Bas C. van Fraassen

Appearance vs. Reality as a Scientific Problem

Bas C. van Fraassen

la pittura è una specie di natural filosofia, perché l'imita la quantità e qualità, la forma e virtù delle cose naturali.[1]

If science is a representation of nature, what precisely does it represent? Paintings and photos depict things as they appear to us in perception. A scientific theory may be said in contrast to depict things as they are. The differences between the two can be striking, and are typically fodder for skeptical arguments such as Descartes adapted to urge the superiority of intellectual understanding over the senses. How an object is represented in Descartes' new analytic geometry was thus very different from that same object's depiction by the painter.

But in the end we can only evaluate the accuracy of any representation by attending to how the represented object appears to us. So 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. To be complete — even if we merely see completeness as a regulative ideal, possibly not humanly achievable — requires a science then to represent the appearances as well as the theoretically postulated reality.

"Reality" and "Appearance" are philosophically loaded terms. In our context they are to be understood quite prosaically. For example, the theoretically postulated reality is a world consisting of atoms, while the appearances are the smelly, colorful, noisy things we perceive, such as apples and horses. Here "appearance" does not refer to subjectively experienced impressions, and "reality" does not refer to Kantian 'things-in-themselves'. In fact, the relevant appearances are the ways that things and processes appear in measurement outcomes (as I shall elaborate below) and thus publically accessible.

Any claim that science's account of the postulated reality is already complete all by itself, in principle, is therefore challenged to give an account of the appearances. This challenge, so very clear to the 17th century scientist-philosophers, was posed dramatically for our time by Einstein and his colleagues in "Can quantum-mechanical description of physical reality be considered complete?". In fact the challenge is perennial and time and again it precipitates radical, revolutionary changes in the sciences. As I will argue here, these radical changes radiate outward from the content of the new theories to the very methodology of science and to the conception of what science is to be.

1. *A salient criterion: Appearance from Reality*

If science is a representation of nature, criteria for its success or completeness must be related to that task, and must appear concretely in scientific theory choice and evaluation. They are not just debated among philosophers, but have been centrally at issue in famous episodes in the sciences themselves. Remarkably, scientific progress at times involves precisely the rejection of previously proclaimed criteria. Remarkably, also, the aftermaths of such developments typically involve sustained reactionary philosophical efforts at restoration.

That typical historical pattern seems to be this. A certain criterion of completeness is held up at least as an ideal — but as attainable ideal — for science. Perhaps it is even said to be satisfied already, details apart. Embattled by new empirical findings, scientists violate and reject the criterion, and succeed by their own new lights. This is hailed as a triumph over a now discredited philosophical ideal. But then the reaction sets in as well: after that success many philosophers and reflective scientists strive mightily to reinstate the rejected criterion, or show it to be "essentially" satisfied after all.

As first example consider the Aristotelian ideal that science must explain how things happen by demonstrating that they must happen in the way they do. It requires that the regularities in the phenomena derive from universal necessary principles. Galileo, Gassendi, Boyle, Descartes, and Newton consciously and explicitly refuse to take on this Aristotelian task for science, or to accept it as criterion for scientific success. Indeed, they claim that in the modern era scientific success derives largely from their rejection of that tradition.

But already in other passages at the hands of these very same writers, we see the ideal, and that criterion, advocated in an even stronger form! There is 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.[2] 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.

However that may be, there is one criterion that appears to be quite generally accepted at least among philosophers and by the general public.

Physics in the modern era depicts nature as being quite different from how it appears. The theoretically postulated reality is different from the appearances. The disparity becomes truly salient when Galileo and Gassendi embrace 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, nor do classical fields when they are introduced later either to augment or to replace matter.

But at the same time these founders of modern science accept that physics must explain how those appearances are produced in reality. It is the demand that this noisy, colorful, smelly but tasty world of appearance be fully explained in terms of the attributes that science explicitly counts among its significant parameters. Science is understood to be incomplete until and unless it meets that demand. I will call it the Appearance from Reality Criterion.

Examples abound to make us immediately sympathetic to the idea that this demand governs and guides the scientific enterprise. We credit science with adequate and satisfactory explanations of how many familiar phenomena are produced: how ash is produced when we burn a cigarette or some logs, how methane is naturally produced in a swamp, and how a flame is turned yellow when a sodium sample is inserted. The last example is already one in which an aspect of appearance (color) is explained, and this explanation is continued from optics to the physiology of vision. In this way the scientific representation of nature is shown to include the appearances in a very specific, particular way. Their 'derivation' is not just as fitting into that representation[3], but as produced as proper part of the depicted reality.

This is in effect a demand for explanation which is satisfiable only by connections deeper than brute or factual regularity. Let us say that to be complete, physical science needs to derive the appearances from that reality — but the term "derive" cannot here just mean "deduce" or "predict". By "derive" we shall here have to mean a connection of the order of explanation through necessity and/or causal mechanisms to be displayed, which produce the appearances. And while I see this as at the crux of 17th century natural philosophy, we can find it spelled out quite clearly in our own time in scientific realist writings:

> A theory is not simply an empirical law or generalization to the effect 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.[4]

Thus writes Jarrett Leplin in his A Novel Defense of Scientific Realism. What contrasts must he have in mind here? When is this demand not met? It is not met if science should simply issue successful predictions of measurement outcomes. That does not suffice by itself even if the prediction is by means of systematic rules of calculation, from the state of nature theoretically described.

For calculational and predictive success does not ipso facto imply an explanation of why and how the appearances must be the way they are.

2. Apparent Rejections of the Fourth Criterion

If it seems that a science cannot show how certain appearances derive from what it postulates nature to be, various reactions are open to us.

> (1) We could still adhere to the Appearance from Reality Criterion, or to some still deeper criterion of completeness in explanation. Then we would regard such a science as incomplete.
> (2) We could deny that there is a gap to be filled, so to speak; it seems to me that this was the Copenhagen physicists' response to criticisms of quantum mechanics.
> (3) Or we could advocate a certain metaphysical doctrine: there is a sense of "derive" (presumably related to notions of causality or necessity in nature) in which the Appearances do in fact derive from the theoretically described reality, but that connection in nature is beyond the resources of this science to make explicit.

We have two quite salient examples in which the Appearance from Reality Criterion is ostensibly rejected as governing the sciences. One comes from the recent history of physics, as I have already indicated. The other comes from recent analytic philosophy of mind and cognitive science. The logical form of such a rejection, however, I see already foreshadowed in the 17th century. Let us begin with a brief look at each, and then go on to a more detailed inspection.

The quantum mechanics challenge

The vehicle for prediction in quantum mechanics is, at heart, the Born Rule. In one form it allows calculation of an expectation value, which pertains to a weighted average in a large number of measurements. In a simple form, it specifies the probability of any given possible outcome in a single measurement:

> If observable A is measured on a system in quantum state $\mathbf{\Psi}$, and $|\mathbf{r}>$ is the eigenstate of A corresponding to its possible value $\mathbf{r}$, then the probability of outcome $\mathbf{r}$ is $(|\mathbf{r}>.\mathbf{\Psi})^2$

The details of this formula do not concern us yet—and the details of calculation won't be needed here at any point.[5] What matters for us at this point is just this:

> (a) that measurement outcomes are presumably a prime

> examples of what we are to classify as appearances;
> (b) The quantum states are then the theoretically described reality,
> and the question before us is then whether the former are so related to the latter as to satisfy the Appearance from Reality criterion.

The Born Rule is one of conditional prediction. What it predicts is what the appearances will be — with specified probabilities — under certain conditions. The Copenhagen physicists astonished not only traditional philosophers but also their colleagues by not recognizing, indeed refusing to acknowledge, any need to close the apparent gaps in explanation.

By itself the Born rule certainly does not give any information about how those appearances are produced. Can we, by looking into quantum theory, find an answer to the question of how the measurement outcome comes about? Does this scientific theory display or allow for a process, whether deterministic or stochastic, by which this appearance is produced? That is the challenge, and we'll discuss it at some length below.

The supervenience of mind challenge

Are psychology or cognitive science generally autonomous or must they be reducible to fundamental physics? That is hardly a practical question for a working scientist, since we have no such reduction even for current materials science or chemistry, let alone physiology. But we can ask about reducibility in principle, and that has been a central question in the story of 'physicalism' in 20th century analytic philosophy of mind.

In the 1950s U.T. Place offered the hypothesis that certain events and processes traditionally classified as mental (for example, sensation) are identical with events and processes in the brain.[6] He called this the materialist hypothesis. It is in principle falsifiable, namely if the described 'mental' events and processes have a certain complexity, which brain events and processes do not have.[7]

Not only this position but every claim concerning reduction of the psychological to the physical had to be given up in the course of the ensuing philosophical debates. Yet our psychological discourse provides adequate, not to say indispensable, representations of the relevant phenomena. The eventual claim, introduced to save materialism or physicalism in principle, became the much weaker one that, though irreducible, mental phenomena supervene our physical reality:

> the actual psychological phenomena could not be different without a difference in the physical state (of the organism, or possibly the organism plus its natural environment, or possibly

of the entire universe).

By classifying psychological phenomena — the subject of the science of cognitive psychology — as irreducible, this position implies a pertinent autonomy for that science, and its independence from fundamental physics. For the 'supervenience without reduction' claim explicitly entails that no mechanism can be displayed even in principle for the production of the (mental) Appearances from the (supposedly physical) Reality. Those appearances depend on the physical in the minimal sense that the appearances could not be otherwise without the physical state being different. But they are not derivable in the relevant sense. The claim of non-reducibility implies that science is not, will not, and cannot be complete in the sense of deriving the psychological phenomena from the postulated physical reality. On the basis that ought implies can we must then also conclude that science as a whole is not required to be complete in that sense.

I am not objecting here to the claim that the psychological phenomena supervene on the physical. Nor am I even maintaining that this claim fails to adequately explain why those phenomena are or even must be what they are! The point is rather that this position in the philosophy of mind implies that the Appearance from Reality Criterion is to be rejected as a completeness criterion for science as a whole.[8]

The *Great Leibnizian Escape* move

The 'supervenience without reducibility' claim asserts a connection in nature which cannot be displayed by means of a theoretical deduction. Deduction is after all an operation to be carried out with certain resources — linguistic, logical, mathematical — and these resources have their limits. While these limits are the proper domain of metamathematics, and have been made precise in our own day, they were vaguely perceived already in the 17th century.

Here Leibniz stands out as aware of possible limits to science. Like Descartes he seems to have initially harbored the dream of a complete theory of everything whose principles can be known a priori. But after a certain point his vision changes. Then he begins to distinguishing between necessary and contingent propositions:

> the former can be proved in a finite number of steps by reducing them through analysis of the involved concepts to identical propositions or primary principles, while the analysis of contingent propositions goes on ad infinitum.

This is why we cannot know the truth of contingent propositions a priori. Only God alone can know this, not because he can complete the required infinite analysis, but rather because he intuits the whole analysis with one glance.

> The criterion for distinguishing necessary from contingent truths emerges from the following feature, which only those who have in them a tincture of mathematics will easily understand: in the case of necessary truths an identical equation will be reached by carrying the analysis sufficiently far, which amounts to demonstrating the truth with geometrical rigor; whereas in the case of contingent truths the analysis proceeds to infinity, with reasons given for reasons, in such a way that there is never a complete demonstration although the underlying reason for the truth is always there, perfectly understood only by God, who, with one stroke of thought, goes through the whole infinite series.[9]

In contemporary terms we could put it this way: given the information that the physical state is thus or so, there is a strict entailment of what the appearances must be. However, as we know from metamathematics, not all entailments are capturable by definable consequence operations.

As I emphasized above, mere deducibility would also not ipso facto satisfy the Appearance from Reality Criterion. But it is certainly a necessary condition for success by this criterion. Remember after all that we are not discussing criteria for God's creation or the structure of reality! Our concern is with completeness criteria for the sciences.

So analytic philosophy of mind is in effect offering cognitive science the Great Leibnizian Escape move: there is a logical reduction of the phenomena to the real, but it is not graspable by a finite mind (read: not definable by finitary or even recursive means ...).[10]

3. *Phenomena versus visual appearances*

There were two developments in techniques of representation before Galileo that we can see as feeding into the kinematic representation developed in his century. The first was that of linear one-point perspective in painting, and the second Copernicus' and Tycho's mastery of transforming geometric models in astronomy so as to shift the center taken as 'at rest'. Both concentrated on how a description of the visual appearance from particular vantage points can be derived from a reality admitting of many different vantage points. Both grew from the subject of Perspectiva, a melange of geometry, optics, and practical drafting techniques, and both were steps on the way to projective and descriptive geometry. But the sorts of representation they provided were more than superficially different.

For, if I may put this anachronistically, the second dealt with transformations of frames of reference in Euclidean space and its consonant kinematics. This technique was mastered in practice by the time of Copernicus though formalized only by the end of the 17th century. In contrast, the study and perfection of perspectival drawing gave rise to the very different subject of projective geometry. That too saw its first rigorous development in the 17th century, but was then neglected, until coming into its own (with a unified treatment of Euclidean and non-Euclidean geometries) in the 19th century.

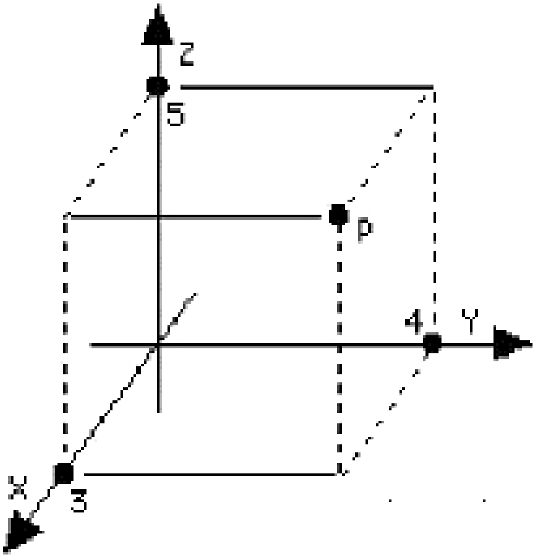
This is not an incidental historical point. Both forms of representation tend to be called "perspectival" and both tend to be thought of as depicting the appearances. But they accomplish very different tasks. Let us tentatively honor the difference between them with distinct terminologies. The geometric representation of e.g. planets and planetary motion I'll say depicts the phenomena, while perspectival drawing of the same events depicts the appearances. The motions of the planets are indeed observable, from any point of view you like. What these motions look like from a particular vantage point (i.e. in a particular measurement set-up) is their appearance (in the measurement outcome). My terminology here is a bit contrived, I admit, but we do need two words to indicate the distinction.

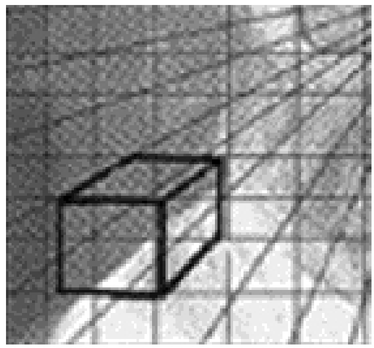
Frames of reference versus visual perspective

Take a look at the two representations of a cube below. On the left you see the geometric representation in the analytic style that Descartes introduced as a tool for physics. I had to draw this on flat paper, and my drawing is not that geometric representation (which is three-dimensional) but a representation of a representation. A moment's reflection reveals that in passage from the real cube to the geometric representation all the Euclidean invariants are preserved: distance, parallelism, orthogonality, angles in general. (Even in my drawing, where unfortunately not all edges can be drawn to be of equal length, parallelism and equality of the parallel edges are preserved!)

In the perspectival drawing on the right that is not the case at all. As every school child learns, parallel lines in a direction away from the painter converge to a vanishing point on the horizon. So neither parallelism nor metric equality of the cube's edges is preserved.[11]

A visual perspective contains comparatively little of the depicted objects and events, due to occlusion and projective distortion. This is not a question of subjectivity: the same is true of a painting in this style or a photo.[12] A geometric frame of reference on the other hand contains everything in the world, in geometrically (and kinematically, if time is included) accurate fashion. The depiction of something in a frame of reference is indeed relative to a chosen origin and orientation, but not subject to occlusion or metric distortion. We





should call it relative (relative to a frame of reference, or to this choice of origin and orientation) but not perspectival.

The standard style of geometric and kinematic representation in modern physics does not capture the appearances; it does faithfully replicate the primary qualities, the attributes of spatial and temporal extension of the observable objects and processes. Perspectival painting and drawing — or motion pictures, to add their recent continuation — on the other hand, not at all faithful to the shape of things, does capture how things appear in visual perspective.

But science aims to save the appearances! It follows therefore that we have not looked far enough yet into the scientific form of representation.

How Copernicus saves the appearances

> 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.
> Copernicus, De Revolutionibus, Preface.

The Ptolemaic system, concretely depicted by an armillary on a table top, represents the motions of the stars and planets in the frame of reference of the earth. In contrast, Copernicus' system of the world represents the motions of the stars and planets in the frame of reference of fixed stars, with the 'mean sun' as center. But because Copernicus devised his system by a sort of 'transcription' of Ptolemy's, he can point out that observations from the earth in his system will deliver the same data.[13]

Consider what is utilized in this 'pointing out'. First of all, there is what the system represents directly, the postulated "general structure of the universe". Secondly, there is the geometric optics, based on the postulate that unobstructed light travels in straight lines with infinite speed. Thirdly — and here we make contact with the visual arts — the appearances to be saved are identified with the projections through a point on the earth of the celestial motions by those straight light-lines.

The appearances, thus conceived, change with time. There were no motion pictures, but of course one could construct a series of 'stills', and one could furthermore combine these into a single picture of a motion over time. This is the birth of kinematics together with kinematic, as opposed to static geometric, representation. The most striking illustration to Copernicus' contemporaries was his new explanation of retrograde motion of the planets. 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 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.[14]

Three-faceted representation

When frames of reference come into their own, we have eventually a 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

[2] The observable phenomena
— Macro 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.

4. *Perspective as measurement*

> 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.[15]

Leon Battista Alberti wrote his mathematically sophisticated De Pictura in 1435, marking the most salient change of style from Medieval to Renaissance paintings in the West, which had began with Giotto in the previous century. Alberti dedicated his work to Brunelleschi, whose famous "experiment" demonstrated the triumph of the perspectival technique. The experiment was a demonstration to all who witnessed it that this new technique did indeed render its subjects precisely as they appear to us. Brunelleschi painted the Florence Baptistry, but made a peeping hole in the painting. A person standing precisely where the painter had stood, and looking through the peephole would see the Baptistry. Then a mirror was inserted between painting and Baptistry, so that one would see the contents of the painting instead. Behold! With or without the mirror, the scene was the same.[16]

Giorgio Vasari's Lives of the Artists about a century later yet proclaimed this style of painting to be the accurate and faithful portrayal of reality:

> painting is nothing more than the simple portrayal of all things alive in nature by means of design and color as nature herself produces them.[17]

Perspective in this sense – one point linear perspective –did not remain the artist's domain. For that this was in effect a method of measurement, with the drawing as measurement outcome, was clearly recognized upon more mathematically oriented reflection.

Alberti's technique was not rigorously applied by painters (and most likely not by Brunelleschi to construct his demonstration piece), but on the other hand it was in accurate use important to architecture, technical drawing, and machine design. Its basis was in effect a very careful and systematic form of measurement, in which certain geometric features are faithfully captured on the picture plane. This is explicitly recognized in Albrecht Duerer's treatise, where the technique is presented in a part entitled Unterweysung der Messung — "Art of Measurement", "Teaching of Measurement". The mathematically precise and practical character of this way of rendering the appearances was there shown through its possible mechanization — though of course some of the moving parts of the machines had to be human still. The content of a visual perspective (with one eye closed, in fixed position) was thus shown to be identical with the content of a complex, technically advanced measurement outcome.

Generalization to conditional perspective

Copernicus' achievement illustrates another important point about how the appearances are derived from the postulated reality in the modern era. Physical theory has the resources to explain how a certain image of the heavens is produced, on a given 'window' plane, by drawing on the Copernican system of the heavens plus geometric optics. But this derivation can be carried out as soon as the location and orientation of the plane plus the projection point (the "eye") are specified. It does not require the actual presence of an eye and canvas or window pane, camera or screen. An appearance is derivable in this substantive sense for each location and orientation in the universe.

Leibniz made the appreciation of this point central to his system of metaphysics. He added chiaroscuro to visual perspective so to speak, and son to lumière, not to mention all the other common and peculiar sensibles. For each location, each orientation there, each specifiable 'window' and every degree of fuzziness, there is a specific monad. This monad has as its intentional state a representation of the universe which is precisely the appearance of the universe from that vantage point to the extent that the monad's specific 'sensory' limitations allow.

In the appreciation of what modern science promised — and largely delivered — we must generalize from actual measurement and actual painting in precisely the way Leibniz did in his Monadology. ***For every triple consisting of a point in space, an orientation, and a plane cutting that orientation, there is a one-point linear perspective projecting the world onto that plane.*** Its content is precisely what the content would be of a Duerer-type measurement there. We can think here literally of a painting with that content, or abstractly of a (enormously complex) indexical proposition describing how the world is 'from here, now'. We can also follow Leibniz by recognizing every possible configuration of limits, thus delivering the very partial appearances that might be captured by any myopic sensorily deprived painter on a small canvas.

These perspectives and the relations between them - - most especially including what is invariant as we move from one to the other — is precisely the subject of projective geometry, initiated in the 17th century by Desargues, Pascal, and La Hire and eventually developed autonomously in the 19th. This is a general study of appearances — which we will have occasion to explore further — with of course no attention to the question of whether or not there is anyone being appeared to or any receptacle capturing, displaying, or in any fashion representing the appearance.

What are the philosophical morals to be drawn here? On the one hand this sort of oblivion to human agency, so useful to formalization, should not tempt us to reify appearances as entities in themselves, belonging to a special realm of the universe's furniture. But on the other hand we should regard the space of appearances, defined by this formal discipline, as much a part of the scientific image of the world as is the theoretically postulated reality 'behind' the phenomena.

5. *The Strange Case of Quantum Mechanics*

Let us now go back to the challenge posed by quantum mechanics. Is this after all the science which definitively breaks with the demand that the Appearances are to be shown as produced in or 'derived' from the theoretically postulated Reality? We have here, it is often said, the most successful theory in the history of science. As far as prediction goes, the riches gained have been beyond the dreams of avarice…. But this theory engendered intense debate about what it meant, and what it could mean for the future of physics, both in the scientific community and beyond. The physicists at least did not lack for philosophical audacity.

I want to take up this question, taking into account what we can say now about measurement and theories. The relevant appearances are the contents of measurement outcomes. But the complaint about quantum theory is precisely that these outcome-contents are so difficult to reconcile with what the theory says about the object measured, the measurement apparatus, and the 'pointer' indications that we identify as outcomes. The differences are basically twofold:

> — there is indeterminacy in the quantum theoretically described world, but nothing of that sort in the measurement outcomes;
>
> — the outcomes are not predictable with certainty, not even in principle, yet the laws that govern the quantum theoretically described world are deterministic.

In response I would like to apply two of the insights emphasized so far: what a measurement shows is not how things are, but how they look in that measurement set-up, and secondly, whether science satisfies the Appearance from Reality criterion (or must do so) is not at all to be taken for granted.

The dilemma argument

Recall the Born Rule which tells us how to derive testable empirical predictions from hypotheses about the quantum mechanical state of a system.[18] Rather than repeat it here, let's just state what it does:

> If observable A is measured on a system in a certain quantum state, then Born's rule provides a recipe for calculating the probability of each possible outcome.

By 'observable' is meant 'measurable physical quantity'. So mass, position, velocity, charge — these are all observables familiar already before, but present also in this new theory. Born's rule is added to the basic quantum theory. That basic theory contains the new mathematical forms of representation of states and observables, and also the dynamical laws that apply to them.

Does this full theory in principle allow for an explanation of how the Appearances are produced? Let us consider what that would require. The Appearances are the measurement outcomes. If the explanation is going to be entirely in the language of the basic theory, then the terms 'outcome' and 'measurement' must first be equated to certain quantum mechanical descriptions of the situation.

How can this be done? The measurement situation is one in which an Apparatus is properly coupled to an Object, for a measurement of a certain observable A. Then 'outcome' must refer to a final quantum state of the Apparatus, and 'measurement' to the evolution of the quantum state of Apparatus+Object during the interaction. Let us suppose that this is so.

At first blush there is certainly a problem. If the Apparatus+Object is an isolated, closed system then the dynamical laws of quantum mechanics specify a deterministic evolution for its state. (The general form of the applicable law is the famous Schroedinger Equation.[19]) What about the outcome, now equated with the final state of the Apparatus? Although quantum theory is 'holistic', and there are subtle relations between the whole and the parts, there is in fact in the quantum theory a standard rule to specify the 'reduced' state of the apparatus, on the basis of the state of the composite system of Apparatus+Object.[20] This rule, we must emphasize, does not tell us that the apparatus' final state is one of a bunch of possibles, unknown but with some probability. On the contrary, it assigns a single quantum state to the apparatus.[21]

Looked at in this way, the dynamics provided by the theory is telling the whole story. And it is a deterministic story! What has happened to the Born probabilities? Surely they indicate an indeterminism in nature, since they only rarely give us certainty.

This situation is often illustrated with Schroedinger's famous thought experiment of a cat in a hellish contrivance, in which it dies if a photon goes through a half-silvered mirror, and survives if the photon is reflected. The Born probability that the cat will survive is 0.5. For the cat is in effect the measuring apparatus, and the photon the object being measured — the possible outcomes are the cat dead, and the cat alive. Hence the 'pointer observable' is the one pertaining to the cat with possible values 'dead' and 'alive'. But if this contrivance is isolated, and Schroedinger's Equation thus applies, then the whole system Cat+(Remainder of the contrivance) evolves deterministically throughout, and the final quantum states of Cat and Remainder respectively are certainly not eigenstates of the respective observables. There appears to be a contradiction.[22]

We have arrived at an apparent contradiction between determinism in the central part of the theory, and the indeterminism that appears in the prediction of measurement outcomes.

A radical response

Nils Bohr insisted that measurement and outcome be described in "classical" language. So he assert that our supposition, in the preceding argument, is mistaken. The terms 'outcome' and 'measurement' cannot be equated to any quantum mechanical descriptions of the situation. They must have an independent meaning or reference. That is part of the original Copenhagen Interpretation of the quantum theory. (Today it is also popular in the very lively information theoretic approach.[23])

On such an interpretation, the most basic necessary condition for satisfying the Appearance from Reality Criterion is not met.

But quantum mechanics has been supplemented by quite a number of different interpretations. Despite the authority and influence of the Copenhagen interpretation we cannot simply base a philosophical conclusion on what it implies.

Outside the dilemma

The argument we just went through does not leave any logical leeway at all. But an argument has premises, and premises can be denied. From the very beginning two options were taken seriously: that either a modification or a supplementation could lead to an empirically equivalent theory in which the outcomes and measurements are identified in that theory's own terms.[24] 'Empirically equivalent' means here that the Born probabilities come out as correct in the new theory as well, conditional on the information contained in the original quantum state of the Apparatus+Object set-up. What is the difference here between modification and supplementation?

- When the theory is modified and not supplemented, the dynamical laws become indeterministic.
- If the theory is not modified but only supplemented, the outcome supervenes on the quantum state plus some hidden variables, which do not change the empirical predictions.

But if any of these efforts is successful in what it sets out to do, is the Appearance from Reality Criterion satisfied? That we cannot say beforehand at all. We need to take a look at them specifically.[25]

Episode One: is there a 'collapse'?

Johann von Neumann was the first to take the bull by the horns, in his 1932 monograph. He identified the outcome of a measurement in a straightforward way with the final state of the measured object. To explain the details, to the extent that they concern us here, we need only to add one technical notion. Some states are called eigenstates of an observable, associated with specific values that the observable can have. According to the Born rule, these are precisely the states in which the corresponding value will be found with certainty.

The Born rule, as interpreted by von Neumann, is then read as follows:

> The outcome is **r** precisely if the object's initial state Ψ changes to the r-eigenstate of observable A.
> That this will happen has probability $(|\mathbf{r}>. \Psi)^2$
> The apparatus' state at the end is the corresponding eigenstate of its own "pointer" observable.

This reading has a principle behind it, what we now call the

> Eigenstate-Eigenvalue Link: observable A pertaining to system X has value **r** if and only if X is in the r-eigenstate of observable A.

Von Neumann was quite right to think that he had to answer the questions to which these points are addressed.

> When probabilities are calculated from the quantum state, we must ask "probabilities of what?"
> When it is asserted that an observable can have different values, we must ask "what is it for an observable to have a value?"

Von Neumann asked those questions and provided answers framed entirely in quantum mechanical terms. He answered the first by saying that the probability in question was the probability of a change of state. And the second he answered by the principle that the observable has a given value precisely if the system in question is in the relevant eigenstate of that observable.

Von Neumann's indeterminism

But Von Neumann's answer implies that the quantum state of the Apparatus+Object does not evolve deterministically. There is a "collapse of the wave packet", a discontinuous and not completely predictable change of the state into one of the observable's eigenstates. (This is also called his "Projection Postulate".) This physical change during or at the end of the measurement process actually violates the dynamical laws that govern isolated, closed systems.

We could try to rationalize this by suggesting that the strange changes happen only in parts of the total system, not to the whole. That would say in effect:

> the Apparatus+Object may be a closed, isolated system to which the dynamic laws apply without exception, but its parts may have to some extent an autonomous status. Certain properties of the parts' states are not entirely determined by the state of the whole, and occur spontaneously, with irreducible probabilities. The measurement outcome — the Appearance we are interested in! — is constituted precisely by those undetermined properties that yield the measurement outcome.

If this is tenable at all, it certainly implies a violation of the Appearance from Reality Criterion. For consistency is preserved here (if it is) by explicitly disavowing even the deduction, let alone explanation, of the Appearance.[26]

There is another alternative: the Born rule, understood as by von Neumann, must pertain to some relation which the Apparatus+Object has to something outside of that. What is that relation? One answer stands out, as undoubtedly the most waved about idea in the history of the subject: that something is the observer.

Eugene Wigner: the peculiar effects of observation

> Is the moon not really there when we are not looking? No, it is not. Has Schroedinger's cat either died or survived until and unless we open the infernal machine, to see what state it is in? No, neither of these! What about us, the observers, then? Are we there when no one is looking? In fact we observers are always observed, namely by ourselves.

Eugene Wigner famously argued that quantum mechanics requires this sort of interpretation. A measurement is not an event completely describable in physics, it must include consciousness, a mind-body interaction.[27]

I don't want to discuss the virtues and vices of this sort of approach — let's just assume that it can be made consistently. The question for us here is just this:

> if this is accepted, do we have an explanation of how the Appearances — the measurement outcomes — are produced?

Unfortunately Wigner's account only looks like it provides such an explanation. His thesis amounts to the assertion that there is an explanation of the collapse, an explanation which if given would display a mechanism of production. But to assert that there is one does not amount to giving one! The criterion of Appearance from Reality is not satisfied by science if we simply add the postulate that it is satisfied in some way by something non-physical.

Moreover, with a crucial term imported from outside physics, and no further account of that term, it actually provides no clue at all to how the Appearances thus derive from the Reality. Hence we must read Wigner's proposal as involving the view that the Appearance from Reality Criterion is not a demand to be satisfied by physics.[28]

The Appearances are as if ...

These early discussions are illuminating not only because they begin to chart our range of options, but also because they were closely related to practice. Whatever the theoretical status of 'collapse', the way the working physicist calculates does always assume that the Appearances will be at least as if states thus collapse in measurement. The Born Rule is not genuinely explained that way, but certainly most easily conveyed in practice. Almost every textbook asserted that upon measurement the object will be in one of the eigenstates of the measured observable, with given probability.[29] The Appearances are as if von Neumann's Projection Postulate is true. Given the various impasses we have now reached, we need to think of how these Appearances could be saved without requiring the kind of completeness the classical mindset desires.

Episode Two: the appearances yoked unto a forbearing reality

There is a radical alternative to what von Neumann proposed: to take quantum mechanics to be incomplete in its depiction of the physical world. If it is incomplete then there is a more complete such depiction, in principle; the new ingredients therein are called "hidden variables". These ingredients may or may not be hidden from our view; they are hidden in only in the sense that they do not appear in the quantum state.

Interpretations and hidden variables

We must carefully distinguish here between interpretations of the theory and rivals. Any implication of different empirical predictions makes for a rival theory — an interpretation does not do that. So if an interpretation adds hidden variables, those variables are "empirically superfluous". Nevertheless, the question of whether it is possible to explain how the Appearances are produced might conceivably be answerable on the basis of a combination of the quantum state plus those hidden variables, empirically superfluous or not. After all that question asks not for a prediction but for an explanation.

If that is possible, will the Appearance from Reality criterion be back in its previously supposed status, as a demand on the scientific enterprise? Not necessarily! That will depend on whether, given this possibility, it is incumbent on physics to extend quantum mechanics by the addition of such hidden variables. The practically universal reaction in the physics community has been that it is not.[30]

But if the hidden variables are innocuous enough it may be possible to recast their introduction as a gloss on or reading of the equally prevalent use of the terms "measurement" and "outcome" in scientific practice — despite their apparent irreducibility to purely quantum mechanical description. I see this hunch as behind the recurrent attempts to depict quantum mechanics as "perspectival". This is what I want to explore here — with the hope or speculation that we may be able to remain in the Copenhagen spirit without feeling forced back upon the choice between empirical collapse postulates on the one hand and the increasingly strange metaphysics that are now so often invoked.

So I turn finally to a class of interpretations that clearly reject the Appearance from Reality criterion.

Modal interpretation: the elements

In his recent book Interpreting the Quantum World, Jeffrey Bub displays a very large class of interpretations under the heading of modal interpretations in a general sense. Besides some that have actually been called by that name he displays Bohm's interpretation as belonging to this. My own favorite, the Copenhagen Variant of the Modal Interpretation (CVMI) does not belong to the precise class he defines, but fits on a somewhat wider definition that I'll take for granted here.[31]

On a modal interpretation there is an important separation between states and observables. Their mathematical representatives remain the same. However, an observable (that is, a physical quantity) can have a determinate value even if the quantum state does not make it so.[32] An observable can have different values in systems which are in the same quantum state. Von

Neumann's basic Eigenstate-Eigenvalue Link is rejected. Attribution of values to observables is not equated with attribution of a quantum state.

At the end of the measurement, the "pointer" of the apparatus indicates, say, the number 17. That means now that the "pointer" observable pertaining to this apparatus has value 17. It does not imply that the quantum state of the apparatus is an eigenstate of that observable. Similarly the measured observable A, pertaining to the object measured, may now have value 17, though the object is not in the 17-eigenstate of A.

Part of the linkage is preserved: A cannot have value 17 if the object is in the 18-eigenstate of A, for example. In that case A does have value 18. But if the object is in a mixed state, of which both those states occur with positive weight, then A may have value 17 or perhaps value 18. Which value does A have then? The whole point is that the quantum state does not determine that. This is where the quantum world's indeterminism appears. The Born rule fills a gap here: it tells us that if this situation is indeed the end state of a certain measurement then there is a definite calculable probability that A has value 17.

On this interpretation a physical system's condition at a given moment has two constituents: its quantum state and a function that assigns values to observables pertaining to it. That function is also a sort of state; call it the value state (sometimes also called the 'property state'). That is, formally speaking, the hidden variable. Given that we are dealing with an interpretation here and not a rival theory, it follows that this hidden variable is empirically superfluous.

But as these modal interpretations were originally presented, the value state does represent a real characteristic of the physical system, omitted from its quantum mechanical characterization. Are we stuck with this way of understanding them?

Modal interpretation, perspectivally

Let us try out the following view instead: the value state is not a separate aspect of the real situation; it is not the case that a system has two sorts of physical states. Rather what is called the value state or property state is the content of a perspective on the system — a perspective of a (possible) measurer or viewer.

The pointer is really at the "17", the cat is really dead inside the box – although the quantum state does not make it so, that is their status in possible or actual measurement outcome. But remember: what appears in a measurement is now how the object is but how it looks. That the pointer observable has value 17: that means that in this measurement, observable A's having value 17 is how the object looks. The cat looks dead — is it dead? As long as cat and apparatus remain in a thoroughly entangled state the cat can look dead or look alive. The cat's role in Schroedinger's hellish contrivance is that of a measuring apparatus (the measurement being performed on the photon). Its 'pointer observable' is the observable with values 'dead' and 'alive'. The measurement outcome could have as content one or the other, these are different perspectival 'takes' on the photon's state. If the two — Cat and Remainder of the contrivance — are disentangled (if through interaction with the environment the situation 'decoheres') this ambiguity in the facts will cease.[33]

Remember also that we must think in the ways of Leibniz's monadology here. There aren't measurement apparatus located at every point, but the theory implies conditional perspectival looks as well. In the case of visual perspectives as treated in projective geometry, we also think of every point and orientation determining a perspective, regardless of whether there is a thus oriented measurement apparatus or viewer present at that point. Think of it here in the same way. The appearances are the contents of possible as well as actual measurement outcomes.[34] Unlike in the classical case, the conditional perspectival looks cannot be jointly realized for all observables at once, however.

The measurement outcomes, these are the Appearances to be saved! They are saved in that the interpretation makes room for them in the theoretical world picture. But they are saved in a way that explicitly rejects their derivability from the quantum state. (In fact, this interpretation does not even yield supervenience on the quantum state: for two systems in the same quantum state may have different value states.)

What are the Appearances like, on these modal interpretations? We do see quite some variation there. I will illustrate with two of them, one favored by Bub and one that I still favor.[35]

'Single perspective' variant of modal interpretation

Bub's interpretation implies that the actual state of the world is characterized by the definiteness of a single 'privileged' observable. One example could of course be position: then everything in the world could have a precise location.[36]

In quantum theory not all observables are mutually compatible. Whatever observable has this privileged status will preclude many other observables from having any definite value at all. Some other such observable could have this privileged status instead, and then the objects in the world would not have definite locations.

On Bub's view we can think of his world as follows. The world is a system which has a quantum state and, in addition there is a privileged observable which has a definite value. So it is just as if that observable had just been measured on the world, with a collapse precipitated by that measurement. In that sense we see that von Neumann's collapse — and the usual practice that seems to instantiate von Neumann's interpretation — are reflected here. The Appearances are indeed just as if certain measurements have projected the measured objects — indeed, all objects! — into an eigenstate of a particular maximal observable.

Can we understand this interpretation perspectivally? I think so. For each quantum mechanical model of the world, there are many models in which the quantum states there assigned are supplemented with value states. Let us call the latter the associated interpreting models. This supplementation is systematic: a single observable has the privileged status that it has definite values, and values are distributed to other observables derivatively from the privileged one, if at all.

This is how, according to von Neumann, the world would look in one of the possible outcomes of a measurement of the privileged observable. What is dropped from von Neumann's interpretation is the postulate that this look comes from a real change in the world's state. Giving up on the idea that the theory is responsible for specifying some physical process by which that appearance is produced, we have left that this is the way the world appears. For each such possible look, compatible in Bub's specified way with the given quantum mechanical model, there is such an interpretative model. These interpretative models therefore constitute the manifold of possible perspectives on the world.

This manifold of perspectives is entailed by the quantum theory, just as the manifold of contents of possible perspectives on the world is entailed in classical physics. Well, not precisely "just as": the means for deriving the appearances from the state of the world plus the origin, orientation, and 'picture plane' of the measurement set-up is lacking in the quantum theory.

But that rejection of the Appearance from Reality Criterion is precisely the option under which modal interpretations are developed.

'Windowing': a different style of painting

Before turning to an alternative, in which the world is depicted as subject of many perspectives at once — in some sort of harmony! — I need to introduce you to a bit more history of perspective.

The fact is that Vasari was quite wrong when he wrote " painting is nothing more than the simple portrayal of all things alive in nature ... as nature herself produces them."[37] A quick look at modern paintings might suggest that from the Renaissance till the 1880's (with Cézanne's perspective sabotaging still-lives) obedience to the structure of one-point linear perspective was a categorical imperative. But that is a mistake practically throughout. The lesson that we can see applied in practice was that “realistic” representation is achieved through distortion — but careful, systematic distortion, even perspectival distortion.

We do not experience the visible world as if we are statically placed with one eye behind a peephole. 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.[38] The artistic representation is not a geometric projection of its subject — it is to be created so that it looks right to the observer.

As an example let’s take this painting from the Northern Renaissance, Dirk Bouts’ Last Supper in Leuven. Views of this painting are easily available now on the internet.[39]

At first sight this is a textbook example of perspectival drawing.[40] But on second look it is not: when you look at each face, or the chandelier, individually, you find that you are seeing it from a point at its 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. Why then does it give it initial impression that the painter rendered faithfully just what a viewer would see when entering the room? Because we are mobile creatures, and our mobility is so deeply integrated into our imagination that the mind’s eye moves, so to speak, even when the body does not.

This technique, beautifully and thoroughly explored in the artist David Hockney’s book Secret Knowledge, is called windowing. It is a clear violation of the technique that Brunelleschi demonstrated, and this degree of violation is actually found in modern visual art from the earliest days.[41] It has of course been suggested that the Northern Renaissance painters were not as sophisticated yet as Alberti and his compatriots, and that this could account for deviations from perspectival painting. Even if that is so, however — not very plausible, since the effects created are dramatically effective in part because of those deviations — there are ample instances of windowing in later paintings, sufficient to make the point.[42]

The appearances to the observer do not derive from the reality by single geometric projection. Is that relevant to science? I have located perspectival drawing under the heading of measurement – as Duerer did – and will even hold it up as a paradigm case. So there is no immediate application: a measurement apparatus does not add imagined movement into its data registry in the way of a human viewer of Bouts’ painting. Nor does the correlation of measurement results at different moments, as for example by Einstein’s imaginary train conductors, violate perspective in that way. Bouts' windowing places appearances that would be consequent on movement all in the same plane as if simultaneously projected — as if distinct frames from a movie were combined into a still, but with such skill that it deceives the eye.

However, when it comes to a theory which subverts still more of our common sense concepts than classical or relativity physics, Bouts may offer us new inspiration. So now let us look at something quite close to Bub's rendition of the quantum world, but with greater perspectival complexity.

'Windowing': the Copenhagen Variant of the Modal Interpretation

My own favored interpretation, the Copenhagen Variant of the Modal Interpretation (CVMI), relates to Bub's family of modal interpretations more or less as windowing does to one-point perspective.[43] There is no simple privileged observable. But it is as if the Ignorance Interpretation of Mixtures is correct, for every object in the world has a 'value state' that is pure. These value states are related to the quantum states and to measurement processes (quantum mechanically defined) so that in consequence it is also as if von Neumann's Projection Postulate is true. Again the 'as if' describes the Appearances, that is, the value states (the contents of possible measurement outcomes) but not the quantum state.

Why do I say that this is like 'windowing' rather than like one-point perspective? These value states are the contents of specific perspectives on those objects — of conditional perspectives, of course, with the assignments subject to constraints that harmonizes them into a single beautiful world of appearance. Here the quantum world does not look as one would expect if the 'collapse' idea had been right and the world had just been subjected to great single comprehensive measurement.[44] Rather, in a CVMI model every object, including every part of an object, 'looks' as if it has just been individually projected into some pure state. Thus it is possible for both the whole and the parts to be definite in their Apparent characteristics. The Appearances thus assigned are as if each object in the world is seen individually from some specific measuring vantage point.

The structure of appearance

On this view, what is the world like? We restrict ourselves here to elementary quantum theory. The world consists of things that however, as Bohr said, resist description consonant with the older ideas of causality and locality:

> the renunciation of the ideal of causality in atomic physics which has been forced on us is founded logically only on our not being any longer in a position to speak of the autonomous behavior of a physical object."[45]

But these objects each have a quantum state (dynamical state); they are often compound, and then their parts all have quantum states too. The quantum state of an isolated system develops in time in accordance with the Schroedinger equation, that is, deterministically. The states of their parts evolve too, in a way directly derivative from the evolution of the whole. All of this applies equally well to those cases in which one part of a system is a measuring apparatus in appropriate interaction with another part.

But besides these physical states that are the subject of dynamics, there are the appearances of these very things in possible determinate measurement set-ups. These appearances are described ***in the same language*** as the dynamical states. (Note that, in our more ordinary context, we describe the shape of a table as it appears in a photo in the same language as we describe its shape simpliciter!) They can be described as value states or property states, represented by vectors in the same Hilbert space that represent the pure quantum states. In actual measurement, these value states are what appear in the measurement outcomes.

6. *The Final Challenge*

The details of quantum theory interpretation are fascinating, challenging, and frustrating, and its problems are by no means all settled. But my main aim in this paper is not to defend a specific interpretation — let alone its details in one form or another! Rather, what I mean to do is to argue that it is perfectly scientific, and scientifically acceptable, to reject the completeness criterion for science that has had such a grip on the modern philosophical imagination. That is a point concerning the aim and methodology of science, directed against at least certain traditional themes in 'realist' philosophies of science.

As I see it, the recent history of science should convince us that this is so. The Copenhagen physicists were acting in a way that counted as real physics when they introduced and developed quite explicitly a theory and an interpretation incompatible with the Appearance from Reality completeness criterion. Therefore that criterion is ***not*** a constraint on the sciences.[46] It is, in that case, just another of those philosophically or metaphysically motivated imperatives that could hamper science if they were obeyed, and though they receive much lip service, are anyway quickly flouted when that hampering is felt.

Princeton University

BIBLIOGRAPHY

Accardi, L. (ed.) The Interpretation of Quantum Theory: Where Do We Stand? Rome: Istituto della Enciclopedia Italiana, 1994 (distributed by Fordham University Press).

Alberti, Leon Battista On Painting. Tr. C. Grayson, with an Introduction and Notes by Martin Kemp. London: Penguin Books, 1991.

Armstrong, David M. and Norman Malcolm, Consciousness and Causality. Oxford: Blackwell, 1984.

Armstrong, David M. A Materialist Theory of Mind. London: Routledge and Kegan Paul, 1968; revised edition with new preface, New York: Routledge, 1993.

Babich, B. E. Hermeneutic Philosophy of Science, van Gogh's Eyes, and God. Dordrecht: Kluwer, 2002.

Bedard, Katherine "Material Objects in Bohm's Interpretation," Philosophy of Science 66 (1999), 221-242.

Bohr, Nils "Causality and complementarity," Philosophy of Science 4 (1937), 289-298.

Bub, Jeffrey "Why the quantum?", *Studies Hist. Phil. Modern Physics* 35 (2004), 241-266.

Bub, J. Interpreting the Quantum World. Cambridge: Cambridge University Press,1997.

Cohen, I. Bernard The Birth of a New Physics. New York: W. W. Norton; Revised ed. 1960.

French, Steven "A Model-Theoretic Account of Representation (Or, I Don't Know Much About Art … But I Know It Involves Isomorphism)," Philosophy of Science 70 (2003), 1472-1484.

Gombrich, Art and Illusion. Princeton: Princeton University Press, 1960.

Gopnik, Blake Pictorial Mimesis in Cinquecento Italy, 1500-1568: Texts, Visual Rhetorics, and a Roman Test-Case. A doctoral thesis for the University of Oxford, Wolfson College Hilary Term, 1995.

Grua, Gaston (1985). Jurisprudence universelle et théodicée selon Leibniz. New York: Garland; reprint of idem, Paris : Presses universitaires de France, 1956.

Grünbaum, Adolf "Complementarity in Quantum Physics and its Philosophical Generalization," Journal of Philosophy 54 (1957), 713-727.

Hockney, D. Secret Knowledge: Rediscovering the Lost Techniques of the Old Masters. New York: Penguin Putnam, 2001.

Jauernig, Anja Leibniz Freed of Every Flaw: A Kantian Reads Leibniz. Dissertation, Princeton 2003.

Kubovy, Michael The Psychology of Perspective and Renaissance Art. Cambridge: Cambridge University Press, 1986.

Leplin, A Novel Defense of Scientific Realism. Oxford: Oxford University Press, 1997.

Lopes, D. Understanding Pictures. Oxford: Oxford University Press, 1996.

Margolis, J. "Patrick Heelan's Interpretation of van Gogh's 'Bedroom at Arles,'" pp. 233-238 in Babich (2002).

Mates, Benson The Philosophy of Leibniz, New York: Oxford University Press, 1986.

Panofsky, Erwin Perspective as Symbolic Form, New York: Zone Books, 1997.

Pauwels, Aimé and Henri Pauwels, "Dirk Bouts' Laatste Avondmaal, een belangrijk keerpunt in de evolutie van de perspectief in de schilderkunst van de Nederlanden," in Dirk Bouts een Vlaams primitief te Leuven, pp. 71-95. Louvain: 1998.

Place, U.T. "Is consciousness a brain process?" British Journal of Psychology 47 (1956), 44-50.

Schroedinger, Erwin "The meaning of wave mechanics", pp. 16-30 in Louis de Broglie physicien et penseur, edited by André George, Editions Albin Michel, Paris, 1953.

Stone, A. "Does the Bohm theory solve the measurement problem?" Philosophy of Science 61 (1994), 250-256.

van Fraassen, Bas C. "Interpretation of QM: Parallels and Choices", pp. 7-14 in Accardi (1994).

van Fraassen, Bas C. Quantum Mechanics: An Empiricist View. Oxford: Oxford University Press, 1991.

van Fraassen, Bas C. Review: J. Bub, Interpreting the Quantum World. Foundations of Physics 28 (1998), 683-689.

van Fraassen, Bas C. "Transcendence of the Ego: The Non-Existent Knight," Ratio (new series) XVII (2004), 453-477.

von Neumann, J. Mathematical Foundations of Quantum Mechanics. Princeton: Princeton University Press, 1955. (German original 1932.)

Weschler, Lawrence "The Looking Glass," The New Yorker 2000-01-31; see further his "Through The Looking Glass — Further adventures in opticality with David Hockney," in the (formerly) on-line art magazine ArtKrush, copied at http://www.geocities.com/newsgrist/newsgrist2-33.html.

Zajonc, A. Catching the Light. Oxford: Oxford University Press, 1993.

Notes

1 Pino, Dialogo di pittura, (1548) IX; cited Gopnik, page 99; see further Gopnik pp. 95-102 on how Leonardo da Vinci and his contemporaries saw the relation between the sciences and the visual arts.

2 As Leibniz made explicit, logically necessary connections may not be finitary, may in fact be inaccessible to any finite mind — (therefore not within even the potential reach of the physical sciences). 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.

3 That would be a minimal requirement — in fact the one that Cardinal Bellarmini suggested to Galileo as solely relevant.

4 Leplin, p. 15. See further e.g. page 80.

5 For simplicity of exposition I assume that A is discrete and not degenerate: there is a single unit eigenvector for each eigenvalue, and the possible values constitute a countable set of eigenvalues.

6 Cf. U.T. Place (1956).

7 See further the similar position by David Armstrong in Armstrong and Malcolm,and his A Materialist Theory of Mind.

8 As a metaphysical postulate this supervenience claim presumably gives some emotional comfort to the materialist. While science is here admitted to be incapable of showing this, the world is still how the materialist would like it to be.

9 Cf. Grua, 303, quoted by Mates, 108-109. For this part, and for these references, I am thoroughly indebted to Anja Jauernig's dissertation (Princeton 2003).

10 If we leave modal metaphysics aside, then the best way to think of supervenience of one sort of description on another is that the one cannot be translated into the other sentence by sentence, paragraph by paragraph, or even recursively specifiable set by set, etc. but there is a translation nevertheless in the abstract sense of an equivalence set by set which is not definable by mathematical or logical means. See the relevant section of my "Transcendence of the Ego ...".

11 In fact, this drawing is in one-point perspective, which is definitely not what a pin-hole camera would capture; it is still quite artificial with respect to the actual content of a visual perspective, where there is much marginal distortion.

12 Such limiting features are crucial to the distinction between visual picturing and other modes of representation; see Lopes (1996, Ch. 6).

13 This makes the point I want to make simple. The entire discussion of modern science that follows here, before we return to quantum theory, could be more informatively developed around e.g. Newton's system of the world — but I think we would lose the forest for the trees.

14 See e.g. I. Bernard Cohen, page 39, figure 10.
15 Alberti, tr. Grayson 1972; 1991 Penguin edition page 54.
16 See e.g. Zajonc, page 60.
17 Giorgio Vasari, Le Vite de' più eccellenti pittori, scultori ed architettori, (1550) ed. Gaetano Milanesi (Florence 1878-85), II, 288; cited in Gombrich, page12.
18 For simplicity of exposition I assume that A is discrete and not degenerate: there is a single unit eigenvector for each eigenvalue, and the possible values constitute a countable set of eigenvalues.
19 The interaction must be governed by a suitable Hamiltonian, to satisfy the requirements for measurement. Schroedinger's equation then shows how the Apparatus+Object state evolves deterministically throughout the time interval in which this system is isolated.
20 This rule, reduction of the density matrix, assigns to the Apparatus the unique state such that the Born probabilities for any observable B pertaining to the Apparatus alone equal those for the observable B I on Apparatus+Object, where I is the trivial 'identity' observable on the Object.
21 This has not always been clear, since the final state calculated directly shows the measured object to be in a mixture of eigenstates of A at the end of the process. It is tempting to think that this means that it is then really in one of those eigenstates, we don't know which, with the mixing coeffients constituting a probability measure of our ignorance. Reichenbach pointed out in the 1940s that this "ignorance interpretation" of mixtures would dissolve the quantum mechanical paradoxes and the measurement problem. But as has been recurrently pointed out in the literature since then, this interpretation of mixed states is not tenable for objects united in an entangled state.
22 The final state of the cat in this scenario (before the box is opened) is a mixture of the 'dead' and 'alive' eigenstates. In early discussions it was sometimes suggested that to be in a mixture of two states is just to be in one of them, with some probability for each —see previous note: that is not a tenable interpretation here since Cat and Remainder are indeed united in an 'entangled' state.
23 Jeffrey Bub, "Why the quantum?", ms. 2003, abstract: "assuming the information-theoretic constraints are in fact satisfied in our world, no mechanical theory of quantum phenomena that includes an account of measurement interactions can be acceptable, and the appropriate aim of physics at the fundamental level then becomes the representation and manipulation of information."

24 There are of course also in this neighborhood rivals to the quantum theory which imply different empirical predictions — and we must distinguish those from attempts at interpretation.

25 It may help if we start first by listing the various alternatives, if premises of the above argument are to be denied.

ALT1. The terms 'outcome' and 'measurement' are not to be equated with aspects of the quantum-mechanically described physical situation.

ALT2. The dynamical laws for an isolated, closed system are to be modified, so as to let in some stochastic element.

ALT3. The Born rule does not pertain to an isolated, closed system, so the dynamical laws of quantum mechanics do not apply directly.

ALT4. The 'standard rule' which assigns a state to the Apparatus, on the basis of the state of Apparatus+Object, is either not applicable here or gives incomplete information about the parts of the total system.

All these alternatives have been pursued; that is why the theory has so many different interpretations.

26 This solution also preserves supervenience of the outcome on the quantum state; in fact the outcome is a quantum state. What is relinguished is the possibility of explaining how the quantum states of the two parts come about — the dynamical laws governing evolution of the system as a whole give no clue to it. But we should note also that the standard treatment of composition and reduction of states in compound systems is not so easily given up or modified! But the difficulties for this idea are not so relevant here, given that our sole interest is in the implications for the Appearance from Reality criterion.

27 Imagine Schroedinger's dismay — he wrote " For it must have given to de Broglie the same shock and disappointment as it gave to me, when we learnt that a sort of transcendental, almost psychical interpretation of the wave phenomenon had been put forward, which was very soon hailed by the majority of leading theorists as the only one reconcilable with experiments, and which has now become the orthodox creed, accepted by almost everybody, with a few notable exceptions." ("The meaning of wave mechanics", page 16.)

28 The 'decoherence' approach to measurement is often mentioned as perhaps doing with a physical environment, in which the measurement is not isolated, what Wigner tried to do with consciousness. While decoherence is an important and arguably indispensable feature in a real measurement, it is generally acknowledged now that this insight does not solve or remove the measurement problem. There is only one move that I am omitting now in this discussion: to say that there is no such system as the whole universe — every physical system is an "open" system.

29 As David Albert has forcefully pointed out, the collapse postulate changes the predictions of the theory. For there is a definable quantity pertaining to the system as a whole (box with Cat etc. inside) for which measurement outcome probabilities are certainly different, depending on whether there was a collapse. 'Recombination' experiments furnish today the most psychologically compelling support for rejecting collapse, but in my view Albert's point is already a solid reason if we are concerned to have an interpretation, without affecting the empirical content.

30 I have to add here too that within an empiricist stance there is absolutely no interest in the question whether quantum mechanics is true under one interpretation or another. In fact, whether there is anything true in the theory beyond what it implies for the observable phenomena is irrelevant to the basic criterion of success in science. But to understand a theory in physics we need to look into what it says beyond that, and the many ways in which what it said can be interpreted. Understanding the theory, to a certain extent, is crucial for us here if we are to appreciate the Copenhagen revolutionary challenge to traditionally proclaimed values and ideals.

31 See my Review of Bub, Interpreting the Quantum World.

32 (p.178) This class of interpretations include Bohm's interpretation, Bub's own, versions of Bohr, Kochen, and many others, though it does not in fact include all modal interpretations — see my review of his book. The Copenhagen Variant of the Modal Interpretation, which I shall discuss below, is not included, but shares the features I am outlining here.

33 Actually, more accurately, the ambiguity will almost cease; we are in the world of quantum mechanics — Dorothy, we are not in Kansas any more ....

34 This must be read very carefully. All those measurement outcome contents must cohere together in a certain way, so that they can be thought of as all perspectives on a single world in some specific quantum state. In just the same way, the entire set of contents of visual perspectives, with origins in both possible and actual viewers, in a given room for example, must cohere so that they can be regarded as being "of" the same room. In the case of the modal interpretations I am discussing, the delineation of what the joint value states can be of the parts of a compound system, given a quantum state for the whole, is directed to this point.

35 Although Bub lists it as one of the interpretations covered in his framework, I am not going to take up Bohmian mechanics here. Bohm allows only one parameter to have a definite value – always the same one, always definite – namely position. This world is one of particles that are always somewhere – and larger objects 'made up' of those particles, always in a precise spatial region. Their motions are continuous in time. This view may have been inspired by the extreme operationalist idea, going back to Mach, that in the last analysis every measurement is a length measurement. (Not very

plausible: could you describe even a length measurement operation using only predicates denoting lengths?) Or perhaps it derives even further back from Descartes' dream of a world whose only objective properties are attributes of extension. That the phenomena are saved in a weak sense only and that there is still an Appearance/Reality gap here is argued in my "Interpretation of QM: Parallels and Choices", as well as in papers by Abe Stone and Katherine Bedard.

36 This is characteristic of Bohm's interpretation, which was given new life for a while by a number of writers in recent decades.

37 Cf. Joseph Margolis in Babich (ed.), page 234: "Brunelleschi had isolated the unique circumstance in which the artificial perspective of two-dimensional representations of natural space coincides with natural perspective [...] The artist is always obliged to reconcile, wherever he has an interest in perspectival realism, the demands of realism (as they are understood in his own age) and the demands of the visual coherence of its pictorial representation viewed as a picture. The decisive factor is this: the normal viewer of a painting changes his point of view while scanning the picture before him; he is not confined to anything like a Brunelleschian peephole ....."

38 See for example Kubovy (1986). This book engages well with the history and philosophy of art and demonstrates how already in the Renaissance painters violated perspective in various ways, to a good purpose, and with good psychological rationale.

39 See http://www.abcgallery.com/B/bouts/bouts3.html.

40 The classic analysis of perspective in Renaissance art appears in Erwin Panovsky's Perspective as Symbolic Form who writes "the perspective of Eyckian pictures is, from a purely mathematical point of view, still "incorrect"; for the orthogonals, although they may converge to a single point within an entire plane, do not so converge within the entire space .... This latter convergence seems rather to have been arrived at first by Dirk Bouts" (page 61), illustrating his point with a schematic depiction of Bouts' Last Supper. One critic's entry on this painting reads: "The real novelty of this extraordinary painting lies in its systematic application of the laws of perspective. Jan Van Eyck and Rogier Van der Weyden had already used perspective, but only in interior scenes that were much simpler than this Last Supper. They had done nothing as complex or as perfect as the architecture of this central room." (The Web Gallery of Art http://gallery.euroweb.hu) See also Pauwels, Aimé and Henri (1998) whose analysis of perspective in this painting is also available on the web at http://users.pandora.be/aime.pauwels/Bouts.engels.html. Panovsky does point out (notes 53 and 60) that the Northern Renaissance painters used 'empirical' methods to construct perspective, inferior to the geometric theory codified by Alberti, but does not discuss whether e.g. Bouts' painting remains perspectival at

the level of detail. The contrary conclusions that I am reporting on here are to be found and demonstrated in David Hockney's Secret Knowledge. These conclusions are quite independent of his much disputed historical speculations — see e.g. Lawrence Weschler.

41 True, the violations starting in the 1880s are more drastic. Bouts knew how to combine the 'windowed' scenes so as to create a "realistic" appearance through distortion of this sort. Cézanne rejects the imperative to create a "realistic" appearance in that sense. This successors went farther, though largely in order to create a greater realism at other levels. .See further Steven French's forthcoming paper from PSA 2002

42 See David Hockney's Secret Knowledge, pages 99-121, and for additional forms of 'faithful distorting', pages 172-179.

43 See my review of Bub for an explanation of how it is related to, but does not fall in, the class described in his book. A complete exposition can be found in my Quantum Mechanics.

44 For in the CVMI the Appearance of a composite system matches its Reality if that system is already in a pure quantum state. In that case it could not be the result of a projection which also projects its components into pure state.

45 Nils Bohr, "Causality and complementarity", cited in Grunbaum 1957, page 722.

46 Note also that if we agree to this conclusion, the lacunae in explications of 'production', 'causal mechanism', 'genuine derivation', and the like, as used in this context (as opposed to their more down to earth uses) are no longer a pertinent problem for us. Such concepts would presumably have to be mobilized if we tried to provide a thorough explication of the Appearance from Reality Criterion, going beyond the logic of these terms. But if the criterion marked in fact only a temporary research program in the sciences, and is rejected from our account of what science is, those problems can be left aside in philosophy of science.