Popper's Views on Natural and Social Science
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# 10. A WORLD OF PROPENSITIES

*I now regard the analysis of causal explanation in section 12 of L.d.F. (and therefore also the remarks in the Poverty and other places) as superseded by an analysis based on my propensity interpretation of probability.*

Karl Popper

Popper came to study probability theory because of his interest in quantum physics which had brought in probabilities after Heisenberg announced his famous uncertainty principle. Simply stated, this held that the more precisely the position of a particle is measured the more imprecise, or uncertain, will become the measurement of it momentum; and vice versa. This finding aroused much interest because it raised the question whether the universe, as physicists had long held, is strictly deterministic; at the basic quantum level the principle of causality seemed not to apply. Yet Heisenberg, Einstein and other scientific leaders clung to an interpretation which tried to preserve the idea of strict determinism by relating quantum uncertainty to limitations on human knowledge because, as Einstein thought, God 'does not play dice'.

Schrödinger developed a wave mechanics and showed that it gave the same results as Heisenberg's particle theory. Born unified the two theories by showing that the amplitude in Schrödinger's wave equation could be used to give the probability of finding the particle within any given region of space. He thus gave a statistical interpretation of quantum theory but held, like others, that the probabilities were subjective, a kind of inverse measure of human ignorance, arising from inevitable limitations on our knowledge of quantum phenomena.

Popper has always argued against Laplacean determinism, and so was dissatisfied with this subjective interpretation of probability. He preferred an objective interpretation, and turned for that to Richard von Mises' theory which took probabilities to be relative frequencies of occurrence that became stable over a sufficiently large number of identical trials.

The main (but not the only) difficulty he saw in the subjective view that probabilities are to be assessed in the light of available information is that the crucially important law of large numbers



cannot be logically derived from the basic assumptions of this theory. For the derivation requires that probabilities are independent in repetitive trials, and this cannot be the case if probabilities depend upon some degree of ignorance or belief about the causal factors which, subjectivists suppose, would fully determine the outcomes. As Keynes had noted, assessed probabilities, are bound to change with knowledge of preceding outcomes. On a simpler level, it seems absurd to think that dice throws are random because of our ignorance of initial conditions and that they would cease to be random if our knowledge could be sufficiently improved. Objective statistical frequencies simply cannot be explained by subjective ignorance or by 'degrees of rational belief'.

Yet there were difficulties, too, in the relative frequency theory. Popper had met some of them in 1935 by amending this theory[1], but worried in later years about a major problem of its application to quantum theory. This was that the relative frequency theory could obviously not deal objectively with *singular* probabilities, i.e. the probabilities of single events. In the *Logic of Scientific Discovery* he had tried to get over this by defining 'formally singular probabilities'. Take, as an example of a statement of a singular probability, 'the probability that the next throw of this dice will be 4 is 1/6'. Popper definition of its formally singular form would have given: 'the next throw of this dice belongs to a given sequence of trial throws such that the probability of any of them yielding 4 is 1/6'. In that way he preserved the relative frequency interpretation of probability by a semantic trick.

But when Born introduced his statistical interpretation of quantum mechanics he made important use of the idea of singular probabilities, although interpreting them as a measure of subjective ignorance. It took Popper some time to see that Born's singular probabilities were meant to be actual and so could not be treated as formally singular.

This difficulty for the relative frequency theory of objective probabilities was, of course, also recognized to some extent by others, but with the result that quantum theorists would inconsistently swing between objective and subjective interpretations of probability in dealing with their problems[2]. It was not until 1956 that Popper reached a new objective interpretation of the probability calculus which covered singular probabilities. He

[1] *The Logic of Scientific Research,* Ch. VIII.
[2] *Quantum Theory and the Schism in Physics,*1982, pp. 104–106.

proposed, in place of the relative frequency theory, what he called a 'propensity' theory[3].

Its starting point, indeed, is the objective probability of a single event. Popper interprets this probability as the weighted possibility of the event being realized among all the possible events that a well defined objective situation, experimental or otherwise, could generate over an *infinite* sequence of repetitions. Each event would have its own weighted possibility of occurrence, and this possibility is interpreted as the measure of the propensity, or tendency, of a possibility to be realized upon repetition. The sum of these weights for all the possible events that the situation could generate is unity because the weights are taken to be probabilities.

To illustrate, take the simple example of tossing a dice. The objective situation comprises an unbiased dice, someone or some device to shake it in a beaker, and an even, horizontal table on which the dice lands when it is cast. All the possible events to which this situation could give rise are the dice turning up 1, 2, 3, 4, 5 or 6. Over an *infinite* number of trials, the *virtual* relative frequency of occurrence of each of these numbers is conjectured to be 1/6; and it is said that the situation has propensities to generate these probabilities.

A probability or propensity distribution is thus regarded as assigning weighted possibilities or *virtual* relative frequencies to all the events to which the situation could ever give rise over an *infinite* number of repetitions. It is to be distinguished from a statistical distribution, which relates to *actual* relative frequencies recorded for a *finite* sequence of repetitions.

Popper emphasizes that such a propensity distribution is a real relational property of the whole objective situation, not of any of its elements and still less of the events which it generates. Nevertheless this distribution of virtual relative frequencies cannot itself be observed, so that it has to be conjectured; i.e. stated as an hypothesis. The hypothesis, however, can be tested against one or more corresponding statistical distributions of actual relative frequencies, and may well be revised in the light of such testing.

He has used a simple example to illustrate the inadequacies of both the classical and the frequency theory; it also illustrates his idea that probabilities relate to situations rather than to events. Consider a true dice and a loaded dice. If only the true dice is thrown all six possible outcomes have, as the classical theory maintains, equal probabilities of 1/6. If only the loaded dice is thrown the classical theory cannot determine the probabilities of the outcomes but the more general relative frequency theory could. If, however, the loaded dice is thrown 10,000 times and if these throws are preceded by 5 throws of the true dice then the 10,005 throws constitute a statistical population. The von Mises theory would have it that the probability of any one side turning up on any throw that belongs to the population is the relative frequency with which that side has turned up over all 10,005 trials. Yet this cannot be true for any of the first five throws. Here we have a mix of two different situations, one involving the true dice and the other the biased dice. The relative frequency theory would obviously give different results if they were distinguished. Probabilities thus depend on objective situations not on frequencies of events.

[3] *Realism and the Aim of Science,* Part II, Ch. 1.



He focuses, therefore, not on the possibilities of an *event* occurring, but on the inherent propensity of a *situation* to generate, upon repetition, a certain statistical average in respect of the event. This means that repetitions of the repetition will lead the resulting averages towards some stable value. And that is his solution to the mystery of relative frequencies tending to reach stable values[4].

It is important to realize that this propensity theory makes all scientific laws probabilistic, including exact causal laws as the special case of probabilities being unity. This is shown formally in a simple way. A probability law can be expressed as

$$p(a,b) = r$$

meaning that the probability of the conditions b producing an outcome a equals a real number r whose value lies between 0 and 1. In this sense a is is said to be causally explained (in a weak sense) by b. An exact causal law is then written as

$$p(a,bx) = 1$$

where x ranges over all possible situations, including those which are incompatible with a or b. Popper regards this as a generalization of his previous analysis of causal explanation.[5]

He sees an analogy here between his probability propensities and Newtonian forces, and so between propensity distributions

[4] *Realism and the Aim of Science,* p. 397; *A World of Propensities,* p. 11.

[5] *A World of Propensities,* 1990; also *Changing Our View of Causality,* a paper delivered at the University of Arkansas, 1988.

and physical fields of force (e.g. gravitational, magnetic or electrical fields). Both, in a sense, are metaphysical in that they are not directly observable but reveal themselves indirectly through their effects. It is well known that Bishop Berkeley made strong objections to Newton's theory as putting invisible and occult properties like forces into Nature, and similar objections were later raised by such physicists as Hertz and Mach. Yet the Newtonian theory proved to have great explanatory power. Popper believes that his propensity theory also has such power, and that his propensities are as real as Newton's forces. Both point to unobservable dispositional properties of the physical world and help in interpreting physical theory, forces to explain observable accelerations and propensities to explain observable relative frequencies.

Watkins points out that the propensity theory of probability refutes Hume's claim that there is no middle ground between sheer chance and complete determinism.[6] If a dice is loaded so as to make 6 turning up more probable, then it is not a matter of sheer chance that 6 turns up more frequently nor is it bound to turn up every time. He also points out that there can be propensities superimposed on propensities, perhaps in a hierarchy as in the case of a pinboard whose pins are altered in accordance with the falls of a loaded dice so that its propensity to give a certain relative frequency distribution for dropped balls is continually altered in accordance with the propensity of the loaded dice to generate relative frequencies of dice outcomes. This, of course, is a very artificial example; a better one could be the tendency of weather variations to affect the tendency of an area's sheep to grow fleeces of various weights.

Only recently did Popper see that his propensity theory, first devised to meet difficulties in interpreting quantum mechanics, had implications going well beyond it and, indeed, far beyond physics.[7] They reach, he now thinks, to any field of knowledge which uses probability laws, including their special case of causal laws, and so to all aspects of the physical, biological and social sciences. All of them can work with an objective theory of probability, and all can give up the idea that the universe, or any part of it, is completely determined. For probabilities, that is, propensities, not only result from situations but, when realized,

[6] J.W.N. Watkins, 'The Unity of Popper's Thought", Ch. 11 of *The Philosophy of Karl Popper*, pp. 388–389.
[7] *Unended Quest*, 1976, p. 219; see also *The Philosophy of Karl Popper*, pp. 1131–37.



can change those situations so that new propensities appear, then new situations, and so on. Over a sufficiently long time span all possibilities, however improbable, could be realized but not all are because situations change before such a time span could be reached. Propensities, accordingly, are not static, but rather ongoing *processes* which make for a changing universe—one in which *only the past is objectively certain, never the future.*

That is shown by the evolution of the cosmos from the 'Big Bang' explosion of an unimaginably hot and dense collection of subatomic particles or forces to the creation of hydrogen which condensed into stars among receding galaxies, and in the stars intense gravitational pressures led to the evolution of heavier chemical elements. But it is perhaps more readily appreciated by considering the evolution of life from organic compounds and the resulting generation of numerous evolving species. More readily still by considering the evolution of society which, even within our own life times, has dramatically changed, in an interacting and consecutive way, the range of possibilities, good or bad, that are open to us.

One major consequence of this new view is de-emphasis on causal laws. The long accepted view that everything in the world is subject to strict causality, and has to be explained by causal laws, is no longer adequate once the world is recognized as being indeterminate and as evolving. This view holds, perhaps, for explanation of the past because propensities have become realized to make the past determinate. But, for the reasons just given, the future with all its potentialities as yet unrealized must be uncertain, and it is the future which is our more important concern in testing or applying theories – and in other ways, too. Even, moreover, if causal laws could completely explain the past, they may not hold indefinitely to give exact explanations or predictions of future events. For all we know, astronomical laws, which seem so certain, may hold for only a period when the universe is expanding, or in a region of it which has comparatively weak gravitational fields.

Other difficulties about determinism have been revealed in recent years by those who have developed the theories of catastrophe and chaos. Catastrophe theory has shown that there can be both strict causal law and sudden, discontinuous and unpredictable changes from one stable state or path to another, and that there are only seven distinct types of such discontinuous change. These cannot be analysed quantitatively but topology can be used to describe them in a qualitative way.

Chaos theory has shown that many natural phenomena are subject, in their dynamic behaviour, not to the linear differential equations which characterize classical physics, but to non-linear differential equations which can be extraordinarily sensitive to even slight changes in initial conditions or measurements. Such changes often lead to long sequences of apparently random and quite unpredictable outcomes. This holds, too, for some non-linear equations which are not differential. It has been found, for example, that Robert May's non-linear logistic equation for population growth,

$$x(t) = kx(t-1)[1-x(t-1)]$$

generates chaotic behaviour after a certain value of k has been reached.

Strict determinism, in physics itself, is thus consistent with unpredictable behaviour, behaviour that cannot be explained even by a probabilistic theory. That, of course, is subversive of generally held ideas that simple systems behave in simple ways, and that complex behaviour implies complex causes so that a system which appears to be unstable or unpredictable must be subject either to a multitude of independent components or else to random external influences. For it now appears that simple systems can give rise to complex behaviour, that complex systems can give rise to simple behaviour, and that laws of complexity hold irrespective of the details of a system. The reductionist programme in science seems now to be impossible of full realization[8].

Popper's defence of an 'open universe' which is not subject to strict determinism is, as he claims, supported by these findings. All this', he says in his latest book, 'is now supported by the new results of the mathematics of dynamic (or deterministic) chaos. This new theory has shown that, even on the assumptions of a classical (or "deterministic") mechanics, we may obtain, from some special but quite simple initial conditions, motions that are "chaotic", in the sense that they quickly become completely *unpredictable*'[9].

How does this new theory of chaos relate to his associated view about the universality of evolving 'propensities'—weighted possibilities that tend to realize themselves and so keep statistical measures stable? He does not say. But it would seem that chaos, being unpredictable, is incompatible with regularities of either a deterministic or a statistical kind—that there are aspects of Nature which cannot be predicted by either causal or probabilistic laws. And that, too, tells against Laplacean determinism because it points to what Popper has called an 'open universe'.

[8] See James Gleick, *Chaos*, pp. 301–304.
[9] *A World of Propensities*, pp. 24–25.