REPRESENTATION AND PERSPECTIVE IN SCIENCE

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Abstract

The world science describes tends to have a very strange look. We can't see atoms or force fields, nor are they imaginable within visualizable categories, so neither can we even imagine what the world must be like according to recent physical theories. That tension, between what science depicts as reality and how things appear to us, though it is more striking now, has been with us since modern science began. It can be addressed, and perhaps alleviated by inquiring into how science represents *nature. In general, representation is selective, the selection is of what is relevant to the purpose at hand, and success may even require distortion. From this point of view, the constraint on science, that it must 'save the phenomena', takes on a new form. The question to be faced is how the perspectival character of the appearances (that is, contents of measurement outcomes) can be related to the hidden structure that the sciences postulate. In the competing interpretations of quantum mechanics we can see how certain traditional ideals and constraints are left behind. Specifically, Carlo Rovelli's* Relational Quantum Mechanics *offers a probative example of the freedom of scientific representation.*

Even if a scientific theory or model represents how things really are, the scientific account is not finished unless it has clear implications for what their appearance will be like under realizable conditions.

This demand introduces a tension. The emphasis can be on representing nature itself, 'how things really are', or instead on the implications for how nature will appear to us. The shift from the second emphasis to the first has often been seen in Einstein's philosophical development. The challenge posed dramatically by Einstein, Podolsky, and Rosen in their famous 1935 article "Can quantum-mechanical description of physical reality be considered complete?" is to develop scientific modeling so that there is an exact correspondence with 'elements of reality'. The Copenhagen scientists complained that they, in their oblivion to that demand, were proceeding exactly as the young Einstein had proceeded when he introduced Special Relativity in 1905. Had he not then been the perfect exemplar for Husserl's call "Back to the things themselves!" interpreted as a call to confront what we are confronted with in experience? Instead of reflecting

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on the nature of reality, he had turned attention to what can be experienced in a procedure to synchronize distant clocks or measure the length of a moving object.

Looking at different aspects and episodes in the sciences, we can see both sides exemplified. To be complete — even if we merely see completeness as a regulative ideal, possibly not humanly achievable — requires a science to represent the appearances as well as the theoretically postulated reality.

But what are the appearances? Within philosophy of science, I submit that what is meant by the requirement that science must 'save the appearances' is the contents of measurement outcomes. Thus they include the 'pictures' that give visual shape to radio-telescope output, the frequency counts of Geiger counter clicking in the presence of a mineral, the dots appearing on a photographic plate in a slow diffraction experiment, and so forth. The content can be presented in pictures, graphs, tables, or descriptions; it is semantic content.

This requirement challenges a science's claim to completeness in the first sense, in its direct depiction of its domain in nature. For the requirement implies that completeness is achieved only when its depiction of the world is already complete all by itself, in principle. I will first place our topic in the context of completeness claims in general. But then I will show how the two sides of the ideal of completeness vie with each other in recent developments in the interpretation of quantum mechanics. These range from overtly 'realist' views, through views of a duality between the real and the apparent (as in Jeffrey Bub's spectrum of modal interpretations), to the more radical perspectival interpretation in Carlo Rovelli's *Relational Quantum Mechanics*.

1. How far have we come since Aristotle?

Aristotle laid it down that a theory should obey the dramatic unities of representation:

> the phenomena show that nature is not a series of episodes, like a bad tragedy (*Metaphysics* N3, 1090b)

complaining, in the *Physics* (198b10–35) that the theory of evolution by mutation and natural selection suffers from precisely that ill. To understand then what he takes to be required of a good physical theory, we need to look to his most extensive work on representation, the *Poetics*. There he gives his definition of tragedy:

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> Tragedy is a representation of a serious, complete action which has magnitude, in embellished speech . . . by people acting, and not by narration; accomplishing by means of pity and terror the catharsis of such emotions. (*Poetics* 49b25-)

This establishes the Aristotelian pattern of definition for a human enterprise, with four parts, to specify the *object, medium, manner*, and *aim or function* of tragedy.

We note in this passage that narration too is a manner of representation; language is a medium of representation, with various linguistic forms possible. So to see what, according to this ideal, a scientific theory should be like, we can begin with the following as outline:

> (*) Science is a representation of *something*, in *a certain form of* language (by people speaking or writing *in a certain way*), accomplishing *by certain means* an *end or aim proper to this activity*.

There is more, according to the *Poetics*, to what it takes to give such a representation, which sheds light on the meaning of his complaint that nature is not to be depicted as just a series of episodes 'like a bad tragedy'. This is the familiar 'post hoc, not propter hoc' complaint that we want from science a systematic explanation, not just a recipe for predictions, and the character of such systematicity is clearly laid down. The action must flow from character, with necessity or probability. Circumstances can be exotic and surprising but the element of chance and unlikely or unbelievable incidents are to be shunned. If needed, they are to be kept off stage. The completeness of the action is assimilated to textual or narrative structure: what is depicted is a "complete action", the beginning must be a radical beginning from which the middle necessarily follows, demanding closure by the end (*Poetics* 50b 25–33).

Then the *Posterior Analytics* explains this ideal very precisely for science — an ideal that guided the sciences for two millennia, and did not exactly lose its grip on the philosophical and scientific imagination even then. According to the Aristotelian ideal, science must *explain how things happen by demonstrating that they must happen in the way they do*. The regularities in the phenomena must be shown to derive from universal necessary principles. Galileo, Gassendi, Boyle, Descartes, and Newton all write in a historical context where Aristotelianism is explicitly and vociferously rejected. But we see the ideal's continuing strength in their talk of laws of nature, not all that clearly distinguished from those lambasted and ridiculed constraints of Aristotelian physics. Even more extreme sentiments take hold: the regularities must derive from not just natural but logical necessity.[1] This sentiment is sometimes encountered still, in physicists' dreams of a final theory so logically airtight as to admit of no conceivable alternative, that would be grasped as true when understood at all.

In the Aristotelian ideal we readily discern a completeness requirement: theorizing is not successfully completed, a theory is not complete, until and unless it accounts for the regularities in the phenomena by means of universal and necessary principles — or later, laws or necessities postulated in nature.

In the 19th century, the related but distinct completeness criterion lies in the claim that all phenomena in nature derive from an underlying deterministic mechanics. We may indeed see this as a criterion of completeness: any apparent gap in determinism is filled by statistical laws, but the statistical probabilities are only a measure of ignorance. Poincaré begins one chapter in his *Science and Hypothesis* of 1905 with

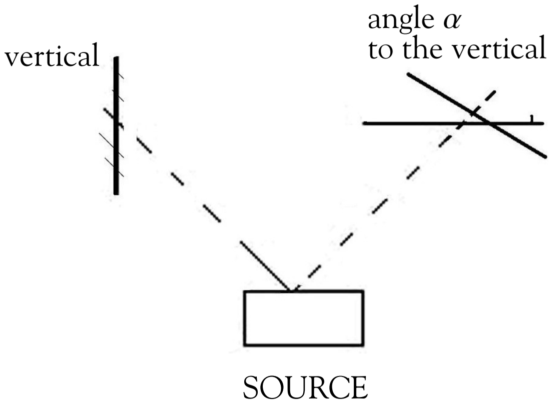
> No doubt the reader will be astonished to find reflections on the calculus of probabilities in such a volume as this. What has that calculus to do with physical science?

The conviction that a scientific account is complete only if it is deterministic was of course strongly supported by the Kantian and neo-Kantian philosophies. For as Kant saw it, the very coherence of experience requires that it takes a form of experiencing ourselves as living in a spatio-temporally definite causal order.

With the advent of quantum mechanics, determinism was seriously challenged. Nature is indeterministic, or at least it can be or may be — and if that is so, determinism is a *mistaken* completeness criterion for theory.

Hans Reichenbach offered a weaker criterion: the world may be depicted as indeterministic, but that does not mean that everything is a matter of sheer chance. The apparently weaker but still substantive new completeness criterion Reichenbach submitted was the *Common Cause Principle*.[2] This principle is satisfied by the causal models of general use in social sciences and for many purposes in the natural sciences as well. They are models in which all pervasive correlations derive from common causes (in a technical, probabilistically definable sense).

But here the challenge by Einstein, Podolsky, and Rosen turned out to show the limits of this new causality constraint. David Bohm showed how their sort of thought experiment could be given a more practical form by considering the emission of an entangled pair of photons. John Bell then demonstrated in the 60's that the phenomena fit such a causal model only if certain equations describing the *appearances* (the contents of measurement outcomes!) are satisfied. A series of experiments, perfected finally by Aspect and his team early in the 1980s, in which Bell's inequalities were violated, shows that even this third criterion was rejected, in effect, by the new quantum physics.[3]



In this experiment, which was thus inspired by the Einstein-Podolsky-Rosen paper, a series of entangled photons pairs were emitted toward two polarizing filters, and the occasions of passing through recorded with receptors. The filters can be oriented at any angles and the correlations between the events in the two investigated. The violations of the Bell Inequalities in the statistical correlations imply that they do not fit Reichenbach's Common Cause pattern. So that cannot be maintained as a criterion to govern scientific representation.

So we see that successive completeness criteria, honored by scientists in certain epochs and seriously advocated in philosophical writings were discarded one by one. Of course, that did not mean, and never will mean, that just anything goes: there are always accepted constraints on scientific representation. But while that is one lesson from the history, the other lesson is that once such a criterion is brought to light and made explicit, it may well be the next one to fall.

2. Representing the Theoretically Postulated Reality

To bring to light another, deeper and more pervasive, criterion that may play such a constraining role on scientific representation, we need to take a closer look at just how the modern sciences confronted the appearances, that often seemed so different from what was to be found in the science's 'official' depiction of reality.

The disparity becomes truly salient when Galileo and Gassendi embrace the atomism which had been revived in the Renaissance. Those atoms have only primary properties such as shape, volume, and number; the appearances are colorful, noisy, smelly, and tasty. Descartes, though not an atomist, goes further by restricting the real attributes of matter to extension in space and time. Newton rejects this ontological asceticism when he introduces forces and mass. But these additions certainly don't diminish the disparity: the Cartesians complain that Newton has brought back the medievals' occult qualities. Nor do the classical fields make nature look more familiar when they are introduced later either to augment or to replace matter.

Once the theoretically Postulated Reality is so different from how the world appears to the observer, emphasis has to be restored to the requirement that science must 'save the appearances', that the appearances must "fit into" this reality. Physics may depict reality as quite different from the appearances, but *a complete physics must explain* ***how those appearances are produced in reality***.

This was certainly recognized by the 17th century new scientists, with both Galileo and Descartes arguing vigorously that the criterion was being met. That today it is still a serious contender is clear in scientific realist writings. Thus Jarrett Leplin, in his book *A Novel Defense of Scientific Realism* writes

> A theory is not simply an empirical law ... that certain observable phenomena occur, but an explanation of their occurrence that provides some mechanism to produce them, or some deeper principles to which their production is reducible. (Leplin 1997, p. 15)

I call this the Appearance from Reality Criterion: to '*derive*' the Appearances from the theoretically postulated reality.

What form must a theory have to achieve this aim? To answer that question we must first ask just what and where are the appearances, and secondly, what form scientific representations of nature took then.

3. Where Are The Appearances?

To answer these questions let us look at a paradigmatic success of this sort. In his Preface to *De Revolutionibus*, Copernicus wrote:

> In the first book I set forth the entire distribution of the spheres together with the motions which I attribute to the earth, so that this book contains, as it were, the general structure of the universe. Then in the remaining books I correlate the motions of the other planets and of all the

> spheres with the movement of the earth so that I may thereby determine to what extent the motions and appearances of the other planets and spheres can be saved if they are correlated with the earth's motions.

Two of the most striking successes Copernicus had in the task of deriving the Appearances from the reality he postulated concerned certain remarkable regularities in the apparent orbits of the planets.

> **Regularity 1.** A *revolution of longitude* of a planet is one cycle of the motion of the planet from West to East, along the inside of the celestial sphere.
>
> A *cycle of anomaly* of a planet is the period between successive collineations of the planet, the Earth, and the Sun — with the planet and Sun on opposite sides of the celestial sphere.
>
> **Regularity:** for superior planets, the number of cycles of anomaly *plus* the number of revolutions of longitude *equals* the number of solar years required for these periodicities.[4]

This was a striking regularity, known by Copernicus' time — striking especially because of its simple form $\alpha + \beta = \gamma$. Copernicus' qualitative model for the solar system attributed circular orbits to the planets, in the informal part of his treatise; his more accurate 'official' model was also more complex, using epicycles for the planets and a deferent for the Earth's orbit around the sun. Nevertheless, on either count, Copernicus could quite readily 'save' this regularity in the apparent motions of the planets. Roughly, Copernicus' relevant postulates are

(a) a solar year = the period of the Earth's orbit around the sun
(b) the period of a superior planet's cycle of anomaly = the period between two successive overtakings of the planet by the faster moving Earth
(c) the average period of a superior planet's revolution in longitude = its orbital period.

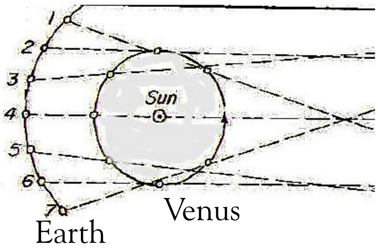
From these the observed regularity can be deduced.

> **Regularity 2.** Contrary to the attribution of circular orbits, the apparent motions of the planets are periodically 'retrograde' motion (e.g. Venus).

This certainly looks like a problem for Copernicus. Chapter 4 of his treatise is headed "The Motion Of The Heavenly Bodies Is Uniform, Eternal, And Circular Or Compounded Of Circular Motions", and in that chapter he notes at once that the appearances seem to contradict that. He points out that the sun, moon, and planets run obliquely through the zodiac, and that they are not seen moving uniformly in their orbits, since the sun and moon are observed to be sometimes slow, at other times faster in their course. Moreover, he adds, we see the other five planets also *retrograde* at times, turning back in their courses and proceeding in the opposite direction. They wander in various ways; that is why they are called "planets" (from the Greek for "wanderers").

We can imagine traditional astronomers of the time telling him: "But the planets sometimes reverse in their paths! We can see with our own eyes that they change direction!" Today we still encounter this fact in astrology: watch out for misfortunes in your love life when Venus is retrograde … But Copernicus explains the *apparent* retrograde motion of an inferior planet such as Venus, by depicting how its motion would look from a slower moving Earth also orbiting the sun.

Lines of sight from the Earth



To apply this derivation to show how the appearances to the astronomical *observers* are produced, Copernicus' model must be read as including the representation of *light* as moving along straight lines, and the measurements whose content is relevant, to be situated on Earth. Besides a good grip on geometric kinematics, Copernicus relied on the sort of geometric optics whose development had already been begun by Euclid, and was a common resource of astronomy in his time.

When frames of reference come into their own, we have eventually a very clear three-level representation: there is the world [1] as described in co-ordinate independent terms, then the world [2] as described in a given frame of reference (co-ordinatization), and finally the world [3] as it looks from a given vantage point with specific orientation. This division corresponds to three ostensibly different domains:

[1] Theoretically postulated reality

  - *– Micro structure, forces, fields, cosmic space-time structure*
- [2] The observable phenomena
  - *– Stars, Planets, macroscopic objects, motions, . . .*
- [3] The appearances
  - *– Measurement outcomes, 'how things look' in observational context*

The first form of representation admits of many of the second sort, and the second of many of the third sort.

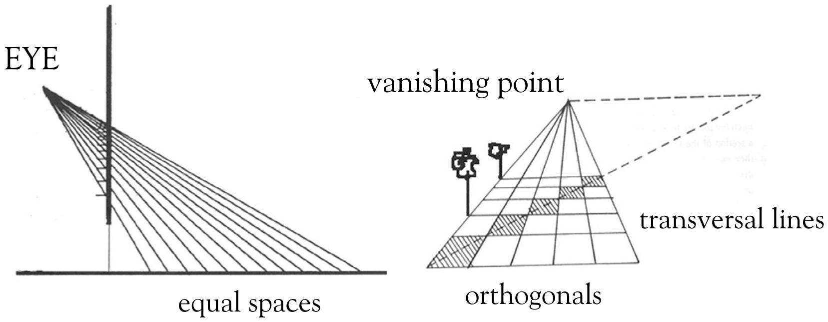
We should thus keep distinguishing the phenomena, whose saving is physical theory's first and main aim, from the measurement outcomes (e.g. visual appearances) which must also be somehow saved — and without which, arguably, it makes no sense to try and save the phenomena.

The phenomena are the observable things, events, and processes in nature. These can be measured and observed in many different ways. How they appear in the measurement outcomes will vary from one way to another — and from one occasion to another — specifically because those outcomes are perspectives on the phenomena. So to say that the theory must save the phenomena *is not the same* as saying that the theory must be in accord with the experimental and observational results! But there is certainly a close connection! If the measurement is well designed for its purpose, what is to be found at its conclusion — such as gauges, print-outs, numbers, computer monitor displays or what have you — will be especially telling when different theories try to achieve their designated ends. But we need to keep remembering: the measurement outcome is or shows not how the phenomena *are* but how they *look*.

4. Depicting The Appearances

Both to understand just how Copernicus scored his successes, and how the later geometric representation of nature proceeded in modern science, it is instructive to look into the development of perspective in Renaissance art. Leon Battista Alberti wrote, in his influential *On Painting* (1435) that "the painter is to draw . . . and paint . . . bodies in such a way that what you see represented appears to be in relief and just like those bodies." That this was possible, and that the new techniques succeeded in making it possible, had been the subject of a famous demonstration experiment by Brunelleschi in 1425. Explaining this success, and offering instruction to the painter concerning the successful execution of the relevant technique, Alberti instructs the painter:

> First of all, on the surface on which I am going to paint, I draw a rectangle of whatever size I want, which I regard as an open window through which the subject to be painted is to be seen. (Alberti, tr. Grayson 1972; 1991 Penguin edition, p. 54)



The most basic exercise of this technique consists in drawing a tiled floor or road, and this not only illustrates Alberti's instruction very well, but its prevalence in artists' instruction is easily seen in many paintings of the period, such as Francesco Rossellini's *Savonarola Burned At The Stake*, of that famous execution in Florence.

Alberti had thus begun the mechanization of visual world portrayal; from this point on the art of drawing and the art of measurement progressed simultaneously toward scientific precision. The most famous later treatise was Albrecht Duerer's *Unterweysung der Messung* ('Treatise on Measurement') which introduces mechanical instruments with sighting devices, to render very precise perspectival drawings. In effect, a drawing made by means of such instrumentation is the outcome of an exact measurement of projective relationships in the represented object.

Taking this as a guide to the concept of a *measurement outcome* we arrive at the following general characterization of its content:

- The measurement outcome is a representation of the measured object/event.
- It is the special sort of representation that trades on 'similarity', but the similarity need not be qualitative, it may be 'structural', at a higher level.
- The representation effected by a measurement is selective, but also indexical (perspectival): it depicts the measured entity as it 'looks' in the measurement set-up.

- The paradigm measurement outcome is not a description or statement but is of a multi-media complexity: *picture-making is the paradigm of measurement.*

5. The Strange Case Of Quantum Mechanics

In the philosophy of quantum mechanics, the ideal of deriving the Appearances appears as what is generally called the Measurement Problem; but one problem with the Measurement Problem concerns just what it is in the first place. What we should ask is:

- In this theory, are the appearances derivable from the postulated reality?
- Does this theory provide an explanation of how the appearances are produced?

Supposing that the real state of a given system is quantum state Ψ, can the appearances be explained or only *predicted*? Max Born added a rule to the basic quantum theory to characterize the general format of predictions on that basis:

> For quantum state Ψ, the BORN RULE answers the question: If A is *measured, what is the* **probability** of each possible outcome?

The answer is of course an algorithm to calculate those probabilities from the state; the details do not matter here.

But what is curious about this is that on the face of it, neither the term "measurement" nor "outcome" is in the physics vocabulary. There we only find terms to describe the states and how they evolve, both for isolated systems and for interactions. So if the Appearances are the contents of measurement outcomes, it is not clear just how Born's rule can be thought of as part of the physics at all.

What is immediately pointed out here, though, is that — leaving the meaning or content aside — the outcome is, or is determined by, the final physical state of the measurement apparatus. Given that the predictions are only probabilistic, it seems then that those final physical states of the apparatus in a measurement interaction are not predictable. And that brings us at once to a second stage in the problem: the evolution of the state of an isolated quantum system is deterministic (governed by the famous Schrödinger's equation).

So then it seems that any indeterminism has to lie in the relation of part to whole. The entire set-up, including object measured and measurement apparatus and its immediate environment, can be an isolated system. If its end-state is determined by its initial state and the form of interaction, then the end-state of its part which is the apparatus can only be less than fully determined if the state of the whole does not determine the state of its parts, in general. And there is nothing in the theory itself that suggests this: it is possible to deduce a state of the part that will serve perfectly well for all predictions of outcomes of measurements made on that apparatus-part . . .

Now of course it feels like we have entered an enchanted wood, with all roads leading in and none leading out. For to understand measurements made on the apparatus and the meaning of the predictions of their outcomes is in essence just the same problem we started with.

So it is not clear at all that the quantum theory can meet the Appearance from Reality criterion. I want to quickly survey here three forms of solution that bite the bullet: kinds of interpretation of quantum theory on which it violates that criterion. That is not an indictment of quantum theory — on the contrary, it suggests that this particular completeness ideal has already bitten the dust in the recent history of physics. Derivation from universal necessary principles, or from laws of nature, as well as determinism and the common cause principle were all left behind. Philosophy has to learn a lesson from this, and the lesson we could add now could be that the Appearance from Reality criterion is also to be demoted to referring to 'nice work when you can get it' from its vaunted status as an ideal that constrains science.

First Pattern of Explanation: the collapse

The first explanation was suggested by John von Neumann, and is referred to variously as his Projection Postulate and as the postulate of wave-function collapse:

> *There is an* indeterministic *mechanism that produces the particular outcomes of individual measurements.*

By itself this does not tell us enough: we have to read it in the context of an identification of the measurement outcomes as uniquely determined by the physical endstate of the apparatus:

> *The appearances (measurement outcomes)* supervene *on the end-state of the measurement apparatus.*

In that case, if the outcomes are not predictable with certainty on the basis of the initial set-up state, it follows that there is indeterministic 'swerve' in the evolution of state.

But what is apparatus and what is object? What, precisely, is the mechanism? Here this sort of explanation faces a trilemma. The first option is quietism: just think of the collapse as interrupting the deterministic evolution of the total state at the end of measurement, and don't ask further. But von Neumann himself saw a problem with that: to be meaningful at all this requires specification of the class of processes that count as measurements, including of course a specification of when they end. If this specification is attempted in purely quantum-theoretical terms, we are just back with the same problem as we started with. So there are two other options:

- hidden variables in the states themselves
- a mechanism 'outside' the quantum system, that disturbs it

The first faced the problem, detailed in many no-go theorems, that adding hidden variables would give implications at odds with the predictions of the original theory. That problem could be overcome by rendering the hidden variables 'empirically superfluous', and this can be done in various ways (e.g. context dependence) but renders the solution uninteresting to physics.

The second option is exemplified by Eugene Wigner's postulation of *consciousness*, the influence of conscious observation at the end of a measurement, to explain the collapse. That is not satisfying when 'collapse' reasoning is employed to describe phenomena beyond human reach, such as in stellar history or in the outer layers of our atmosphere.

But more important for our present discussion is this: none of these options lead to the conclusion that the quantum theory in the actual history of 20th century physics satisfies the Appearance from Reality criterion. The hidden variable theories are not part of that history, but only of theoretical speculation in the 'foundational' and philosophical literature. The postulate of a mechanism outside the domain of physics certainly does not bring us a *derivation* of the appearances.

Second Pattern of Explanation: Appearances Yoked Unto a Forbearing Reality

Once the first pattern of explanation is left behind, the options narrow, for it seems (though we shall come back on this below) that they must all begin with the denial:

> *The appearances (measurement outcomes)* do not supervene *on the end-state of the measurement apparatus.*

This is the pattern exemplified in the so-called modal interpretations of quantum mechanics. One complaint about these we must admit at once: the quantum states and their evolution alone are described by the theory, and no predictive value is added to this description, yet the appearances are not uniquely determined by them. So those appearances can now be classified as 'empirically superfluous'. Advocates of this sort of interpretation do not admit that of course: how could they be empirically superfluous when they *are* the very outcomes that are predicted? Without them, according to this sort of interpretation, it does not even make sense to speak of empirical content of the theory.

In this sort of interpretation, the physical situation is represented by assigning to each physical system a quantum state and a value state. The latter consists, essentially, in the values of those measurable parameters that have values at all in that situation. The value state is constrained by the quantum state, but is not uniquely determined by it.

Modal interpretations come in two versions (Bub 1997; van Fraassen 1998). On all of them an observable (that is, a physical quantity) can have a determinate value *even if the quantum state does not make it so*. (That is, this observable can have different values in systems which are in the same quantum state.) Thus no collapse (of the quantum state) is needed for measurement outcomes — or indeed any other sort of event — to be characterized by a definite position, or definite velocity, or definite charge, or definite death-or-life. Hence the object is *as if* it is an eigenstate of the pertinent observable, although in fact its quantum state does not imply that at all. So we have here a clear dichotomy of Reality (the quantum state) contrasted with Appearance (the 'value state'; or 'property state').

One version, which has a whole spectrum of instances, is presented by Jeffrey Bub in his book *Interpreting the Quantum World*. Besides some that have actually been called *modal interpretations* Bub displays Bohm's interpretation as belonging to this spectrum. What is characteristic in this version is that there is a privileged observable, which has definite values in the situation — values of other observables are not determined any further than the values of this privileged observable allows. In the Bohm version, the privileged observable is position. So all the objects in the domain have well defined positions, and time is an independent variable, so they also have definite velocities, but the ways in which those velocities change with time is entirely unconstrained, except that in the end, the statistical predictions of the theory come out right.

To visualize Bub's world in terms relating back to the more familiar Copenhagen view, we may think of the world as a whole as submitted to a complete measurement of that one observable that has the privileged status. So we can think of this as a 'one point perspective' representation of the world (to use terminology from the visual arts). At the same time this 'virtual' measurement is not to be thought of as disturbing the quantum state: that state continues its deterministic evolution governed undisturbed by Schrödinger's Equation.

My own favorite, the *Copenhagen Variant of the Modal Interpretation* (CVMI) does not belong to the precise class Bub defines, but fits on a somewhat wider definition that I'll take for granted here. Many [compossible] perspectives are realized at once. The physical system typically has many parts, and each part of the system has both a quantum state, and a definite appearance. In many respects this sort of modal interpretation is like Bub's but no observable is especially privileged over the others. This is not a 'one point perspective' representation; on the other hand it is not to be thought of as e.g. a 2-point or N-point perspective. Rather the apt analogy in the visual arts is the so-called '*windowing*' technique in perspectival painting.[5]

There is a good deal of literature now that corrects the simplistic story of Renaissance painters slowly learning how to get it right. While drawing on the geometric perspectival constructions, the painters did not find them artistically adequate. They modified the construction to make it more 'perceptually acceptable' — but also exploited violations of perspective to shape the viewers' experience of the religious and spiritual content. *The artistic representation is not a geometric projection of its subject* — it is to be created so that it looks right to the observer.

Often, at first sight, a painting may strike us as a textbook example of perspectival drawing. But on second look it is not: when you look separately at various features, at different heights in the picture, it turns out that you are seeing them from a point at their own height. Hence the scene is not painted as seen from a single vantage point. Indeed, it is painted as if we have for each object a specific perspective, from a point aligned specially for that object.

Third Pattern of Explanation: No Physical State

The two patterns we have examined now took for granted that the quantum state is, according to the theory, the physical state of the system. They divided then on the additional question:

> *Do the appearances (measurement outcomes)* supervene *on the end-state of the measurement apparatus?*

The information-theoretic approach of recent years denies the initial presupposition. As Christopher Fuchs presents it:

> The quantum system represents something real and independent of us; the quantum state represents a collection of subjective degrees of belief about something to do with that system. (Fuchs 2004, p. 5)

This approach has been developed variously by Carlo Rovelli, Christopher Fuchs, Jeffrey Bub, Christopher Timpson, and others. Here I will briefly present Carlo Rovelli's early version, his *Relational Quantum Mechanics*.[6]

Rovelli is very explicit about how Einstein's early approach in relativity theory inspired him. Just as Einstein talks vividly of observers, and demotes the main parameters of classical physics — time and space — to observer-relative quantities, so does Rovelli for the quantum mechanical observables. In Rovelli's world there are no observer-independent states, nor observer-independent values of physical quantities. The state is what an observer assigns to a system on the basis of measurement results, and no knowledge is possible of the system beyond what those results reveal (relative to the theory — within which the operations are classified as measurements of certain observables). Rovelli offers as his "Main Observation":

> In quantum mechanics different observers may give different accounts of the same sequence of events.

Are there any 'absolutes'? Any relations between different observer-relative states? To answer that we need to have a quick look inside Rovelli's formulation.

> If a system O asks the N questions in the family c to a system S, then the answers obtained can be represented as a string that we denote as $sc = [e_1, \ldots, e_N]c$.
>
> *Complete information* comes from a *maximally non-redundant question-answer sequence*; on that basis it is possible to assign a pure state.

There are indeed 'Absolutes' in this interpretation. The first constitutes just what questions an observer can ask of a given system S; it is the algebra of observables that pertain to that system. The second is the information $sc = [e_1, \ldots, e_N]c$ that a given observer O has about S (which can be different for different observers, contingency in measurement results). The third is the transition probability for the answer to 'next question' that observer O can ask of S.

Note well that it is not part of Rovelli's interpretation — any more than it was in Einstein's introduction of Relativity — to suggest that conscious agents have a special status in the physical world picture. Rather, any system can be thought of as an observer, in just the same way that any system can be thought of as the 'anchor' of a spatiotemporal coordinate system. However, the information available 'at' a system — and hence the states relative to that system — derives entirely from the preceding physical measurement interactions.

Clearly in this interpretations the appearances are, in some sense, primary. They are the states, but here states are not conceived of as independent physical characters that physical systems simply have. In the modal interpretation, if a value state is represented by a vector just like a quantum state, that vector simply encodes the right information about what values the observables have. We can say the same about Rovelli's interpretation: if a state of S relative to O is represented by a vector, that simply encodes the total information — specifying the values of observables pertaining to S — available for O. The difference is of course that in the modal interpretation there was a distinct physical state, and the value state was not relative.

On Rovelli's interpretation, does the quantum theory satisfy the Appearance from Reality criterion? Not at all: in one sense Rovelli is rejecting our question, and in another he is explicitly — if I may now put this in Fuch's terms — rejecting the supervenience of the 'subjective' on the 'objective'. (I am here equating what Fuch's refers to by these terms with, respectively, the relative states and the 'absolutes' in Rovelli's Relational Quantum Mechanics.)

6. What Is A Philosopher To Think?

As I see it, the obligation to 'derive' the appearances was rejected in the course of physics in the 20th century, thus unseating the Appearance from Reality criterion from its status as completeness criterion for science. The relevant episode in this history, which was the development of the new quantum theory, was reckoned as an advance in science.

What if that theory is superseded by another one, in which the appearances are derived from the postulated reality as successfully as Copernicus derived the appearance of retrograde motion? Then we must still admit, on historical grounds, that this was not a criterion that constrains science, even if it is 'nice work if you can get it'. In any case, we see no sign that the quantum theory can be superseded by a more 'classical' looking one of that sort.

So, I submit, science must be differently conceived, not as the realists do. The Appearance from Reality criterion was part of the impression that in the sciences, as in philosophy, the demand for explanation has hegemony. A more tenable, contrary, view will see the sciences as engaged in constructing models with a good fit to the appearances.[7]

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Resumo

O mundo que a ciência descreve tende a ter uma aparência muito estranha. Não podemos ver átomos ou campos de força, nem são eles imagináveis dentro de categorias visualizáveis, assim nem mesmo podemos imaginar como o mundo deva ser de acordo com teoria físicas recentes. Essa tensão entre o que a ciência representa como realidade e como as coisas aparecem para nós, embora seja mais notável agora, tem estado conosco desde que a ciência moderna começou. Pode ser tratada, e talvez mitigada investigando-se como a ciência representa *a natureza. Em geral, a representação é seletiva, a seleção é do que é relevante para o propósito que se tenha, e o êxito pode mesmo requerer distorção. Desse ponto de vista, a exigência sobre a ciência, que ela deve 'salvar os fenômenos', toma uma nova forma. A questão a ser encarada é como o caráter perspectival das aparências (ou seja, conteúdos de resultados de mensurações) pode ser relacionado à estrutura oculta que as ciências postulam. Nas interpretações rivais da mecânica quântica vemos como certos ideais e restrições tradicinais são deixados para trás. Especificamente, a* Relational Quantum Mechanics, *de Carlo Rovelli, apresenta um exemplo comprobatório da liberdade de representação científica.*

Palavras-chave

Representação, realismo, completude, quantum, perspectiva.

Notes

[1] That logically necessary connection may not be finitary, may in fact be inaccessible to any finite mind — as Leibniz made explicit (therefore not within even the potential reach of the physical sciences) — but be graspable only by the divine mind. There are many ambiguities in these developments. Sometimes Descartes and Leibniz do sound as if there can be only one world, of logical necessity. The popular version would go like this: from the concept of God it follows that he would not create a world if among all the conceivable ones there was not a best one (Leibniz' *Theodicy*) or one uniquely transparent to the human mind (Descartes' posthumous *The World*). But at other points the claim is that although the regularities derive with logical necessity from the laws of nature, those laws characterize a selection from the realm of conceivable possible worlds which has no further rationale, at least within the context of even these 'theories of everything'. Notice that we have here perhaps the first 'supervenience without reduction' claim, for reduction would require finitary reasoning but the demonstrative link is claimed to be non-finitary. I will return to questions of supervenience below.

[2] Cf. my 1982 and references therein. Under certain conditions this criterion actually demands determinism, as I show there. But from the example of Bohmian mechanics, we can also see that satisfaction of this criterion is not logically implied by determinism; see further notes below. By the way, contrary to interpretations of Reichenbach as having offered this as a constraint on nature, in a scientific realist spirit, his writings make it clear that he offered it for scientific methodology, in a pragmatic spirit, recognizing the sheer contingency of whether common cause models must fit. If he had backed up his recognition of the possibility of what he called 'causal anomalies' with a logical analysis, he would have come to the results John Bell found in the 1960s.

[3] Bohm's mechanics is deterministic of course, but also violates the sorts of locality constraints required by Reichenbach's criterion; surprisingly it presents a picture of 'determinism without causality' so to speak.

[4] For discussion see Glymour 1980, p. 196–8 and Abernethy 1987.

[5] See Hockney 2001. That he is right about windowing does not entail, of course, that his speculations, e.g. about how optical instruments were used by the actual painters, are correct.

[6] Rovelli 1996; Laudisa and Rovelli 2005; see further my [forthcoming]

[7] I want to express my thanks here especially to the organizers of the Fifth Principia International Symposium for this opportunity to develop my own thoughts further and to benefit from the many valuable and challenging contributions to the Symposium that addressed my work. This paper extends and revises previous work, including my 2004 and 2005, in the light of my new appreciation of the nuances of representation and the importance of the information-theoretic approach to the interpretation of quantum mechanics.