12-24-2014

A Structured Reality

Jeremy Berke

Recommended Citation

Berke, Jeremy, "A Structured Reality" (2014). Thesis. Rochester Institute of Technology. Accessed from

A Structured Reality

Jeremy Berke

Abstract

Science has become an arbiter of truth in today's society. For example, think of how people say "It's a scientific fact" to imply that their position is infallible. As such, we should understand what science can tell about the universe. In this thesis I argue that science is telling us about the *structure* of reality, and that science only illuminates the relations among things, and not the things themselves.

What is science? What does it tell us about the world? How should we incorporate scientific theories into our world view? Galileo thought that science was the only way to understand the universe. In his 1623 work *The Assayer* he wrote

> Philosophy [i.e. physics] is written in this grand book — I mean the universe — which stands continually open to our gaze, but it cannot be understood unless one first learns to comprehend the language and interpret the characters in which it is written. It is written in the language of mathematics, and its characters are triangles, circles, and other geometrical figures, without which it is humanly impossible to understand a single word of it; without these, one is wandering around in a dark labyrinth.

It is here that the seeds of science were sowed. In 1641 Rene Descartes expanded on these ideas in his *Meditations on First Philosophy.* There he writes about the process of understanding a piece of wax, concluding that the only things he can truly know about the wax, and indeed about anything, are those that are clear and present to the mind. This leaves out perceptions of smell and taste and touch, and leaves only numbers, the only thing understandable through pure intellect alone.

The scientific revolution germinated from these ideas and has come to dominate our modern understanding of the world. We break everything down into numbers: economics, engineering, physics, biology, medicine, brewing, distilling, sports. Everything that can have a number does.

In our numericized world have we achieved a better understanding of what is going on? Are we able to point to some entities in our theories and say “that right there is real”? Can we say for certain that we have uncovered the fundamental reality of the universe? The answer, I think, is: *sort of*. I will argue that we can know about the structural relations between objects but not what the objects themselves are. There is no reason to think that we can know the individual constituents of reality, but we can know how they interact and relate to one another. In order to do this we must assign properties to the world which have a numerical value, and then use the scientific method to uncover relations among this set of properties. This view is called Scientific Structural Realism.

How is this distinction and discussion not relegated to the ivory towers of academia? Can it have any influence on our day to day life? In a very direct way: why does the scientific realism debate matter? The short answer is that it matters because we have turned to science as a main source of truth and knowledge of the world: consider that when someone says “it is a scientific fact” they are really saying “don't even try to dispute this claim because you will be wrong”. This shows that being a scientific fact is equivalent to being Truth in our modern society. If we only take scientific facts as Truth then we have implicitly placed science on a plane above all other areas of inquiry. Hence, we ought to understand what exactly science can say about the world and how we should interpret its claims.

On a more pragmatic level, science and the fruits of its labor – engineering – have built a world that we can control to unprecedented levels. We can push around electrons to make the internet, televisions, cellphones, cars, etc. We can produce better light bulbs by understanding how light can be both particle and wave, and how it interacts with matter. It is hard to look at the world that science has allowed us to create and not think that what it is telling us is at least approximately true, and that if our current theories are wrong then we took the worst turn at Albuquerque. Since we see the very real and useful effects of science we are inclined and allowed to ask questions about its relation to reality. Are there really such things as electrons, photons, holes, voltages, currents, inductances, impedances? Or are these merely useful fictions?

The long answer will be explained in the pages of this paper. It involves an investigation of the very basis and verification of all science: measurement. What is measurement? Can it be a reliable guide to reality? From there I turn my attention to specific scientific theories in the area of electrodynamics and electrical engineering to give us a solid ground on which to stand when we ask what they are telling us about the world. Hint: they are telling us solely about the relations among things. But we must keep in mind how we got to these theories, namely through ideas about relations among things and measuring those predicted relations. In making this claim we must be able to answer the "pessimistic meta-induction" argument while not being able to commit to the "no miracles argument". From this standpoint I will be able to show how structural realism is the best way to understand the story science is telling.

1. Pessimistic Meta-inductions & No Miracles

The "pessimistic meta-induction argument" against scientific realism, first articulated by Larry Laudan, goes like this. In the past we had scientific theories which we thought were correct, yet have turned out to be false. There is no reason the same fate should not befall our current theories: in the future they might all turn out to be false. Take, for example, the planetary model of the atom. After Rutherford ran his gold foil experiment and found that the atom was mostly empty space except for a small positively charged nucleus – completely displacing the plum pudding model – he theorized that the electrons must orbit the nucleus much like the planets do the sun in order for his experimental results to make sense. However, with our current understanding of quantum mechanics, we know that this model, too, is, strictly speaking, incorrect. In the quantum world the electrons are in probability density clouds of various shapes and orientations, and all atoms occupy the same volume. By looking at the evolution of our understanding of the atom and how it has changed many times in the past, even though those theories were thought to be complete, we are in no position to say that the quantum mechanical model of the atom won't change in the future and be replaced by something else. As a result, on this view, the prudent thing is to withhold asserting that our theories describe how nature actually is.

The “no miracles argument”, first proposed by Hilary Putnam (1975, p. 73), is the counter to the pessimistic meta-induction argument and it claims that we can, and indeed should, take our current theories to describe the fundamental nature of reality. Its power is derived from the power of our current theories. General relativity and quantum mechanics have been so successful in describing the world and making predictions which have been calculated and measured to extraordinary accuracy, that if they did not describe the world as it actually is, their success would be a miracle. In general most people do not accept miraculous explanations of natural phenomena, so our current most successful theories must be describing nature as it actually is. The force of this argument would lead most people to become scientific realists, but upon further inspection and thought we must not go as far as committing to scientific realism, but must back away and take the position of scientific structural realism.

2. Measuring What?

The most crucial aspect of any area of science is measurement; without it science is just as good as astrology. Every time we create a theory we ask what predictions it can make, then go out into the world, measure, and see if this corresponds to the prediction made. This may seem easy, but as is usually the case, the devil is in the details. Even something so simple as measuring the mass of an object is not as straight forward as getting a triple beam balance, or a spring with a known spring constant and a ruler.

Look at any scientific law you please, such as Ohm's law: $V = IR$. We know what each of those symbols means – voltage, current, and resistance – but we have no way of ensuring that they correspond to anything in reality. As Eran Tal writes "Considered purely as elements of formalism, such parameters [voltage, charge, wavelength, etc] are not yet associated with empirical content. It is only once linked, or 'coordinated' with one or more procedures for determining their values that such parameters acquire their empirical significance" (Tal, 2013). Tal's point is that, for our theoretical terms to have meaning, they must have some way of being measured. But this puts us in somewhat of a circular argument, since in order to test a theory we must measure, but in order to measure we must understand the theory.

Traditionally the way out of this circle is to create analytic statements of coordination which, being analytic, do not need to be tested. For example, length could be defined by placing rigid rods of some size end on end and seeing how many rods long something is. By defining length as some number of standard rods we set one side of the coordination. This leaves the problem that there are multiple ways to measure a length and each could be considered distinctly different since, fundamentally, they are using different definitions of length. The fact that they coincide if a conversion factor is established is just a matter of coincidence under this idea of measurement. To establish the coordination is a matter of convention: there is no inherent reason why the second was chosen for a unit of time other than it was convenient, the meter was originally a millionth the distance from the equator to the north pole since that length was practical for everyday uses.

This idea of measurement may be practical, but if measurement is merely conventional this would seem to run counter to the whole institution of science – which continually challenges conventions to see if they can break and, if they do, replace them with something better. However, recent work in the philosophy of measurement has embraced this circularity, and sees it as a virtue and not as a vice. Measurement in this new paradigm is seen as a process of epistemic iteration: so that, “with each successive iteration the quantity concept [is] re-coordinated to a more stable set of standards, which in turn allowed theoretical predictions to be tested more precisely, facilitating the subsequent development of standards, and so on” (Tal, 2013).

Take, for example, resistance. At first we had ideas about voltages and currents and related them through the idea of a resistance (again, Ohm's Law V =IR). So to measure this resistance we placed a voltage source across the device under test and measured the current, took their ratio and got the resistance. As technology advanced we were able to create sinusoidal voltages and then carry out the same process. But then we noticed something strange. The current and voltage waveforms were not always in phase; one might lag or lead. The idea of impedance then took the place of resistance, and from it we are able to build better and more efficient devices.

Before moving on, a quick aside about AC and DC current, and resistance and impedance. A DC current and voltage are sometimes called “steady state” current and voltage because there is no time variation of the currents and voltages. If you were to connect the positive and negative ends of an AA battery (1.5 V) with a 10 Ω resistor, then 150 mA of current would flow through the resistor. This is figured out but using Ohm's law: $V = IR \rightarrow 1.5\ V = I*(10\ \Omega) \rightarrow I = 1.5/10 = .15\ A = 150\ mA$. AC currents by definition have a sinusoidal variation such that any AC voltage or current has the form $f(t)= A\sin(\omega t+\phi)$ where f(t) is either current or voltage, A is the amplitude, ω is the angular frequency, and ϕ is some phase term. If we now ask the same question as to what happens when you put an AC voltage across a resistor, we get the same answer, but the current now varies in time as follows: $i(t)= 150\sin(\omega t)$. We are able to disregard the phase term since it is the same in both the voltage and current. This example does not do impedance justice because we get the same answer just in a slightly different form. It really shines when we ask: what is the voltage and current relationship across a capacitor? A capacitor has a complex impedance, not complex in the sense that it is long and convoluted, but that it is expressed using the imaginary number: $j=\sqrt{-1}$. $Z_c=\frac{1}{j\omega C}$. Sparing you the math, you find that if you put some AC voltage of the form $v(t)= V_{max}\sin(\omega t)$ across the capacitor, the resulting current is $i(t)= \omega C V_{max}\sin(\omega t+ 90^{o})$. Now the phase shift cannot be ignored. A result like this could never have been computed with just the idea of resistance alone.

For example, your house runs on AC power and has an impedance. If you are not careful then your house's impedance can cause the voltage and current to become out of phase and reduce the amount of useable power. This is energy inefficient and causes your electric bill to increase. Thankfully, though, we are able to build devices with known impedances which when combined with your house negate these effects, realign the waveforms, and have you running as efficiently as possible. Furthermore, we can ask about the impedance of a wire and get measurements that could not have been thought of if just resistance was considered. More properties, techniques, and designs become available with more sophisticated measuring techniques. Do you like rock music? Jimi Hendrix's distorted guitar sound would be impossible without the idea of impedance (among other things).

Armed with this new idea of impedance – a frequency dependent complex resistance (complex in that we must express it using complex numbers) – we can make better devices to measure it, and better devices to measure voltages and currents at various frequencies more accurately. This is precisely the positive feedback loop described above. We started with very crude measuring devices and hit upon a relation between current, voltage, and resistance. These new ideas allowed for more accurate measuring devices which allowed for an improvement of what we called resistance. This new idea of impedance allowed for the development of more sophisticated measuring devices and refinement of what is meant by impedance and how best to express it. This new idea did not completely remove the idea of resistance; rather, resistance is the impedance when the frequency is 0 (R = Z(0)). This means that we can recover the "classical" Ohm's Law as a limit of the "improved" Ohm's Law.

$$\lim_{x\to 0} v(\omega)= i(\omega)\, Z(\omega) \rightarrow V = IR \quad .$$

Crucially this lead to the question "What counts as a measurement of X?" being inseparable from the question "What is quantity X?" They must be answered at the same time, and continually be fed back into one another. This feedback loop creates a situation where we can know what we are measuring and whether we are doing it accurately. Our theories help us think of new ways to measure quantities (maybe even new quantities – weak charge was not a thing until the 1960s) and our measurements of these quantities help us refine our theories (what is the weak mixing angle?).

But what about accuracy, precision, error, and uncertainty? The account of measurement just described has no way of accounting for such things which are essential to science. Expanding measurement into a two level process allows for these concepts to be incorporated into a theory of measurement. On one level there is the interaction between the object, the measurement apparatus, and the environment. On the second level the theoretical and or statistical representation of the process. If we view this account in light of the circularity of measurement we can see, as Bas van Fraassen argues, that the outcome of a measurement points us to some region in the space of theoretical parameters (region since the measurements have uncertainties) through the indicators on the given instrument (van Fraassen 2008: 164, 172). Accordingly, this though implies that many different theories, as long as they point to the same region in parameter space are equivalent. This makes him an anti-realist, since we only seek empirically adequate theories, but as time goes on, I think the feedback of measurement and theory will continually narrow that region in parameter space eliminating theories until one is left standing.

This implies that measurement gives us information about the state of the system in question, and so we have come to an answer about one of our questions: namely, measurement *can* give us information about the world other than what we actually construct for ourselves. Maybe we did choose the starting points of measurement out of convenience, but as we took more and more measurements, and developed better and better theories, those convenient units turned into something much more: a coherent and simple framework which we can use to make accurate predictions, and understand how physical quantities are related to one another. For example, the length of a second used to be 1/(24*60*60) parts of a day, now it is "... the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom" (NIST). Now that we have defined a precise measurement of what a second is, we can now reliably make measurements in the femtosecond range (10^{-15} s), which we can use to precisely measure the decay rates of particles. This accurate measurement feeds back into our theory about particles and allows us to refine calculations and parameters which will be used to predict new phenomena with increasing accuracy.

Before we put this question of measurement to bed, there is one more nagging issue: what about measurements made when the quantity in question is not directly observable? Surely no one has ever seen a voltage or a current, touched an inductance, or heard a capacitance, but these are all quantities that every electric component has. Moreover, they are required in our current theories of electricity and magnetism. To answer this we can go back to the feedback loop that allowed us to establish measurements in the first place, and back in time to when Coulomb was measuring the force between two charged balls. Theoretical work was then able to show how a force can be derived from another quantity, and knowing this bit of theory allows us to construct new measuring apparatuses which can give us information about the state of this new quantity in any given object. What we have done though is to go from something directly observable (the twisting of a torsion pendulum for Coulomb) to a device that works via theory and allows us to measure quantities that cannot be seen directly such as electric potential. The only reason why we believe a multimeter and oscilloscope is because we can trace the development of the model of the interaction between the device and phenomena to something that we can directly experience. If we wanted to we could use the voltage to drive current into an electromagnet and have it push a slider on a ruler, then we could “see” the effect of current into a resistor. This is all possible thanks to the theory-ladeness of observations.

3. Flavors of Scientific Realism

When it comes to scientific realism, the pessimistic meta-induction argument and the no miracles argument pull us in opposite directions. The no miracles argument makes traditional scientific realism the best option: since our theories are so good at prediction, we should believe that they give at least approximately true accounts of the nature of reality. The pessimistic meta-induction forces us to abandon all forms of realism and supports the idea that these theories are merely useful tools for making things and cannot, therefore, give a literally true account of reality. Since both of these arguments carry a lot of weight and are mutually exclusive it seems as though we must choose which one to believe.

At first glance, the pessimistic meta-induction (from now on referred to as PMI) argument has the upper hand. Even if our current theories are really good at prediction, there might be one that comes along which is just as or more empirically adequate but has none of the same ontological commitments. However, if you think that our current theories are so advanced and so much more successful than any other previous theory that they are highly unlikely to be replaced, you might not be convinced by PMI, and instead think that you are warranted in believing that our current theories are true; in other words, that the theoretical entities successfully refer. Could there possibly be a position that can successfully defeat PMI, yet not fully commit to the existence of current theoretical entities since, after all, they may one day be replaced by some other theory with different ontological commitments?

One position that fulfills these requirements is *structural realism*. In its most basic incarnation, it is the claim that our scientific theories are not telling us anything about the nature of things in themselves, but rather about the structure, the *relations* between things, leaving the nature of things themselves unknown. In taking this stance structural realism avoids both PMI and the no miracles argument.

> Since there is retention of structure across theory change, structural realism both (a) avoids the force of the pessimistic meta-induction... and (b) does not make the success of science seem miraculous. (Ladyman, 1998)

A good definition of structural realism has been given by Michael Redhead “[R]ealism about what? Is it the entities, the abstract structural relations, the fundamental laws or what? My own view is that the best candidate for what is 'true' about a physical theory is the abstract structural aspect” (Redhead, 1996). This view was first proposed by John Worrall whereby he argued that what was keep across theory change from Fresnel's wave optics to Maxwell's theory was continuity of “...form or structure, not of content” (Worral, 1989, p. 117)

Structural realism gets around PMI by claiming that the mathematical structure of a theory is carried across theory change. In going from Newtonian Dynamics to Special Relativity the relationship between the energy of a moving object to the velocity of a moving object remains, just hashed out differently. It's $K=\frac{1}{2}mv^2$ In the Newtonian theory, but $K=\frac{mv}{\sqrt{1-\frac{v^2}{c^2}}}$ in the special theory of relativity. So although the exact details of the relationship may have changed, the relationship still remains. This is true with a lot of theoretical quantities such as forces, energies, and work.

The way it gets around the no miracles argument, I think, is more interesting. Science is a ruthlessly competitive arena. Any theory that does not have predictive success will not survive. This means that each successive theory must have better predictive success, so the level of success ratchets up over time. But just because one theory is more successful (by the fact that it survives) does not mean that we should commit to its theoretical entities. It does not beg the question of how true or approximately true the theory is since it has enjoyed great predictive success. This is analogous to the anthropic principle in cosmology: of course we live in a universe that can support life; if the universe did not support life then we wouldn't be here. However, it does not imply that the universe must be constructed in such a way that life must be a consequence; we are just a happy accident.

As is always the case in philosophy, upon further inspection the position is not as basic as you would think or hope. (And that's one part of what we love about philosophy!) There are two ways of adopting structural realism: epistemic structural realism (ESR), and ontic structural realism (OSR). James Ladyman argues that ESR is incorrect since it gains no advantage over traditional realism, so we must view structural realism as a metaphysical theory. ESR is the idea that our description, our epistemology of the world, is all about structural relations; the only important part of any scientific theory is its empirical content and the structure there of. This view has been criticized on the grounds that since ESR makes no mention of theoretical entities that it is not really realism, that it is more of an anti-realism. OSR is the idea that nature is fundamentally structural, that its entities enter into relations with one another. Furthermore, it goes on to state that when we are doing science we are actually uncovering those relations; when we mathematically describe a phenomena we have found the relation between the properties that the natural entities posses. This is much more realist than ESR since it proposes that there actually are relations in nature, and furthermore, that our scientific theories have been uncovering them and allowing us to understand the relational content of reality.

ESR can be traced back to Bertrand Russell's later philosophy in which he argues that we can only know about theoretical entities by their description. That is, we know them via their structural properties. Furthermore, this is the limit of our understanding. This amounts to thinking that the only things we can know about the world are descriptions of phenomena. For a scientific theory this prioritizes observational content over the existence of theoretical entities. This is codified in the idea of Ramsey sentences: $\varnothing\,(O_1,\ldots O_n;T_1,\ldots T_m)\rightarrow\exists\,t_{1,.}\ldots,\exists\,t_m(O_1,\ldots,O_n;t_1,\ldots,t_m)$ (Ladyman, 2004, §3.2).

In this process O_n is any observation, and T_m is a theoretical entity. So the left side of the conditional says that given a set of observations, there is a set of theoretical entities that support these observations. The right hand side (the Ramsey sentence) says that there exists a set of theoretical entities that can produce the given observations. It is a process of taking direct references to theoretical entities to making direct reference to observations and obscuring the theoretical. It is the difference between "A potential difference is produced by a collection of electrons" and "A potential difference can be produced if there exist electrons (or some other theoretical entity)."

According to such a theory the only open question is that of cardinality. Any set of objects can be made to have the same structural relations, so just a set of relations is not enough to single out a unique referent from these relations. As Ladyman points out, if the Ramsey structure is what is meant by structural realism, then all theories with the same empirical consequences are equivalent, we should not favor one set of theoretical entities over another since, at the end of the day, all we care about is the observational content. "If we treat a theory just as its Ramsey sentence then the notion of theoretical equivalence collapses onto that of empirical equivalence." (Ladyman, 1998). However, empirical equivalence and evidential equivalence are not equivalent. Just because there are two theories that have the same observational content does not mean that we have no way of deciding between the two. For example, both Maxwell's and Fresnel's theory of light predict the same interference patterns, but we use Maxwell's equations as the starting point for optical phenomena because we have more evidence for the existence of the electric and magnetic fields than we do for a scalar field.

4. Ontic Structural Realism

Having determined that epistemic structural realism does not get us where we want to go, we must investigate ontological structural realism and see if it is any better (pssst, it is!). Ladyman defines OSR as "... any form of structural realism based on an ontological or metaphysical thesis that inflates the ontological priority of structure and relations." (Ladyman, 2007). As always, general statements always require refinement, and that is what the rest of this section is about: breaking down the different types of OSR and explaining the arguments for and against the various types.

A very radical version of OSR states that there are no individuals, there is only structure. This position is know as eliminativism since it completely removes the idea of individuals from the conception of scientific theories. This idea is very counter-intuitive since, intuitively, there is no relation with out relata. The relationship "is taller than" requires at least two distinct individuals which you are comparing, and the same goes for "has more energy than."

Ladyman thinks that there are a few ways to show how this intuition is false. First is the idea of a universal. When we investigate the relation of 'more energetic than' we are interested in the formal properties of the relation itself, outside of any particular instance of the relation. What he is getting at is that relations can be symmetric (if aRb then bRa), reflexive (aRa), transitive (if aRb and bRc then aRc), etc, and that these properties of the relation are independent of any particular instance when we use the relation to describe the state between two relata. This is an interesting thought, but the fact remains that for the relation to have any meaning, it must have input relata; otherwise, I only have a rule for how the relation would work if there were things to relate. Such a theoretical relation is useless unless it can actually apply to objects in the real world.

A second way around this weird notion of relation without relata is that *prima facie* it seems that relata-relation-relata is the way things are, but actually each relata is in itself a relation (Ladyman, 2007); it's relations all the way down. This is not as troubling as there being no relata at all. Now the term relata is just a place holder for the inputs to a relation, whatever those inputs may be. But at least the idea “it's relations all the way down” sounds like “it's turtles all the way down” and no one really likes infinite regression as it is a sure sign that something is dubious. But again, this just seems weird, because there might be relations that don't have anything to do with each other so relating them through another relation is strange: is orthogonal to is smaller than is more capacitive than (what!?)

I think it is safe to assume that any notion of structural realism must have some notion of objects themselves. Otherwise, what are the relations between? This leads naturally to another version of OSR that claims the relations between individuals supervene on their intrinsic properties and their spatio-temporal relations. Or as David Lewis puts it:

> [A]ll there is to the world is a vast mosaic of local matters of particular fact, just one little thing and then another … We have geometry: a system of external relations of spatio temporal distance between points (of spacetime, point matter, aether or fields or both). And at these points we have local qualities: perfectly natural intrinsic properties which need nothing bigger than a point at which to be instantiated … All else supervenes on that. (Lewis, 1986)

This, I think, is a very natural view to take since it conforms with everyday experience. However, some people think that quantum entanglement dispels the idea that the world is “... just a set of separately existing localized objects, externally related only by space and time.” (Ladyman, 2007). However, I would argue that this is false. Rather, quantum entanglement is the idea that two objects (each defined by their own wave function) can enter into a new state where the resultant waveform cannot be factored into parts of the separate wave function. To successfully describe the system a single entangled wave function must be used. Two important things to note. One, entangled states are very hard to maintain for any appreciable period of time (in quantum terms appreciable is microseconds), so even if wild particles do become entangled, they will quickly decohere and will then return to being individual particles. Second, the entangled state does not imply that the two objects have formed into one; rather it states that they cannot be described independently. The two electrons in the singlet state (total spin equal to zero) *are* described by one wave function, but that wave function describes how the *two* spins of the electrons are related, so there are still *two* objects present.

Having established that there must be individual objects of some kind, we must ask if they have intrinsic properties. One answer to the question is: no, individual objects do not have intrinsic properties, they are not individuated by an haecceity or primitive thisness (Ladyman, 2007). This is the view taken about classical particles. Consider two electrons: you have one in one box, and one in another. Call them electron-A and electron-B. You are asked to turn around, and someone shuffles the two boxes around. When you turn around again you are asked to identify which box has electron-A in it, and which box has electron-B. Since every electron is the same, there is no way, even in principle, for you to figure out which is which. Furthermore, there is no way that nature can tell which electron is which, since every single electron is the same to every other. At most it can tell you that there are two electrons, one in box A and another in box B. This example shows that intrinsic properties are not enough to distinguish individuals; there must be something else. There must be, at some level, an intrinsic haecceity of every object. If there are two electrons in the first orbital of two hydrogen atoms, they have exactly the same wave function, but yet we are entitled to say that there are two electrons. They might have the same exact properties, but if I were to go count the number of electrons I would end up with two, not one.

Perhaps the most sensible way to understand OSR is to take it that there are individual entities, but they do not have any irreducible intrinsic properties. In this position, one maintains that “(a) relations require relata, but denies that (b) these things must have intrinsic properties over and above the relations in which they stand.” (Esfeld, 2004). This idea, sometimes called moderate structural realism, claims that there are relations and relata, but neither is ontologically primary or secondary: all the properties of objects are relations to other objects. When looking at the form of equations used in scientific theories we can see that this view is very natural. Consider the electric field of a point charge, $\dot{E}=\frac{q}{4\pi\epsilon_0 r^2}\hat{r}$. This relation has as its relata the electric field, the magnitude of the charge, and the distance between them. This equation requires that there are objects which can have the property of charge, and that there is this other entity, a field, that gets produced by objects with the property of charge.

How can we tell which came first, the relation or the relata? I do not think we will ever be in a position to answer that question, so we must treat them equally, at least when it comes to their ontological status. This may seem like scientific realism, but the important point to keep in mind is that these individual objects that we are positing only have properties that facilitate the relations between them, and these properties are not intrinsic to the object.

5. Defending OSR

OSR is the best way to be realist about our best scientific theories, that our scientific theories are telling us about the structure of reality, and that structure is actually how nature is constructed. Not only can it defend itself from the PMI, but it can also answer the no miracles argument. Also, in practice, whenever we make measurements about an object, we are always measuring how that property is related to others, never the property itself. Finally, it respects the fact that the language our theories are cast in is purely relational, there is never an equation that tells us explicitly what an electron is, just how its properties relate to other objects in the universe.

Recall that PMI states that in the past we had theories which we thought were right, but now know are false; therefore, we must not claim that our current theories are correct. OSR claims it is the relations of our theory which are the true aspects of any scientific theory, regardless of the exact definition in the respective theory. In Classical Mechanics we had a relation between mass, velocity, and kinetic energy; and we had a similar yet different relation in General Relativity, but the important point to note is that even across theory change the theoretical terms of energy, mass, and velocity were all related. This shows us that we have uncovered a fundamental relation of the universe: moving things carry some amount of what we call energy, dependent on how much stuff is in them (mass) and how quickly they move (velocity).

You might argue that the theory has actually changed, in a very fundamental way, since the amount of kinetic energy one thing has is very different in each separate theory. This would be true if we were strict scientific realists, but we are not committing to nature behaving exactly as our theories say; instead we are only committing to nature having this relation between these aspects which we currently think behaves in this way. Since we are only committing to the reality that there is a relationship between mass, velocity and kinetic energy, we are still correct even after theory change should those properties enter into our relations.

OSR does not support the no miracles argument either, since we have found that there is a fundamental relationship between mass, velocity, and kinetic energy. Is it any surprise that the more and more we investigate this area, the more accurate our theories about this relationship become? The hard work was finding that there is a fundamental relationship; after that, refinement is a much easier task. This progresses much in the same way as measurement does, and I think is a consequence of how we measure.

Measuring is a cyclical process: we start with rough ideas about the relation that we want to measure usually found through a mere groping about, and next we build a device which we think will do the trick. Then we start turning the dials and reading the screens and deriving equations to model the relation. Finally we try differing forms of the terms in the relation to see if they still hold or need to be modified. This evolution is how we moved from resistance to impedance and from classical Ohm's law to the current one.

Measurement, which is so fundamental to science, only tells us about the property it is measuring through the relations that property has to others; it never measures the property itself. When you take an ohm-meter and measure the resistance of an object, the meter itself applies a known voltage, measures the current, divides the two (R = V/I), then displays the result. So the device is not measuring the resistance alone, it is doing so by examining how it relates to voltage and current.

The most compelling piece of evidence for OSR is that every scientific theory that we have is always written as a relation, namely that of equality;

$$V = IR, \qquad K = mgv, \qquad \nabla \times E = \frac{-\partial B}{\partial t}, \qquad \hat{H}\psi = E\psi$$

Never will you find an equation that tells you explicitly what an electron is. Rather, you have to tease out what we mean by “electron” from how it is used in relation to other terms. The only thing our scientific theories are telling us is how the proposed theoretical entities in them are related to other theoretical entities. When I say 'electron' I do not mean an object that is a point particle, that has a negative charge, a very small mass, spin of ½; what I am saying is that there is this object which enters into certain relations with other theoretical entities, and that is a collection of relations.

But surely, one might think, electrons themselves have properties! For example, they have a charge of 1.60217677 x 10^{-19} C, a mass of 9.10938291 x 10^{-31} kg, etc. Wrong! These "properties" are just ways of creating the proper relation between electrons and energy, electrons and acceleration, electrons and other charged particles. The world viewed through the scientific lens is one of relations and that is all. Hence, the way we speak and describe the world through science must be through relations.

A very useful analogy is to examine group theory and then see how we can use our understanding there to help us understand what is going on in OSR. A mathematical group is a collection of elements with certain operations that obeys: closure (any two elements acted on with the group operation is in the group), associativity (the grouping of operations does not matter; (a + b) + c = a + (b + c)), identity (there is an element such that a + e = e + a = a), and an inverse (an element such that a + b = b + a = e). A group has a very loose definition such as the group of all rotations on the unit circle about the origin. This is enough to define the group, but when we work with it, we might want some mathematical representation of the group so that we can investigate it in more depth. One such representation is through a matrix and vectors. Each vector v = $[x\ y]^T$ if right multiplied by the matrix

$$R(\phi)=\begin{matrix}\cos(\phi) & -\sin(\phi)\\ \sin(\phi) & \cos(\phi)\end{matrix}$$

produces another vector rotated by an angle of φ. This group can also be represented using complex numbers where the vector is now in the form v = $e^{j\varphi}$ and R = $e^{j\Delta\varphi}$. Multiplying R*v = v' the new vector rotated an angle of Δφ. So it can be seen that the description of the group is more fundamental than the particular representations of the group. For any group there are many ways of representation, but some are more useful and easy to understand than others, even though they all do the same thing.

In the analogy, scientific theories play the role of the descriptions of groups, and the theoretical elements of the theory are the elements of the group under a given representation. Science is telling us about the general properties of the universe through the relations among its elements. The electron is a certain representation of the group which we have chosen to use for its mathematical and theoretical elegance. We could have come up with some other elements in the universe related in different ways, but they might not have been as convenient to work with. The phrase "convenient" might smell of anti-realism. The thought to keep in mind is that what we are really after is the real relation between the convenient elements. Using the elements we currently do has resulted in certain scientific equations; had we chosen other elements, the equations would be cast in different terms, but the underlying relations would remain. The equations that we uncover tell us how to transform from one element of the group to another, how they are composed of one another, how they stand in relation to one another. The theoretical elements of the equations are just place holders for the endpoints of the relations and have nothing special in and of themselves.

So when asked what science tells us about the world, the answer we must give is: it tells us about the relations between the things we have chosen to use. Neither the object nor the relations are prioritized over the other, but the scientific method can only every tell us about the nature of the relations between the objects. Part of this is due to the fact that our measurements are theory laden: they can only produce meaningful results when we view the measuring device as a physical embodiment of a relation which has the property we want to measure (think of how many different ways we can measure the mass of something). The other part is due to the language we have chosen to express our theories in. A mathematical equation does not make sense unless there is an equal sign, or some other relational operator ($<$, $>$, $\leq$, $\geq$). Clearly, our scientific theories are telling us about the structure of reality, how the different objects relate to one another, not how the objects themselves are.

Works Cited

Esfeld, M., 2004. *Quantum Entanglement and a Metaphysics of Relations.* Studies in History and Philosophy of Modern Physics, 35: 601–617.

Lewis, D., 1986. *On the Plurality of Worlds*, Oxford: Blackwell.

Ladyman, James, 2004. *Structural Realism.* The Stanford Encyclopedia of Philosophy

URL = <http://plato.stanford.edu/archives/spr2014/entries/structural-realism/>.

Ladyman, James, 1998. *What is Structural Realism?* Studies in History and Philosophy of Modern Physics. Vol 29, No 3. 1998: 409 – 424.

Putnam, H., 1975. *Mathematics, Matter and Method*, Cambridge: Cambridge University Press.

Redhead, M. L. G., 1996. *Quantum Field Theory and the Philosopher*. Unpublished transcript of paper.

Russell, B., 1927. *The Analysis of Matter.* London: Kegan Paul

Tal, Eran, 2013. *Old and New Problems in Philosophy of Measurement*. Philosophy Compass: 1159–1173.

van Fraassen, Bas C, 2008. *Scientific Representation: Paradoxes of Perspective*. New York: Oxford University Press

Worrall, J., 1989. *Structural realism: The best of both worlds?.* Dialectica, 43: 99–124. Reprinted in D. Papineau (ed.), The Philosophy of Science, Oxford: Oxford University Press, pp. 139–165.