Narratives in Physics: quantitative metaphors and FORMULA ∈ tropes?

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‘One should not spoil such things with words’, remarks the Captain in Goethe’s ‘Elective Affinities’ and continues in ‘sign language’:

> Suppose an A connected so closely with a B, that all sorts of means, even violence, have been made use of to separate them, without effect. Then suppose a C in exactly the same position with respect to D. Bring the two pairs into contact; A will fling himself on D, C on B, without its being possible to say which had first left its first connection, or made the first move toward the second.[1]

What is it that the Captain would spoil with words and for which he has to use other signs? What do we understand by ‘sign language’? What do we understand by ‘formulae’? Is it enough for ‘sign language’ to use *symbols* as, for example, the Captain uses ‘A’ and ‘B’ instead of the names ‘Eduard’ and ‘Charlotte’? Is it necessary to use *numbers* or other mathematical signs as in $A = 5$, for example? Is ‘FORMULA ∈ tropes’ a sensible formula or does the *experience of nature* need to be codified, as in that most famous of formulas $E = mc^2$? In the following, I argue that, in physics, signs without numbers do not make sense, and that numbers without narrative are meaningless. Signs can be interchanged at will, not, however, a narrative that gives rise to a number and not the synonymy of narratives that becomes apparent through numbers.

In order to explore the epistemological function of ‘sign language’, we first have to go back a step and take a closer look at what the experience of nature is and what it has to do with metaphor. The German word for an experience – ‘*Erlebnis’* – already indicates that phenomena are always related to living – *lebende* – people, who perceive and act and who are capable of language. Concepts function due to the *independence* and *persistence* of experiences. We all understand the concepts ‘sun’, ‘cow’ and ‘milk’ because collective memory has taught them to us and, over millennia, the sun has continued to appear in the sky as a yellow disk and cows have continued to produce a drinkable white liquid. The natural variation of *singular* events is reflected in the indistinctness of the concept: what we term ‘milk’ is impossible to ascertain with precision and *equivalence* is, indeed, not defined. Nevertheless, we recognise certain unchanging phenomena as events – independent of the context, time or location of the observing party.

Only two aspects of this naïve definition of a concept will be important in what follows.

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[1] *The Elective Affinities* in Kuno Francke (ed), *The German Classics of the Nineteenth and Twentieth Centuries*, Vol. II, *Johann Wolfgang von Goethe,* translated by James Anthony Froude and R. Dillon Boylan, New York, German Publication Society, 1913-1914. http://www.gutenberg.org/files/11366/11366.txt

Concepts are based on the 'persistence' of experiences of nature that enables us to identify a 'equivalence' between singular events. At first glance, neither aspect has much to do with 'sign language' or even mathematics, rather they form the natural basis for concept formation of every sort. The very definition of equivalence is, however, the number, since 'equality' is, in set theory, the defining feature of the number and not some additional or secondary characteristic. Yet in order to apply the concept 'number' to an event, there has to be a measurement narrative. Let us observe, for example, a herd of cows. They can be counted by walking the entire herd through a gate and making a tally for each cow on a piece of paper on which the numbers 1 to, let us say, 100 are written. The last tally made then gives the concept 'five', for example, as the number of cows in the herd. If the experiment is repeated the next day, a number is obtained whose equality to the previous concept 'five' can be ascertained with certainty. Because the concept of the number is unequivocal, 'persistence' has taken on a precise meaning. In contrast to the concepts 'cow' and 'milk', with the concept 'number' it is possible to state with precision whether it is the same and has remained unchanged by, for example, time, place or context. The possibility of numerical measurement in persistent experiences, i.e. the determination of equivalence, allows a completely new type of 'transfer' or, in other words, of metaphor – this is the central thesis of this paper.

Quantitative metaphors: measurement narratives

In Friedrich Nietzsche's unpublished papers, a text was found 'On Truth and Lie in an Extra-Moral Sense' that, due to its radical critique of knowledge and language, became an influential text in the 20th century:

> What is a word? The portrayal of a nerve stimulus in sounds. […] We believe that we know something about the things themselves when we talk about trees, colours, snow and flowers, and yet we possess nothing but metaphors for things which do not correspond in the slightest to the original entities. […] every word immediately becomes a concept precisely because it is not intended to serve as a reminder of the unique, entirely individualised primal experience to which it owes its existence, but because it has to fit at one and the same time countless more or less similar cases which, strictly speaking, are never equal or, in other words, are always unequal. Every concept comes into being through the equation of non-equal things. […] What then is truth? A mobile army of metaphors, metonymies, anthropomorphisms, in short, a sum of human relations which have been poetically and rhetorically intensified, transferred, decorated and which, after lengthy use, seem firm, canonical and binding to a people: truths are illusions that are no longer remembered as being illusions, metaphors that have become worn and stripped of their sensuous force, coins that have lost their design and are now considered only as metal and no longer as coins.[2]

For Nietzsche then, concepts are already metaphors because they transfer meaning onto singular

[2] Friedrich Nietzsche, *On Truth and Lie in an Extra-Moral Sense,* in F. Nietzsche, *Writings from the Early Notebooks,* edited by Raymond Geuss and Alexander Nehamas, translated by Ladislaus Löb, Cambridge, Cambridge University Press, 2009, 253-264.

events. Here they will be termed **type 1 metaphors** in order to distinguish them from the term metaphor as it has been understood – in ongoing modification – since Aristotle. Essentially this understanding is based on one concept being transferred onto another, which is why in what follows, these classical metaphors will be termed **type 2 metaphors**. In his *Poetics*, Aristotle defined metaphors in the sense of shortened analogies:

> [Metaphor] is the transference of a name … on the grounds of analogy. … As old age is to life, so evening is to day; accordingly, the poet will call evening the 'old age of the day' or, like Empedocles, age the 'evening of life' or the 'sunset of life'.

Here a '*tertium comparationis'* makes the improper use of the image-giving concept possible. Achilles is no lion, he is 'merely' like one – measured against 'courage' as the *tertium comparationis.* The term 'lion' is used improperly in the metaphor 'Achilles is a lion'. Is 'green quark' therefore simply a risky metaphor, similar to 'green fingers'? What then is the *tertium comparationis*? For many physicists, 'green quark' is no metaphorical turn of phrase but rather a description of nature. For others, a 'green quark' is completely incomprehensible and cannot even be recognised as synaesthesia, as in a 'green smell'. In his Büchner Prize acceptance speech, Paul Celan, pointed out that 'the black milk of daybreak' was not a metaphor but a description of nature, and that the experience of 'trading milk on the black market at daybreak' constituted the framework for understanding.

I want to focus here solely on this discernable epistemological function of metaphor and disregard it as a stylistic literary tool. I will also not go into current theory of metaphor in all its variously differentiated forms and instead merely refer as a frame of reference to the *conceptual* metaphors used in the constitution of theory as proposed by George Lakoff and Mark Johnson.[3]

According to Aristotle, a metaphor can be understood as a form of analogy that transfers a concept from one field of experience into another through the use of a similarity. Two criteria are important here: two different fields of experience are present and there is a 'resemblance', 'similarity' or 'equivalence of meaning' that enables a transfer between these fields of experience. The metaphor is thus a cognitive method for seeing 'the similar in the different'. As a rule, metaphor works through recourse to culturally transmitted knowledge. Collective memory allows an association between such different fields of experience as a ship on water and a camel in the desert.

Physics has – at least since Galileo Galilei – found a genuinely unique way of connecting different fields of experience and constituting similarity: measurement. Since then, the core of any natural science has been not just observation, association, comparison (on the basis of knowledge accumulated over time) and concluding, but rather the concrete action of creating a 'scale' and 'applying' this to what is being observed, to events. This operation can then be applied in different fields of experience and the agreement between the values given by the scale constitutes transferability of meaning between one field of experience and another.

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[3] George Lakoff and Mark Johnson, *Metaphors We Live By,* Chicago, University of Chicago Press, 1980.

Let us take, for example, the term ‘attraction’, the apparent subject of the quote from the ‘Elective Affinities’. Bodies attract one another, become ‘glued’ together even, and metaphorically we speak of the attraction between people. If we were to observe the pace at which this kind of process of attraction proceeds, then the length of time could be measured using a clock. The quicker the attraction happens, the stronger it appears to be. Through the measurement narrative of the ‘clock’, the field of experience ‘time’ is linked to the experience ‘attraction’ and, through the measurement narrative, the ‘similar’ is the ‘length’ of the process. ‘Instant glue’ can thus become a metaphor for a particularly good and strong attraction. I will now take a closer look at this epistemologically similar function of metaphor and measurement, namely the transfer of meaning from one field of experience to another through the comparison of something similar.

We have to be somewhat cautious when using the term ‘metaphor’. In the phrase ‘the milk is white’, we would understand the use of ‘white’ not as a metaphor but as the description of a property. But if we were to say ‘this quark is green’, it is not clear which property is being referred to without further explanation. Arguably, both ‘quark’ and ‘green’ are being used metaphorically and clearly do not mean what they do in their everyday context, to which ‘milk’ and ‘white’ belong. However, this metaphorical usage is incomprehensible without knowledge of the specific physical context.

If we now hone in on the two criteria of a metaphor – ‘transfer’ and ‘similarity’ – then ‘the milk is white’ is also metaphorical speech: ‘white’ is not, first of all, a property of liquids or of bodies in general, but of light. Only light appears to us unequivocally in a particular colour, whilst we can alter the colour of milk at will by, for example, shining different coloured bulbs on it. From the point of view of physics, we are using a particular measurement narrative (illuminate milk with sunlight and observe the colour of the reflected light) to transfer a property from one field of experience (light) to the field of experience of bodies (milk). Since this measurement narrative corresponds to a traditional context and since the eye is no longer considered a measuring instrument, in the collective wisdom of seeing humans, ‘white’ has become a property of the liquid ‘milk’ and has ‘died’ as a metaphor. In order to grasp ‘the milk is white’ as a metaphor again, we have to become aware that in dealing with liquid bodies (haptic experience) and light (optical experience), we are dealing with two different fields of experience that only ‘come together’ through humans’ natural environment and their natural measuring instrument, the eye. It is in this epistemological sense that I want to understand ‘the milk is white’ as a metaphor, even though stylistically it is certainly not one. Nevertheless, I want to use the term metaphor in order to make it clear that ‘white’ is not a property of a thing, just as Achilles is not a lion. ‘Properties’ and ‘things’ are ontological categories of a realistic world view that are unnecessary at this level of reflection on cognitive processes in physics. ‘The milk is white’ is simply the transfer of the optical experience (measurement) of ‘white’ on to the haptic experience (measurement) of ‘liquid’.

Central to every measurement is the use of a scale from which a numerical reading can be taken. But are numbers not the death of metaphor? Physicists are fascinated by numbers for through their exactness, the unequal comes to light. But what does number have to do with metaphor?

When a concept, i.e. a type 1 metaphor, is defined by an instruction to read from a scale, then I propose calling this a *quantitative metaphor*. Every physical quantity is a quantitative metaphor that uses a measurement narrative to transfer from a field of experience onto singular events. 'Temperature', 'colour', 'weight', even 'distance' and 'duration' are quantitative metaphors created through measurement narratives: 'time' is that which is displayed to me by a clock; 'colour' is that which is displayed to me by a spectrometer; 'force' is that which is displayed to me by a dynamometer. In the heartbeat, the eye and the muscles, the human body possesses excellent measuring instruments for 'time', 'colour' and 'force'. This can now be summarised as a formula:

physical quantity = number + measurement narrative

When I speak of 'time', 'force' or 'colour' in the following, I am referring to the respective field of experience that, through a measurement narrative (natural or technological), is furnished with a scale, i.e. numerical values can be assigned to it. The metaphorical content then no longer lies in the numerical value, but rather in the **unit** designated by the field of experience, the measurement narrative and the scale. This can be summarised in the formula:

physical unit = measurement narrative

Well-known examples of this are 'metre', 'second', 'kilogram' but also 'Newton', 'volt' and 'Celsius'. For these units, we can introduce **symbols** that stand for the unit – the measurement narrative – and become fixed through convention. Well-known examples are m for 'metre', s for 'second' and kg for 'kilogram'. A quantitative metaphor, i.e., a physical quantity defined by a measurement narrative and which can be assigned a number through the action of measuring is also marked by a symbol, e.g. x for 'position', t for 'time' and F for 'force'. In this way, $x = 5m$ becomes shorthand for the quantitative metaphor 'the distance is five metres'. The measurement narrative, or the transfer process involved in a quantitative metaphor, only becomes apparent when we ask what '5 Kelvin' or '6 Fahrenheit' *actually* means. The actual meaning of a quantitative metaphor is often grotesque, for what does a man's name (Kelvin) have to do with temperature? What matters in any formula is not therefore the symbol, but rather the transfer of a number through a measurement narrative.

Introducing this kind of symbol can open up a treacherous epistemological trap. The symbols suggest that physical quantities are objective properties of things in a world that can be determined ever more precisely through measurement. From this perspective, units are simply *definitions* of measurement narratives capable of grasping a thing's physical properties ever more accurately. This naïve realism would provide a wonderful explanation for the persistence of experiences, but it is neither a necessary prerequisite for nor consequence of an objective knowledge of nature.

Most fields of experience allow neither their persistent (and also independent) quantitative formulation nor quantitative metaphors. For example, 'ship of the desert' may employ a technological instrument in the comparison but not, however, a scale. At first glance it is thus not a quantitative metaphor. ‘Achilles is a lion’ is a classical metaphor which, on closer inspection, is also a quantitative metaphor. ‘Achilles is a cow’ or ‘Achilles is a rabbit’ lessens the transfer of courage or strength somewhat. Let us imagine that we were to compare the courage (strength) of those animals being assigned to people and to put them in order from, for example, rabbit to cow to lion. Convention allows us to agree on, say, 100 animals, numbered through from 1 to 100. Now it is enough to just say ‘Achilles is a 10’ or ‘Achilles is a 84’ on the animal scale. Of course, the rhetorical metaphorical value is lost in this mathematisation, the metaphor is dead. Epistemologically, however, ‘Achilles is 84’ corresponds to the original metaphor which has been rendered quantitative simply through the convention of the scale, through a measurement narrative. In principle, this kind of procedure is possible for a large number of metaphors. Indeed, this kind of animal scale is not unusual. There are, for example, ‘bird song clocks’, ‘flower clocks’ and ‘blossom calendars’. We use ‘light as a feather’ and ‘to weigh a ton’. We can even modify our ‘ship of the desert’ to give a ‘tanker of the desert’, a ‘sailing dinghy of the desert’ or a ‘schooner of the desert’. The degree of rocking motion associated with each can be re-ordered and re-quantified.

But how worthwhile is this kind of procedure? Naturally the answer depends on the specific interests that a metaphor is to serve. For the natural sciences, that interest lies is the search for constant numerical relationships, since we are interested in the persistence of experiences. In our experience, scales based on subjective human assessment (animal scale, ship of the desert) are subject to greater fluctuation than scales stemming from insensate nature (flower clock) or indeed scales deriving from inert matter. In the history of physics therefore, the most *persistent scales* possible were sought through conventions around particular technical procedures. The convention of what ‘temperature’ is, i.e. how ‘temperature’ should be measured, has thus shifted from the crook of a healthy man’s arm to the consistency of butter to the expansion of a thin, liquid column of mercury, still prevalent today. What remained unchanged throughout these different measurement narratives was the number’s metaphorical significance as the ‘*tertium comparationis’* that enabled a comparison and a transfer.

The metaphoric process involving a measurement narrative described above may be based on convention, but it is not subjective or arbitrary, since the measurement narrative always results in a number through a concrete action. This is set by persistent and independent nature and not by the measuring party or the measurement narrative. In the action of measuring, i.e. in implementing the measurement narrative, the *resistant nature of the world* becomes manifest. This coupling of measurement narratives to phenomena, to singular events, is central to physical knowledge. Only by carrying out the measurement narrative, only through action, does a number emerge and is the measurement narrative rendered quantitative. The result of the measurement is not subject to the whim of the measurer but is an expression of nature. Often enough a measuring event is a happening; an unexpected event that goes against expectation and experience. Here the resistance of the world shows itself, which a scientist has learned to accept and which is constitutive of natural science’s success in using quantitative metaphors to describe phenomena.

Physical quantities are number and narrative, in which number represents the rigorous, precise part. In the measurement narrative, however, there remains an indeterminacy or unsharpness familiar from linguistic phenomena: misunderstandings, ambiguities, vagaries, … Cultural influence and historical traditions also determine how measurement narratives are read. The measured number is nevertheless incorruptible and lays bare the indeterminacies of a measurement narrative.

Thus far we have been dealing with physical quantities that are concepts attended by numbers. Drawing on Nietzsche we have termed them type 1 quantitative metaphors, in order to underline the process by which a measurement narrative is transferred onto singular events through the concrete action of measurement. Yet on the basis of their quantitative character, we can also transfer measurement narratives onto other measurement narratives.

This is already hinted at in the metaphors ‘warm colours’, ‘pitch’ (in German: *Tonhöhe* or lit. ‘tone height’) and ‘luminosity’ (in German: *Lichtstärke* or lit. ‘light strength’). Here different fields of experience come into contact through comparison: perception of colour and measurement of temperature, perception of sound and measurement of height, perception of brightness and measurement of energy. If scales are introduced for these measurement narratives, then the numerical value permits these type 2 quantitative metaphors.

Every comparison derives from numbers, even when these are not made explicit. Every comparison is a more or less of something, i.e. a bigger or smaller, a higher or lower on a scale. ‘High notes’ are perceived sounds where the measurement narrative ‘number of oscillations’ results in a high value; our ear is a good measuring instrument for this and, through habit and convention, we no longer need to take an exact reading from a scale in order to differentiate ‘high’ from ‘low’ notes.

Synonymous quantitative metaphors: laws of nature

Natural science has, it seems to me, two fascinating and complementary aspects: the *discovery of diversity* of possible events and the *ordering of experiences.*

The first happens when an explorer sets off for unknown waters or continents, goes into the jungle and finds new species; or when an optician invents a telescope and suddenly sees galaxies; or when a physicist builds a particle accelerator and discovers quarks. The broadening of human experience is a fascinating aspect of natural science: through technological achievements stars and galaxies, atoms and quarks become observable. Since these new phenomena must also be labelled, a series of fine metaphors emerge through physical research and technological invention, for example ‘ship of the desert’ or ‘coil spring’ (in German: *Spiralfeder* – lit. ‘spiral feather’). Some of these new concepts can become viable quantitative metaphors. Concepts are suddenly given double meanings, rendering them challenging mystery words in a game of ‘teapot’: ‘current’ for electricity and the flow of the stream; ‘field’ for magnetic pull and the grass that sways in the wind. This diversity of phenomena leads to ever new ontological metaphors, which label phenomena as new things in the world and which we will have to look at in more detail below since they guide a mathematicisation of the experience of nature.

The second fascinating aspect of natural science is the discovery of laws of nature that give order to a phenomenon's diversity and reveal redundancies. In laws of nature we see that that which initially appears to be different is in fact equal. The value in proposing physical quantities as 'quantitative metaphors' turns out to be the new possibilities of transfer resulting from the number. The attempt should now be made to formulate an epistemology of physics based on metaphor. This discovery of the identical in synonymous quantitative metaphors will now be examined in more detail. To start with we will be guided by Friedrich Nietzsche's 'On Truth and Lie in an Extra-Moral Sense':

> Anybody who is used to such reflections has certainly felt a deep distrust of any idealism of this kind every time he clearly recognised the eternal consistency, ubiquity and infallibility of the laws of nature. He has concluded that in nature, as far as we can penetrate to the heights of the telescopic world or the depths of the microscopic, everything is so certain, complete, infinite, regular and without gaps that science will be able to dig in these shafts successfully for ever, and all its findings will harmonise and not contradict each other. How little this resembles a product of the imagination: for if it were that, it would necessarily betray the illusion and the unreality at some point. Against this it must be said, first: if we all still had different sense perceptions; if we could only perceive now as a bird, now as a worm, now as a plant; or if one of us saw the same stimulus as red, another as blue, and a third even heard it as a sound; then nobody would talk about such a regularity of nature but would understand it only as a highly subjective construct. And second: what is a law of nature really to us?

Let us imagine that two men – one blind and one disabled – are sitting by a stream. The blind man puts his hand into the water and feels the 'force' of the flowing water. Through touch he surveys the flow, the eddies and rapids and, using the numerical measurements, he compiles a map of the local distribution of force in the stream. The disabled man remains seated and observes the streamlines, the floating leaves, how they come up against rocks, turn, speed up and slow down. He too draws a map, not of the forces but rather of the velocity or momentum currents, i.e. of the numbers obtained according to the measurement narrative 'momentum current'. With amazement they realise that their maps are equivalent, i.e. that

map of forces sensed = map of momentum currents observed

When the same part of nature is observed or surveyed through touch, with different words and images being used, it should nevertheless come as no surprise that some descriptions, by no means all, are redundant. In speaking different languages we need a dictionary to translate words that mean the same thing. What is astonishing about the equivalence of quantitative metaphors is, therefore, to lie not in the equivalence of what seems different, but in the possible variety of perceptions of the same. Yet this results from the diversity of nature, which has evolved so many different sensory organs and fields of experience, and from the human capacity to create numerous measuring instruments and speak numerous languages.

If a law of nature is the discovery of the same in different perceptions, then we must be able to find it in all possible contexts of these perceptions. Whether we observe the change in momentum of the water or a stone, or whether we measure the force of the flowing water or the force with which we throw the stone, for the law of nature it should be immaterial whether, as the expression of synonymous measurement narratives, 'force' or 'momentum current' is used. Isaac Newton recognised that force F, measured by a 'muscular instrument' (e.g. a coil spring) and momentum current dp/dt, which Galileo's measuring specification for velocity and time rendered measurable, are always proportional to one another, irrespective of the body the measurements were taken on. He thus formulated the **Newtonian law of motion**

'force' = 'momentum current'

as the universal expression of the equality of the two measurement narratives 'force' and 'momentum current'. If we use symbols for the physical quantities, then we can also write $F = dp/dt'$ for the law of motion.

Another well-known example is the relation between 'voltage' U and 'current' I in a conductor discovered by Simon Ohm, namely,

'voltage' = 'current'.

Here too it becomes clear that what is meant is not the literal meaning of 'voltage' or 'current', but rather the metaphorical meaning given by the measurement narrative.

Laws in natural science thus discover that some type 2 quantitative metaphors are, in fact, synonymous. This is at the heart of this epistemological understanding of physics as a metaphorical process. The crucial difference between this and transfers between languages or the use, for example, of automobile as a synonym for car, is that the transfer between 'force' and 'momentum current' is only possible on the basis of a number, i.e. on the basis of the quantitative nature of the metaphors 'force' and 'momentum current'.

Synonymous quantitative metaphors are only possible with type 1 quantitative metaphors, since equality is only given by numerical value. But not every type 2 quantitative metaphor is also a synonymous quantitative metaphor. Thus, for example, Ohm's law 'voltage corresponds to current' is a type 2 quantitative metaphor, since it transfers one type 1 quantitative metaphor ('voltage') onto another quantitative metaphor ('current'). But it is not a law of nature, i.e. not a synonymous quantitative metaphor, since other quantitative relationships are possible: there are contexts and materials for which deviations from Ohm's law can be found.

In contrast, the Newtonian law of motion 'force = momentum current' is found no matter which bodies, gasses or liquids the measurement narratives are applied to. We will call this kind of type 2 quantitative metaphor, where agreement is invariably found, '*synonymous quantitative metaphors*'. Therefore we must differentiate between actual synonyms – the so-called fundamental laws of nature – and simple type 2 quantitative metaphors, which are only possible for specific situations and phenomena.

The equality of the number makes it possible to discover an equivalence of quantitative metaphors that is constituted solely through the agreement of the numbers. Calling laws of nature synonymous quantitative metaphors draws attention to the fact that laws of nature are founded neither on their mathematical formulae, nor are they ontological definitions in a world of things. Rather they are an expression of redundant perceptions cast in quantitative concepts.

So seen, laws of nature explain very little, since they express what is 'merely' redundant and thus, given the diversity of phenomena, provide a meagre tally of that which is the same. The motion of a stone is contingent upon it being thrown. The law of motion, i.e. the synonymous quantitative metaphor 'force = momentum current', only determines how it must travel after it has been let go of. This is quite a lot for the behaviour of a stone, but then again not much in the face of the diversity of possible phenomena. It is interesting, however, that there are unpredictable consequences of different measurement narratives, namely laws of nature that express what remains the same, i.e. equal.

Physics, and probably all natural sciences, are based on the astonishing observation of the persistence over time of this kind of equality of numbers, which we call *laws of nature*. Most are hidden and not as obvious as the number of cows in a herd. This has led to the centuries-long search for this kind of equality of numbers in variable observations, a search we call *natural science.*

Thinking this metaphorical approach to its logical conclusion, we can no longer speak of objects and their properties, but only of fields of experience and the transfer of experience through measurement narratives. Only when this narrative corresponds to natural human experience, i.e. is given by the natural senses in a natural environment, are the transferred meanings understood to be the properties of objects, giving rise to the myth of the 'real thing'.

Mathematical-ontological metaphors: Model narratives

A key phenomenon is the experience of 'materiality' in nature: we experience bodies, particles, objects, things. Primarily, our sensory organs let us experience mediated properties, e.g. solid, liquid, gas. These phenomena, together with identity constructions based on memory, allow us an experience of things: solids as 'bodies', gasses as 'ether'. 'Stone' and 'air' are still considered familiar concepts for describing that which we meet in nature, the things of the world. 'Bodies', 'particles', 'fields' and 'ether' are already abstract concepts that encompass whole classes of things but which are still familiar from everyday speech. 'Quarks' and 'quanta', distributions and 'state vectors' are, however, concepts accessible to very few people although, like 'stone' and 'particle', they are simply describing things in the world or a class of things abstracted from the singular. I would like to term them all 'ontological metaphors' since they do not describe any (measurable) property, are not a measured quantity or a quantitative metaphor, and instead describe entities that can be more or less definitely characterised using more or fewer measured quantities. A ‘stone’ extends in space, is solid, has a particular weight, a particular texture, … As with type 1 quantitative metaphors, we have to narrate what a stone is, what properties it has and transfer this narrative onto a phenomenon. In contrast, it is not a measurement narrative leading to a number but a *model narrative* that constitutes a ‘thing’, that draws together and explains our observations. We can transfer the (type 1) quantitative metaphors used in the measurement narrative onto the mathematical-ontological metaphors of the model narrative and, in doing so, create (type 2) quantitative metaphors in the sense of abridged analogies: ‘white milk’ or ‘the stone weighs 5 kg’ mean that the milk is like ‘something’ from which white can be measured, and that the stone is like ‘something’ that, when weighed, gives the number 5, when the measurement narrative ‘kg’ is used.

Usually, this metaphorical process is understand as the ascription of properties to things, since the metaphors have become so familiar to us they are dead. ‘The quark is green’ transfers the measurement narrative of the chromodynamic colour-charge ‘green’ onto a constituent of protons that has shown itself to be point-like in scattering experiments and is characterised through a range of other measurement narratives such as ‘charge’, ‘spin’ and ‘mass’. As with ‘stone’, in everyday speech ‘quark’ is initially an ontological metaphor for a range of observable properties.

Clearly there are ontological metaphors that can also have meaning in mathematical language, such as ‘point particle’ or ‘field’, and some that are utilised only in everyday language, ‘stone’ or ‘quark’, for example. In mathematical language, a *point particle* becomes, like a point in space, a real function $r(t)$, which gives its trajectory, i.e. its position r in terms of time t. As with an entity that is continuously changing in space, a *field* is described in mathematical language as a function F(r) of positions r, where the target quantity F can be mathematical objects such as scalars, vectors or tensors. Often the mathematical character of an ontological metaphor becomes clear when an addition defines more precisely what is understood mathematically by ‘particle’ or ‘field’: point-particle, vector-field, quantum-field.

Indeed, these model narratives are much more detailed for portraying all aspects of the mathematical model of a thing. In our context it is important that these narratives are used metaphorically, i.e. ‘the milk is a fluid’ and the ‘stone is an inert body’ are not to be understood in an actual but in a metaphorical sense. This metaphorical process is the *mathematisation of the experience of nature*, i.e. it represents mathematical modelling in physics. The stories necessary here are model narratives, in contrast to the measurement narratives of quantitative metaphors. I would like to term ontological metaphors that can be translated into formal mathematical language *mathematical-ontological metaphors,* in order to differentiate them from ‘stone’ and ‘milk’.

Whether an ontological metaphor will permit mathematisation is not initially apparent. There have been numerous attempts to introduce material objects into model narratives of nature where it was not, however, possible to allocate measured quantities to them in such as way that mathematical modelling consistently described the mathematical-ontological metaphor. Therefore, there are also ontological metaphors that vanished again: ‘caloric’, ‘ether’, ‘N-rays’, ‘partons’ and maybe even ‘strings’. The ‘quark’ or the ‘quant of the chromodynamic field’ is, in contrast, a successful mathematical-ontological metaphor that stands for an object that extends in space (‘field’) but that also appears particle-like (‘quant’) and takes on particular values of quantitative metaphors, especially ‘colour-charge’, ‘spin’, ‘extent’.

Mathematical-ontological metaphors constitute a new world in a new language: the mathematical model. By being transferred onto mathematical objects they create a stage on which a mathematical play can be performed. The metaphorical character of physical properties becomes especially clear now when, for example, we speak of the ‘velocity of a point-particle’. We understood the ‘velocity’ of a stone as a quantitative metaphor that applies a measurement narrative to that which is described as a ‘stone’ in nature. Indeed, ‘velocity’ is not a property of the object ‘stone’ but a linguistic means of connecting a measurement narrative to an ontological metaphor, becoming a number through action. As such it does not matter whether the connection is related to an everyday description of a natural object or a formal linguistic description of a mathematical object. The ‘velocity of a point-particle’ has no actual meaning, only a metaphorical one when the measurement narrative ‘velocity’ is applied to the mathematical-ontological metaphor ‘point-particle’.

If an mathematical-ontological metaphor is used to describe an object, then a measurement narrative can be understood not just as an action, as an actual measurement, but also as a mathematical operation in a formal world, as a remodelling of the mathematical object. Thus measuring the velocity of a ‘point particle’ becomes, in the mathematical world, the formation of a differential quotient $dr(t)/dt$ of the point particle $r(t)$.

Through the action of measuring in nature, quantitative metaphors become ‘measured quantities’, i.e. numbers with a unit. Through the action of measuring in the mathematical world, quantitative metaphors become *‘state quantities’*, i.e. mathematical objects with a unit. State quantities are not measured quantities, since they are not only numbers but also carry a series of mathematical structures. Hence the measured quantity ‘position’ is simply a number, whereas the state quantity ‘position’ is a continuous and differentiable function $r(t)$.

It is quantitative metaphors that are the *tertium comparationis* of metaphors such as ‘point particle’ or ‘the stone is a point particle’. The number permits the comparison of measurement narratives for different objects, be they illustrative objects in nature or mathematical objects in a formal language. If the values given by the measurement narratives for the object in nature and the mathematical object always agree, then the transfer of one concept onto the other is possible: the stone is a point particle. The actual meaning would be abstruse.

mathematical-ontological metaphors may allow the mathematisation of the experience of nature, but it is quantitative metaphors that enable a connection and a comparison between the mathematical model and nature.

What then are ‘green quarks’? The colour of quarks has nothing to do with the colour of visible things. It has its origin in the metaphorical play with colour mixing, with the overlapping of green, red and blue light resulting in the appearance of white. The colour of a quark is a metaphor for the attraction between ternary poles, for a three-way 'polarity'.

We are familiar with the reciprocal attraction between positive and negative electrical charges. If you bring a positive (+) and a negative (–) charge together in a unit, the charges cancel each other out and the unit appears *neutral*. Added together, + and – give 0, i.e. a non-charged particle. In contrast to the positive and negative binary poles of electrical interaction, various experiments involving protons (number of jets in high-energy particle collisions) have established that there is strong interaction from *three different* sources, and that when these three 'charges' are brought together, the result is a non-charged, i.e. neutral particle. This 'trinity' was reminiscent of 'additive colour mixing', where three different primary colours – 'red', 'blue' and 'green' – are mixed together to produce 'white', i.e. the neutral colour. On the basis of this analogy, the observed sources of this strong interaction were named after the three colours, resulting in terms like 'red-charged' particles, for example. The colour does not therefore describe any visual property, but rather the 'colour-charges' of a 'colour-interaction' that cause a 'chromodynamic' of the particles. Their measurable sources are described as 'red', 'blue' and 'green' because together, the three different sources cancel each other out and externally, no interaction is visible, i.e. they appear neutral.

What is important here is that this metaphorical process is based on measurement narratives. The three colours 'red', 'blue' and 'green' are terms for marks on a scale in, for example, polarisation measurements in heavy ion scattering experiments. They are quantitative metaphors whose values can be compared to other measurements and then transferred onto the measured constituents of the proton, the so-called quarks. It is only in measuring these quantitative metaphors that a ontological metaphor is constituted as the carrier of these properties. A 'quark' is that which appears as 'colour charged', 'spin carrying' and 'point-like' in measurements on protons.

Whilst quantitative metaphors as measurement narrative for physical quantities offer an experimental approach to phenomena, mathematical-ontological metaphors lead to a mathematisation. This goes hand in hand with an ordering of phenomena, but also with a reduction to a finite number of degrees of freedom. In mathematical modelling, the diversity of phenomena is reduced to equations of motion of state quantities. This mathematical transfer process is justified through quantitative metaphors, whose numerical values permit comparisons between the not actually comparable.

Ontological metaphors order quantitative metaphors in that they can grasp them as properties of an object. Thus 'position', 'velocity' and 'colour' are not simply measured quantities, but measurements of 'something'. This something, the identity of the object, allows the different measurements to relate to one another as properties of the present state of the unchanging thing.

A 'point particle' corresponds to a function $r(t)$ in the mathematical world. Through measurement narratives for this mathematical-ontological metaphor, quantitative metaphors become mathematical quantities that can be derived from the function $r(t)$. Thus, for example, the ‘position’ of a point particle corresponds to the value of $r(t)$ itself, the ‘velocity’ $v(t)$ to the differential quotient $v(r)=dr(t)/dt$ and the ‘force’ acting on a point particle becomes a function $F(r(t))$ of $r(t)$. Key here is that all these quantitative metaphors have become, through mathematical language, derived quantities of the mathematical-ontological metaphor ‘point particle’.

The crucial point is that this must be the case for all possible point particles and not just for one concrete example where the function $r(t)$ attains particular numbers. In order to mean a particular point particle, one would have to choose a concrete function $r(t)$ from the set of all possible functions. In this case, we would say that the ‘point particle’ is in the particular *state* $r(t)$. The particular values of all measurement quantities can be derived from the state of the ‘point particle’ and compared to the measurements carried out on ‘things’ in the world.

How does one get to a mathematical description of ‘state’? The mathematical-ontological metaphor guides the mathematisation, but the metaphor itself is guided by relations between quantitative metaphors. Let us take a stone, for example, then the measurement quantities position x and time t are always in a specific relation. In this case, due to the monotony of time measurement, this can even be expressed as the function $x = r(t)$. This relation or function is the mathematical form of the ontological metaphor ‘particle’, which thereby becomes the mathematical ontological metaphor ‘point particle’. This origin of the metaphor ‘point particle’ in measurement quantities is the reason why the metaphor ‘point particle’ can put in order the measurement quantities as derived quantities.

Thus far, *laws of nature* have been understood as synonymous quantitative metaphors. Key here was the identity that the equality of the number made clear. Mathematical structures of objects were of little importance. These only became relevant through mathematical-ontological metaphors, which resulted in the diversity of measurement quantities being reduced to state quantities. What happens to laws of nature during the mathematisation of nature? Synonymous quantitative metaphors become *equations* or *formulae* between mathematical-ontological metaphors, i.e. between mathematical objects. Equations are the mathematical, symbolic expressions of a law of nature. Formulae can take on different forms depending on which symbols are used for quantitative metaphors; the law of nature remains the same regardless.

That ‘force’ and ‘momentum current’ are synonymous quantitative metaphors becomes, when transferred to a ‘stone’, **Newton’s equation of motion**

$$F(r) = m\, dv/dt$$

as the mathematicised form of the law of motion ‘force=momentum current’. Despite the different ontological metaphors and mathematical notations, the core of the law of nature remains the redundancy of the two measurement narratives for ‘force’ and ‘momentum current’, a redundancy that was first discovered through a quantitative comparison of the measured numbers.

FORMEL ∈ tropes? Physics and Poetry

In spite of numbers, which have almost silenced narrative in physics, the metaphor in physical research cannot be made to vanish. Perhaps metaphors are so important as a heuristic tool for discovering new physics because the entire cognitive process in physics is a metaphorical one that was both enabled by the number and at the same time hidden by it. Because formulae are mathematical metaphors, they can also be used rhetorically and literarily. Physical quantities and formulae are thus to be viewed as a new type of trope that can open up nature.

Through measurement narratives, 'green quarks' has a link to nature and can, at the same time, have a literary function as a metaphor. Through measurement it has been observed that a 'proton' is comprised of *three* differently colour-charged quarks. Externally no colour interaction is visible, i.e. the proton is *colour-neutral*, in other words *white.* With some justification we can say that a proton is white quark. Friedrich Nietzsche noted that:

> The drive to create metaphors, that fundamental drive of man which cannot be calculated away for a single moment because in the process man himself would be calculated away, is not truly defeated but barely tamed by constructing for itself, out of its own evaporated products, the concepts, a world as regular and rigid as a prison fortress. It seeks a new territory and a new channel for this operation, which it finds in myth and in art as a whole, It continually confuses the conceptual categories and cells by introducing new transferences, metaphors and metonymies, and it continually reveals the desire to make the existing world of waking man as colourful, irregular, free of consequences, incoherent, delightful and eternally new, as the world of dreams. […]
> For the liberated intellect, the huge structure of concepts, to whose beams and boards needy man clings all his life in order to survive, is only a scaffolding and a toy with which to perform its boldest tricks: by smashing, jumbling up and ironically reassembling this structure, joining the most alien elements and separating the closest, it demonstrates that it can do without those makeshift resources of neediness and is now guided not by concepts but by intuitions. […]
> There are eras in which rational man and intuitive man stand side by side, the one fearful of intuition, the other scornful of abstraction. The latter is just as irrational as the former is inartistic.

The diversity and singularity of phenomena is based on the multiplicity of that which is not determined by laws of nature. Freedom and historicity are, therefore, possible natural phenomena that comply with the laws of nature. Traditionally, the philosophy of science considers Rene Descartes' *Discourse de la méthode* as the foundation of natural science. If, however, you understand measurement narratives to be a significant epistemological practice in experimental physics, then you also have to comprehend Giovanni Battista Vico's *Prinzipi* as a foundational text for all the natural sciences. Knowledge in science is based not only on conceptual clarity and Cartesian mathematisation, but also on human history. Talk of the two cultures of the humanities and the sciences thus becomes untenable.

What physics reveals as the fundamental laws of nature are not the diversity of occurrences and also not predictions for the future, but only that which remains the same. Naturally it is an enormous scientific achievement to have found the constant in natural processes. However, the other fascinating thing in science is the discovery of the fantastic diversity of phenomena: the forms of life, the interplay of motion, the fashioning of material. This is perhaps the scientific reasoning behind Charlotte's 'moral' argument in the Elective Affinities:

> These comparisons are pleasant and entertaining; and who is there that does not like playing with analogies? But man is raised very many steps above these elements; and if he has been somewhat liberal with such fine words as Election and Elective Affinities, he will do well to turn back again into himself, and take the opportunity of considering carefully the value and meaning of such expressions.