavenly bodies – this is the second emergent element in the blend. Once the previous two elements are realized, this element emerges naturally. Because the Sun has force that acts on the planets and since there is equivalence between the Sun and the planets, it follows that heavenly bodies in general act with the same kind of force on other heavenly bodies. This element makes possible Kepler's proposition that Moon (later he also added Sun) acts on Earth, thus causing tides.
The Moon as an apple Author: Newton Influence: Kepler, Galileo, Descartes Timeline: 17th century AD	Domain: Heavens as epitome of the Holy Trinity Type of blend: double-scope Elements and Compressions: Blend has one element and one pre-existing compression: 1) Heavenly bodies. 2) Cause-effect compression – heavenly bodies have a force by which they act on other heavenly bodies.	Domain: Earthly bodies Type of blend: single-scope blend Elements and compressions: one element and one pre-existing compression: 1) Earthly bodies 2) Cause-effect compression – Because of their mass, earthly bodies have a property (inertia) by which they resist change to their velocities.	One vital relation is mapped between IS1 and IS2: 1) Similarity: heavenly bodies and earthly bodies are similar in the sense that they both have mass.	Type of blend: an emergent structure in this blend makes it a double-scope metaphorical blend. The organizing frames of both input spaces make contributions to the blend (see Table S2). Elements and compressions: Four elements appear in this blend, two of which have emergent qualities: 1) All bodies have inertia – this element is projected from the similarity vital relation and cause-effect compression projected from IS2. It hints of Newton's law of inertia.

Metaphor	Input space 1 (IS1)	Input space 2 (IS2)	Cross-space mappings between IS1 and IS2	Blended space or metaphorical blend
				2) All bodies have gravity by which they act on other bodies – this element is projected from the similarity vital relation and cause-effect compression projected from IS1. There are hints of Newton's law of universal gravitation. 3) All bodies have inertia and gravity. This is the first emergent element in the blend and it emerges as a result of the previous two elements. 4) Between two bodies, both endowed with inertia and gravity, the result is a tug of war. This is the second emergent element in the blend and is derived from the previous element. It hints of Newton's laws of acceleration and of reciprocal action and reaction.

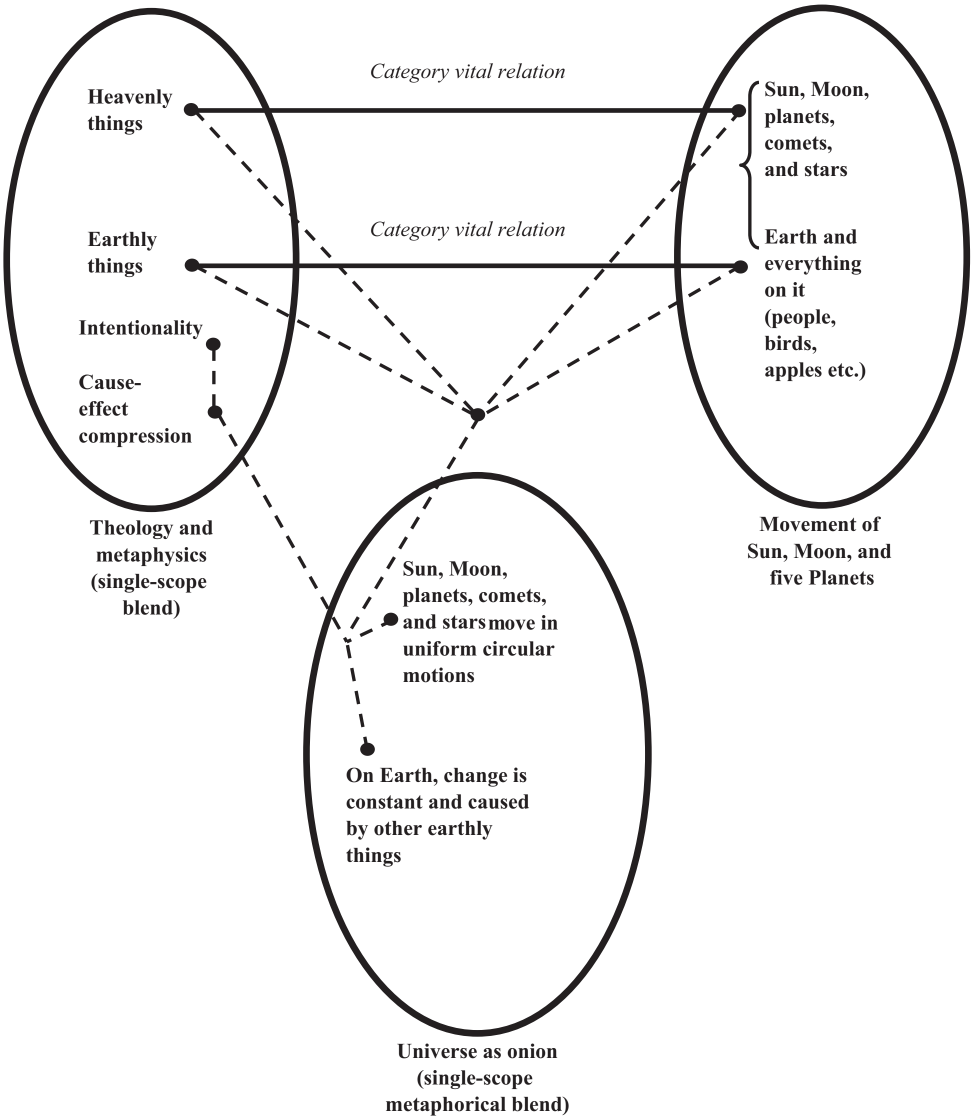

Figure 2. Map of Universe as onion metaphorical blend

Ptolemy's solution rests on concepts of deferent and epicycle. Deferent is a big circle and epicycle is a small circle whose centre moves round the circumference of the big circle. By using different ratios between the diameters of deferent and epicycle and different speeds for each, Ptolemy was able to approximate the observed motions of celestial bodies.

To explain the movement of Sun, Moon and five planets, the system needed 40 wheels. Although produced by a complicated combination of circular motions between deferent and epicycles, the resulting planetary orbits were no longer circular, but eccentric and appeared elliptic. Interestingly, the geometrical properties of ellipse were familiar to Ptolemy, but that did not deflect him from circular orbits. Koestler (1989) argues that the belief in Aristotle's model of the Universe acted as a kind of censor planted inside the mind of Ptolemy:

> Having set ourselves the task to prove that the apparent irregularities of the five planets, the sun and moon can all be represented by means of uniform circular motions because only such motions are appropriate to their divine nature. We are entitled to regard the accomplishment of this task as the ultimate aim of mathematical science based on philosophy. (Koestler, 1989, p.77)

This is an excellent example of an inability to realize significant differences between the prevailing metaphor and reality. The key differences are (1) 'apparent' irregularities in the motion of five planets, and (2) elliptic planetary orbits resulting from the application of deferent and epicycles.

The Universe as ferris wheel with the Sun (almost) at the centre

The two significant differences play no part in Copernicus's system. Rather, his system is an attempt to reform not to refute Ptolemy. Kepler says: 'Copernicus tried to interpret Ptolemy rather than nature' (Koestler, 1989, p.203). Copernicus realized that Ptolemy was not entirely true to Aristotle. In the Ptolemaic system, planets move in circular motion but not at uniform speed. To account for the irregularities observed in planetary orbits, Ptolemy had to use different ratios between the diameters of deferent and epicycles, and different speeds for each. Copernicus disagreed with the latter:

> Our ancestors assumed a large number of celestial spheres for a special reason: to explain the apparent motion of the planets by the principle of regularity. For they thought it altogether absurd that a heavenly body should not always move with uniform velocity in a perfect circle. (Koestler, 1989, p.205)

Copernicus needed something that would help him to rearrange the Ptolemaic wheels to satisfy the dogma of uniform circular motion:

> Having become aware of these defects, I often considered whether there could perhaps be found a more reasonable arrangement of circles in which everything would move uniformly about its proper centre, as the rule of absolute motion requires. (Koestler, 1989, p.206)

The solution came when he relaxed the other two dogmas of Aristotle: immovability of the Earth and its centric location.

Nevertheless, his solution is still geometrical. Furthermore, it is more complicated than that of Ptolemy. Copernicus did not reduce the number of wheels, but increased them. In total, his system uses 48 wheels (Koestler, 1989, p.195). That his system was driven by geometrical rather than physical explanations is evident from his calculation of the centre of the Earth's orbit. This is not the Sun, but a point in space removed from it by about three times the Sun's diameter. In his system, the planets do not really revolve around the Sun, but around the centre of the Earth's orbit. Since Earth still governs the movement of planets, Copernicus' system is similar to that of Ptolemy's.

Copernicus was a conservative Aristotelian who only wanted to rectify Ptolemy. More progressive scholars of his era had rediscovered the Pythagoreans (Herakleides and Aristarchus) and were widely discussing the ideas of a moving Earth and a heliocentric Universe. This helped Copernicus to create a system that conforms to the strict dogma of uniform circular motion (Koestler, 1989). His reality is identical to that of the Universe as onion metaphor, but with one minor 'cosmetic' difference: the prime mover now takes the identity of the Christian god. As it continues to be located furthest from humans and their world, the Christian god is still acting from the outside.

The Heavens as epitome of the Holy Trinity

Copernicus's system played an important role for Kepler, though its value lay not in the system itself, but in what it implied. This is best exemplified in the tension between the doctrine of Christian theology at the time and Copernicus's system. Thus, John Donne sees Copernicus as the principal pretender to Lucifer's throne. Donne explains this by the fact that Copernicus raised Lucifer and his prison into the Heavens, while relegating the Sun to the lowest part of the Universe (Koestler, 1989). This shows how in the Middle Ages the dogma of the dualism of supra-lunar and sub-lunar regions was understood as identical to Christian theology.

What helped Kepler was a new image of the Christian god, which took the form of an omnipresent god. It replaced the non-involving and remote prime mover/god of Aristotle, Ptolemy and Copernicus. As a young person, Kepler's aspiration was Christian theology, not astronomy. His interest in Copernicus's system was not from an astronomical perspective, but from the perspective of the system's implications for Christian theology. Inspired by contemporary Christian theologies, Kepler saw all physical powers of god radiating from the centre. From this, he derived Heavens as the epitome of the Holy Trinity metaphor:

> The sun in the middle of the moving stars, himself at rest and yet the source of motion, carries the image of God the Father and Creator. He distributes his motive force through a medium which contains the moving bodies even as the Father creates through the Holy Ghost. (Koestler, 1989, p.264)

This image left a lasting impression on Kepler. As Koestler says, 'it crops up in his writings over and again: there is a force in the sun which moves the planet' (1989, p.329). To elaborate and test this idea, Kepler needed reliable astronomical observations, which he found in Tycho Brahe. With Brahe's data, Kepler was able to test and refine his theory. He identified four significant differences between Copernicus's system and the observations: (1) deviation of Mars's orbit from circular shape, (2) the centre of the Earth's orbit is a vacant point in space, not the Sun, (3) time taken to go round the Sun is different for each planet, and (4) planets revolve with different velocities around the Sun. To explain the differences, Kepler had to discard all the dogmas of the Universe as onion metaphor. He realized that the only shape that fitted the observations was an ellipse. This, together with the idea that 'there is a force in the sun which moves the planet', helped to explain why planets further from the Sun revolve more slowly than closer planets. It also accounted for the variable speeds with which planets revolve throughout the year.

All this came from a realization of similar differences between the Holy Trinity and the relationship between the Sun and the planets. From the analysis of this metaphor (Figure 3 and Table 3), the reality ensues in which all heavenly bodies are imbued with a force through which they act on other heavenly bodies. That he had made the realization is clear from his explanation of tides, which he attributed to the attraction of the Moon to which he later added the effect of the Sun. The mystery is why he failed to realize what Newton did after him.

The Moon as an apple

Little is known about the inner workings of Newton's mind (Koestler, 1989), which makes it hard to reconstruct the exact mental process that led to his synthesis. Parts of the puzzle came from Kepler, Galileo and Descartes. In the case of Kepler, this involved his three laws of planetary motion. In the case of Galileo, Newton built on his studies of the motion of bodies on Earth. However, the two parts did not fit together and were providing contradictory ideas. According to Kepler, planets moved in ellipses, but according to Galileo in circles. Kepler believed a force drove the planets while Galileo believed planets were not driven at all. He thought inertia made planets persist in going round in circles while Kepler used inertia to explain why planets tend to lag behind. Like Galileo, Descartes rejected Kepler's force and he believed, contrary to Galileo, that inertia made bodies persist in linear and not circular motion. These conditions shaped Newton's synthesis.

In contemporary culture, this synthesis is depicted with an image of a falling apple. Embodied experience is central for metaphors and an image of a falling apple may have helped Newton. Thus, Bohm and Peat (2010) say that the genius of Newton is in realizing that there is no difference between the forces that keep the Moon in its orbit and the forces that attract all things on Earth. Newton had realized that there are similar differences between heavenly and earthly things.

Even before Newton, telescope observations had shown that the Moon had a surface like the Earth. This led to a conviction that heavenly bodies were of an earthly nature with mass being

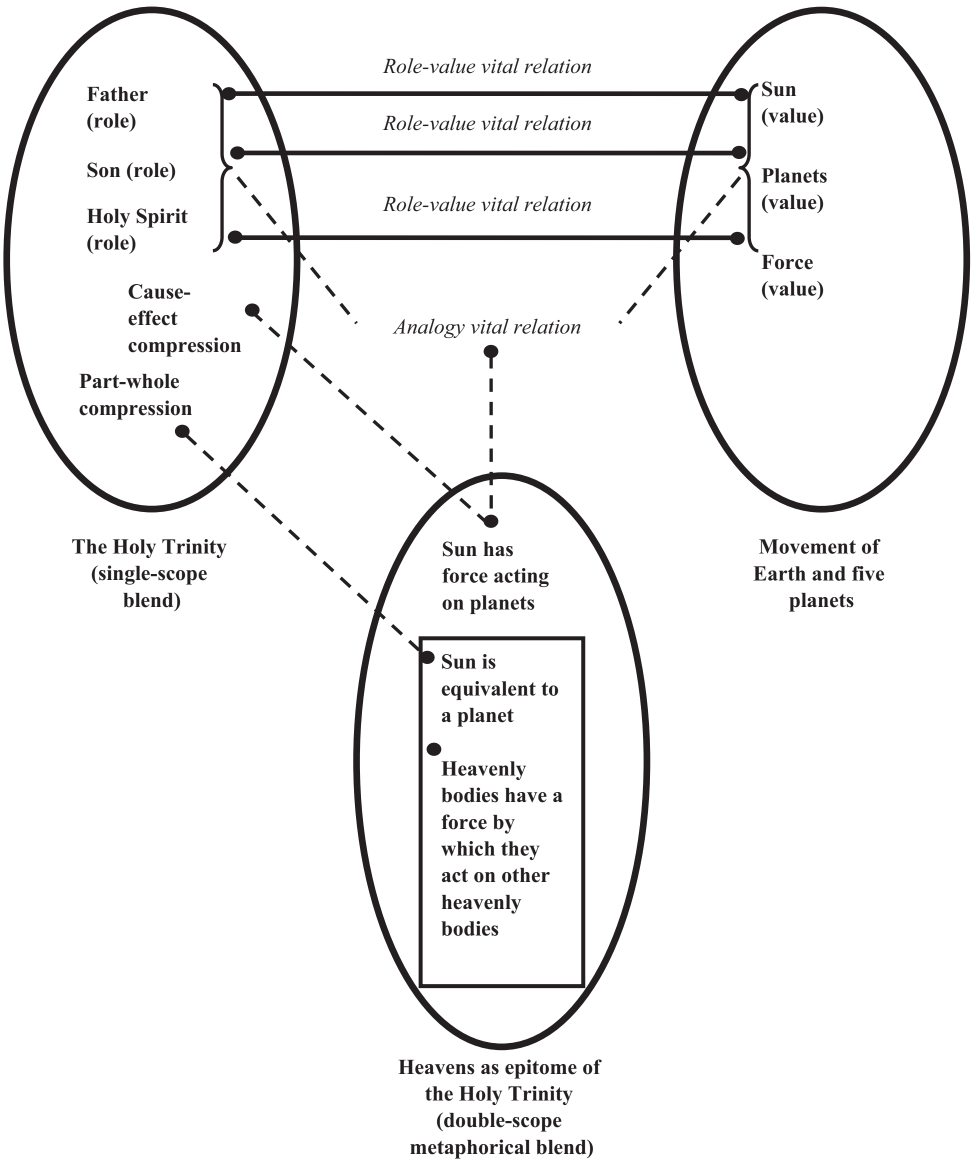

Figure 3. Map of Heavens as epitome of the Holy Trinity metaphorical blend

the most conspicuous quality of earthly bodies (Koestler, 1989). Inertia, or resistance of a body to change in its velocity, is one of the primary properties of mass. Galileo (Table 2) initially developed the concept. On the other hand, Kepler's laws rest on a notion that all heavenly bodies are endowed with a force by which they act on other heavenly bodies. In the concept of mass, Newton found similar differences between heavenly and earthly bodies. The dynamics between inertia and Kepler's force explain why planets orbit in elliptic motions. The two act in a kind of tug of war: Kepler's force of the Sun and the linear inertia of a planet. Newton's synthesis (Figure 4 and Table 3) is a unification of the heavens and earth. The synthesis created a reality in which, in physical terms, there is no difference between forces acting on a planet and those acting on an apple. Inertia and gravity become qualities shared by all matter in the Universe.

Discussion

This section discusses findings from the metaphorical analysis of astronomy and their support for the five propositions in Table 1.

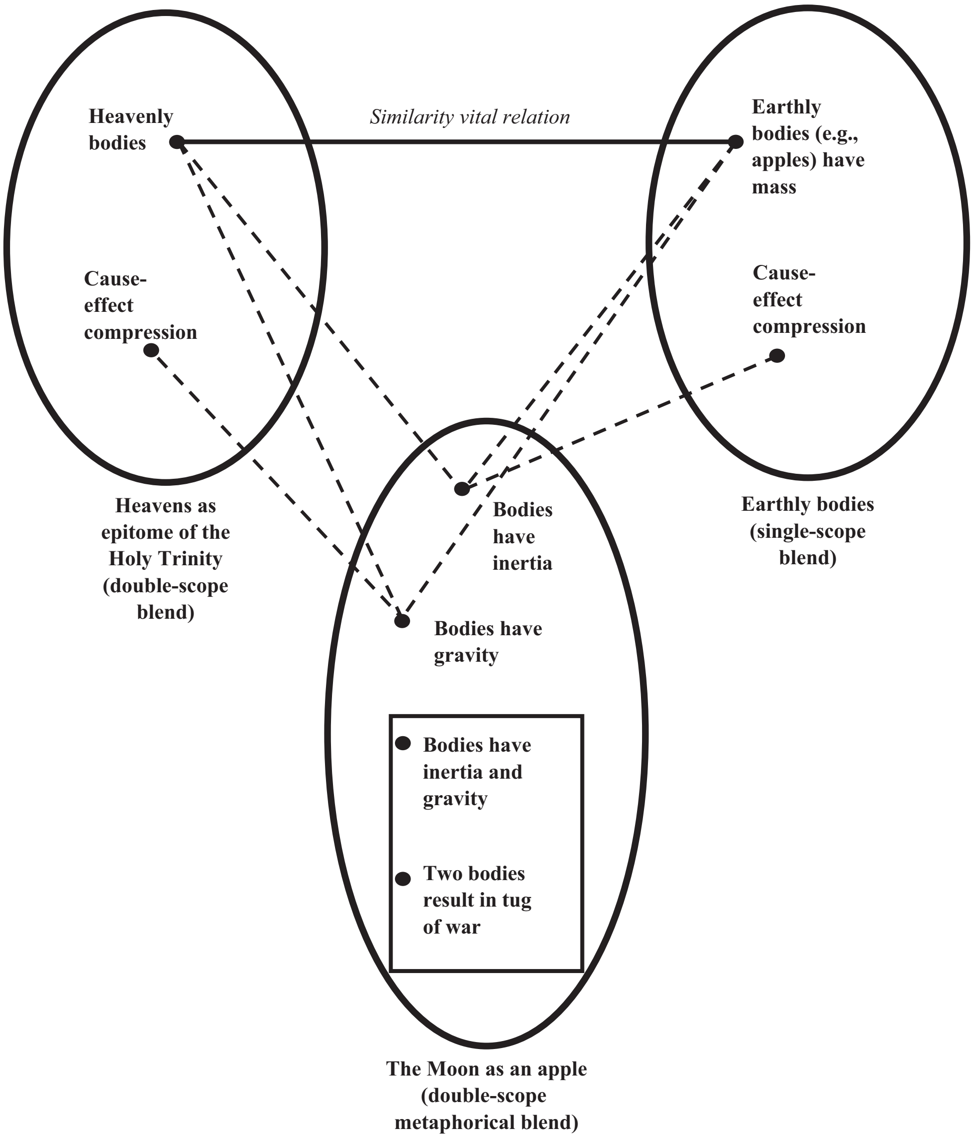

Figure 4. Map of the Moon as an apple metaphorical blend

Metaphors create realities

Feyerabend (1999) defines real as that which plays an important role in the kind of life one wants to live. The Universe as onion metaphor is a great example of this. The metaphor created such a compelling reality for Copernicus and Ptolemy that they completely ignored the significant differences between the metaphor and reality.

Modern astronomy uses a parameter called 'orbital eccentricity' to determine how much an orbit of a planet deviates from a circular orbit. A value of zero means a circular orbit, values between zero and one mean an elliptic orbit. When orbital eccentricities for the five planets known to Aristotle, Ptolemy and Copernicus are considered, we see that most planets deviate very little from the circular orbit (NASA, 2022). It is argued (Proposition 1) that a metaphor's capacity to create reality is determined by its experience-imposing side which, because of placing too much emphasis on the similarities, may result in an inability to sense significant differences. For Ptolemy and Copernicus, the movement of planets was the problem framed entirely in geometrical terms. They saw no need for any physical explanations to account for the irregularities; the solution lay in better geometry and not in physics. In this reality, there are only motions, but no moving forces.

There are only geometrical laws, but no physical laws. It is not that astronomy is divorced from physics, but that the former has no need for the latter. Whether the centre of the Universe is Earth (Ptolemy) or some vacant point in space (Copernicus) is irrelevant as long as the dogma of uniform circular motion is satisfied.

Because metaphor is an abstract intermediary between senses and experiences (see below), it imposes structure on our experience, thus producing a metaphorical concept of what is real. Aristotle made the entire Universe a material metaphor of his philosophy. In this metaphor, humans and their world are the lowest in the hierarchy of beings, with the prime mover standing at the top. What may have motivated Aristotle, which resonated with the Christian theology of the Middle Ages, is the political, social and economic decay of his time (Koestler, 1989). Yearning for stability and permanence (of the heavens) and abhorrence of change (experienced everywhere) found places in Aristotle's philosophy. The latter reflected what he believed to be important for the kind of life he wanted to live. Dyson (2008) argues that modern science grew out of Christian theology, which is a product of Greek philosophy. He claims that the idea that god may be understood through intellectual analysis is uniquely Christian. This resulted in long theological disputes that may have nurtured the habit of analytical thinking that could also be applied to the analysis of natural phenomena. So, Greek philosophy had metamorphosed into Christian theology from which Western science grew. Nowhere is this more obvious than in Kepler.

Limits to metaphorical reasoning

Christian theology played an essential role in Kepler's laws of planetary motion. Heavens as epitome of the Holy Trinity metaphor brought potent inference logic, which enabled theorizing about gravity. Its central element is part–whole compression that means that gravity is a quality possessed by all heavenly bodies (Table 3). This is a prime example of the creative and emergent aspect of metaphors (Proposition 3). Only a small step separated Kepler from proposing that gravity is a general principle in the Universe. However, he never took that step.

From Kepler's writings it is evident that he came very close to the idea of universal gravity. 'Gravity is the mutual tendency between cognate bodies towards unity or contact (of which kind the magnetic force also is) so that earth draws a stone much more than the stone draws earth' (Koestler, 1989, p.342). He applies this understanding to propose the first correct explanation of tides. Nonetheless, Kepler failed to propose that gravity is a general principle in the Universe. Koestler (1989) attributes the failure to Kepler's struggle to conceptualize gravity. We argue that the struggle may have been attributable to a metaphorical void associated with the concept of gravity. For this action-at-a-distance force, he could not find a metaphor that would help him to reason about it without relapsing into metaphysics. Ironically, Kepler was the first to frame science in terms of physics, yet his theory rested on a metaphysical concept.

Interestingly, Galileo and Newton also experienced strong mental resistance towards gravity. Even Descartes rejected the idea. Galileo rejected Kepler's explanation of tides because 'despite his open and penetrating mind he has lent his ear and his assent to the moon's dominion over the waters to occult properties and such-like little fancies' (Koestler, 1989, p.486). Newton insisted that:

> gravity should be innate, inherent, and essential to matter, so that one body may act upon another, at a distance through a vacuum, without the mediation of anything else, by and through which their action and force may be conveyed from one to another, is to me so great an absurdity, that I believe that no man who has in philosophical matters a competent faculty of thinking, can ever fall into it. Gravity must be caused by an agent acting constantly according to certain laws; but whether this agent be material or immaterial, I have left to the consideration of my readers. (Koestler, 1989, p.511)

The reason why Descartes, Galileo, and Newton thought of gravity as an impossible, occult and absurd concept respectively is the same as why Kepler failed to realize that gravity is a general principle in the Universe. It is because of the metaphorical void associated with the concept. We see here a parallel with quantum physics. Bohm and Peat (2010) say that the very abstract nature of quantum physics, where the whole emphasis is on the equations, is because it has never been understood in terms of physical concepts. Said differently, because of the lack of experientially motivated metaphors that would help us relate to the surreal world of quantum physics, it has evolved into a form dominated by mathematical abstractions. This is the only part of the theory that everyone understands (Bohm and Peat, 2010). However, neither Schrödinger's wave equation nor Newton's law of universal gravitation is able to tell us what it is that they manipulate. The two cases show that the fact that a theory works does not require that we understand its assumptions.

The point about metaphorical void implies an important lesson. Metaphors are grounded in and constrained by experiential structures which arise from the interactions between us and the environments in which we live (Lakoff and Johnson, 1999). That is, imagination may be a vast resource, but it has limits set by these structures. They both enable and constrain our reasoning.

Paradoxical nature of metaphors

No matter how insightful a metaphor is, it is inevitable that it is going to constrain our reasoning. A metaphor has a creative and a reality-creating side (Proposition 2). This paradoxical nature of metaphors is demonstrated in the Moon as an apple metaphor. The same metaphor also shows that inability to sense differences is caused by unconsciously emphasizing the similarities (Proposition 1).

The central element of the Moon as an apple metaphor is the similarity vital relation (Table 3), elaboration of which leads to new and emerging insights and understanding (Proposition 3) about dynamics. Newton's genius was in his realization that heavenly and earthly things are not different but similar. He found similarity in the quality of mass. However, Newton's laws do not hold for things moving close to the speed of light, in which case Einstein's theory of general relativity is used. The latter is primarily a theory of gravity, describing the gravitational field as a curvature of space-time and explaining the fall of an apple as the response of the apple to the curvature of space-time induced by the Earth (Dyson, 2008).

Richard Feynman argued that Newton's concept of gravity as force acting at a distance, and Einstein's concept of gravitational field filling and warping space between bodies, are scientifically equivalent but psychologically different (Lightman, 1989). Put differently, the two concepts of gravity imply two different metaphors, entailing two different inference structures. In the case of Newton, gravity is a force, but in the case of Einstein, gravity is space-time curvature. In the case of Newton, the focus is on two masses; in the case of Einstein, the focus is on the space between them. Our understanding depends on the specific metaphor we employ to reason about gravity. With this in mind, let us turn to the reality-creating aspect of the Moon as an apple metaphor. We show how 'psychological' reasons prevented scientists working with this metaphor to realize the significance of the Hamilton-Jacobi theory.

Developed in the 1860s, the Hamilton-Jacobi theory anticipated the quantum-mechanical notion of wave-particle duality and special and general theories of relativity (Bohm and Peat, 2010). It provided an alternative way of treating the mechanics of moving bodies, but received very little attention. Newton explained motion in terms of the trajectories taken by bodies. The Hamilton-Jacobi theory presented a new way of treating motion that is based on waves rather than on bodies. Though Newton's mechanics assumes that mass is essential to matter while the Hamilton-Jacobi theory implies that matter is of a wave nature, the two theories generated the same results. Being mesmerized by the concept of mass, scientists working within the Moon as an apple metaphor were not able to realize the potential of Hamilton-Jacobi. Instead, they perceived it simply as a mathematical transformation of Newton's equations. If this 'psychological' reason had not prevented them, the developments of quantum mechanics and relativity physics might have occurred earlier.

The case of the Moon as an apple metaphor shows that the same metaphorical reasoning can result in scientific discoveries and in scientific fallacies. It demonstrates the dual nature of metaphors; their creative and reality-creating sides. A potent metaphor fuels our understanding with a structure and the inference patterns it carries. However, by constraining what inferences can be drawn and what is actually possible, the same structure and patterns distort our understanding. This paradoxical nature of metaphors explains why metaphorical reasoning is an open-ended process (Proposition 4).

Metaphors as abstract intermediaries between senses and experiences

Our final proposition (Proposition 5) argues that a metaphor is a compressed interpretation of the world characterized by the discarding of information. We show next how these features explain the paradoxical nature of metaphors. What is remarkable about the metaphor is the sparsity of its concepts and the richness of meaning it provides. For example, with only a few concepts, the Moon as an apple metaphorical blend (Figure 4 and Table 3) provides hints of Newton's three laws of motion and the law of universal gravitation. The metaphor is a compression tool *par excellence* (Fauconnier and Turner, 2003). A metaphorical blend compresses vital relations into a compact gestalt packed with meaning. Because of the very limited bandwidth of consciousness (<40 bits/s), the compressions reduce the cognitive load. Instead, the metaphor focuses on only a handful of similarities at the expense of obliterating the differences. If the metaphorical blend is a single-scope type, the compressions carry only the existing similarities. More potent and creative are metaphorical blends of double-scope type, which go beyond surface similarities. These metaphors have emergent structure and meaning. It is shown next how the same property explains why metaphors discard information. Thus, emergence explains both the creative and reality-creating side of metaphors and is responsible for their paradoxical nature.

Colloquially described, emergence is where the whole is different from the sum of its parts, implying a non-linear relationship between parts and whole. This agrees with Stacey (2005), who defines emergence as both a product of, and a process forming, the interactions between parts and whole. Thus, emergence is temporally recursive, using itself in its own definition. Emergence is also the hallmark of complexity. Research into measures of complexity led to the concept of 'thermodynamic depth' (Lloyd and Pagels, 1988). The concept describes complexity as equal to the amount of information tried and shunted by a system in the process of constructing a particular state. It views complexity primarily as a process with history and equates it with the amount of information discarded in the process. Information in mathematical theory of communication (Shannon, 1948) is equated with entropy, which makes it a measure of disorder. Hence, information cannot be used as a measure of complexity. On the contrary, life creates and maintains order by exporting disorder (entropy/information) to its surroundings (Schrödinger, 1944). Having emergent structure and meaning, the longer the process or history of metaphor use, the more information the metaphor discards and the more complex the metaphor is.

The information discarded by a metaphor amounts to differences between the interpretation provided by the metaphor and the studied phenomenon. Since the sole purpose of knowledge is to minimize an organism's consumption of energy for a given amount of effort (Boisot, 1998), a way to achieve this is by focusing the organism on a handful of similarities and ignoring the differences. An organism discards information by means of metaphor (entropy), thus sustaining its order while minimizing its consumption of energy. Implicit in this is that similarities and differences are subjective and defined by an organism involved in the metaphorical reasoning. This is in agreement with the concept of entropy, which is a subjective property. Because their entropy is equal to the area of their surface, black holes are the only things in the Universe for which entropy can be determined objectively (Bekenstein, 1973).

Therefore, a metaphor is a compressed interpretation of the world, which, by emphasizing similarities, offers a speedy interpretation at a minimum cognitive load within the limited bandwidth of consciousness. This happens at the expense of discarding information on differences between the interpretation and the world, thus sustaining order and minimizing consumption of energy. So, a metaphor is an abstract intermediary between senses and experiences. We do not experience what we sense; we experience an interpretation of what we sense, according to the metaphor.

Conclusion

This paper has presented a process of metaphorical reasoning that investigates how metaphors support theory development, a little-understood phenomenon. The process was applied to astronomy, and the results advance our understanding about how metaphors support theory development in seven ways:

- First, an explanation for metaphors creating realities is provided. This is because of their experience-imposing properties, which, by placing emphasis on similarities, may result in an inability to sense significant differences.
- Second, the limitation of metaphorical reasoning is demonstrated. Although imagination may be a vast resource, it has limits set by the embodied nature of our experience, which both enables and constrains our reasoning.
- Third, this study shows that the creative side of metaphor cannot be separated from its reality-creation. Because of the paradoxical nature of metaphors, the same metaphorical reasoning can result in scientific discoveries and in scientific fallacies.
- Fourth, the paradoxical nature of metaphors makes metaphorical reasoning an open-ended process. No matter how insightful a metaphor, the process of metaphorical reasoning 'predicts' that significant differences will form a starting point in the next round.
- Fifth, it is demonstrated that emergence, a fundamental property of metaphors, explains both their creativity and reality-creation, and is responsible for their paradoxical nature.
- Sixth, this same property also explains both compression and the discarding of information achieved by metaphor.
- Finally, it follows that metaphors are abstract intermediaries between senses and experiences. We do not experience what we sense, but experience an interpretation of what we sense according to the metaphor. This explains the experience-imposing aspect of metaphor.

Given that metaphors are central to reasoning and theorizing, it is not surprising that these findings are consonant with what we know about theory (creative, reality-creating, sparse, abstract and open-ended). What is surprising, though, is that discarding of information seems to be essential for theory. This suggests that theory may be characterized by high complexity, but low information content. Consequently, the more complex the theory, the greater its reality-creating potential. This is explained as follows: characterized by sparsity of its concepts and the richness of meaning that emphasizes similarities, a theory offers a speedy interpretation at a minimum cognitive load within the limited bandwidth of consciousness. This occurs at the expense of discarding information on differences between the theory and the world. Most of the time the discarded information is 'noise' and focusing on similarities is sufficient to contribute to the preservation of order and energy. However, the temporally recursive nature of theory, by which it is both defining and being defined by the interactions between the organism and its environment, reinforces its experience-imposing side and only furthers dependence on the similarities. So, the more complex the theory (i.e., the longer its 'use history') the more information is discarded, and consequently, the greater the likelihood of discarding the significant differences. Since theory is only an abstraction – meaning that its application needs to be made particular to the situation – every use of the theory may lead to its potential transformation. This particularization may result in the realization of significant differences and of the theory's inadequacies. Therefore, every use of theory is a bifurcation point, leading either to its transformation or to the reinforcement of its reality-creation.

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