A Brief History of Science
Part 9: The Development of the Ideas of Causality and Determinism

Soumitro Banerjee*

IN THIS INSTALLMENT of the essay, instead of proceeding chronologically following the discoveries in specific periods in history, we shall deal with two concepts that are central to the whole of science. We shall see how these concepts evolved, and to trace the development all the way to the modern age, to arrive at the modern understanding of these concepts.

Causality

Causality is one of the central doctrines in science. Much of science bases itself on the premise that nothing happens without a cause. Scientists look for the reason behind every event. When an apple falls from a tree, they ask why did it come down? When they see the moon moving around the Earth, they ask why does it do so? When they see someone ill, they look for the reason behind the disease. All such investigations start from a question that the scientist forms in his mind, and the question mostly concerns the cause of various things we see around us.

Even though causality is such a crucial issue in science, it has been subject to intense controversy among scientists and philosophers on the question of what constitutes a cause for an event. Both the definition of 'cause', and the way of knowing whether A and B are causally linked have changed significantly over time. In order to develop a clear idea about the modern concept of causality, we have to work step by step through the course of the history of evolution of the idea of causality.

Aristotle's causality

The idea that there is a cause for every event was based on man's day-to-day experience, and naturally the initial formation of the idea took place in the early human society. In fact, all human actions are based on some understanding of causal relationship. Tigers *cause* death, and so keep away from tigers. The little seed *causes* the tree of the future, and so you plant the seed where you want the tree to be. Such mundane day-to-day actions of man also depended on some rudimentary concept of causality.

As far as we know, the idea first took a well articulated and concrete form in ancient Greece. We find a rather refined expression of the idea of causality in the writings of the prominent Greek philosopher Aristotle. He defined four types of causes behind every event: material cause, formal cause, efficient cause, and final cause. Consider a bronze sculpture, and ask what is the cause behind it? Aristotle says that the cause can be searched in

*Dr. Banerjee is a Professor at the Indian Institute of Science Education & Research, and General Secretary of *Breakthrough Science Society* .

four different ways. First, it is made of bronze. Hence the material, bronze, is a cause in the sense that the sculpture would be impossible if the bronze were not there. This is the material cause. Second, the sculpture has a form, and the sculptor had that *form* in mind when he worked on the bronze. This is the formal cause. Third, the sculptor is the external agency that acted in order to produce the sculpture. Hence the sculptor is also a cause—the efficient cause. The final cause is that for the sake of which a thing exists, or is done—including both purposeful and instrumental actions. The final cause, or teleos, is the purpose, or end, that something is supposed to serve.

The last one, the final cause, had an obvious religious leaning. So, during the advent of the middle age, the Church establishment latched itself to it, and saw divine hand as the "final cause" behind everything that happens. It became the default Church philosophy and was taken as the theoretical grounding behind the scholasticism practised throughout the middle age, only to be overthrown at the advent of Renaissance.

During the renaissance, this concept of causality came under scrutiny as scientists of that period no longer accepted the authority of Aristotle and refused to take his ideas as infallible truth. We notice a change in their idea of causality by the way they pursued their science, that is, the way they looked for the cause behind different natural phenomena. But in this period we do not see any focused treatment of the subject in the writings of the scientists. Only in Galileo's writings we see a rejection of the idea of final cause.

David Hume (1711-1776)

Hume's causality

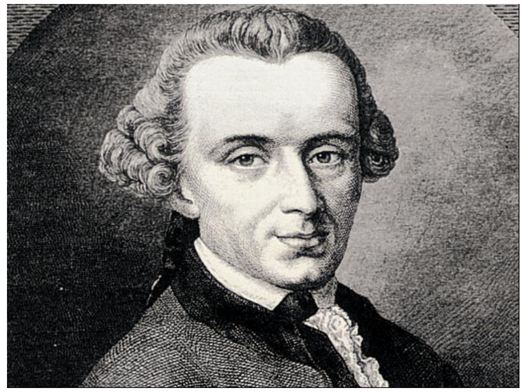
In the 18th century, the Scottish philosopher David Hume (1711-1776) offered a full discourse on the problem of causality in his famous book *A Treatise of Human Nature*. Hume freed the idea of causality of religious orientation, and made it stand on an empirical ground. He found worthless the medieval scholars' appeals to the power of God to cause things to happen, since, as he said, such claims give us "no insight into the nature of this power or connection" (1978 edition, p. 249). Instead, he proposed an idea of causality that could be tested. According to Hume, two events A and B can be said to be causally connected if they satisfy three criteria:

- *Precedence*: A must precede B in time;
- *Contiguity*: A and B are contiguous (that is, not widely separated) in space and time;
- *Constant conjunction*: A and B always occur together.

By secularizing the notion of causality and by making it testable, Hume made an enormous contribution to the advancement of human thought. Much of the development of post-Newtonian science follows the path shown by Hume.

Yet, his definition of causality had important flaws. Indeed, one could erroneously conclude "day causes night," because the occurrence of day and night follow all the criteria set by Hume. One problem of Hume's criterion of precedence was pointed out by the eminent German philosopher Immanuel Kant: If a lead ball rests on a cushion and makes a dent, it is clear that the dent is caused by the pressure of the ball. Yet, the resting of the ball and appearance of the dent occurs simultaneously, not one after the other. Had Hume said "an effect cannot precede the cause," this logical problem would not occur. The criterion of contiguity follows from common sense: If a person is found murdered, the investigator should look for the cause in the immediate vicinity, not one hundred miles away. But the tides in the Sunderbans are caused by a distant object—the moon—and hence the cause is not contiguous with the effect in space. The criterion of constant conjunction also has similar problems. It is known that quinine cures malaria. Yet, if you administer quinine to a hundred malaria patients, 95 may recover and 5 may not. If we were to follow Hume, we could not conclude that quinine causes cure of malaria.

Hume had also argued that the notion of causality is a mental construct, not a property of nature. According to him, humans observe certain sequence of events repeatedly, and notice that certain events occur in contiguity, succession, and constant conjunction. This experience leads the mind to form certain habits: to make a "customary transition" from the cause to the effect. So instead of ascribing the idea of necessity[1] to a feature of the natural world, Hume took it to arise from within the



Immanuel Kant (1724-1804)

human mind, when the latter is conditioned by the observation of a regularity in nature to form an expectation of the effect, then the cause is present.

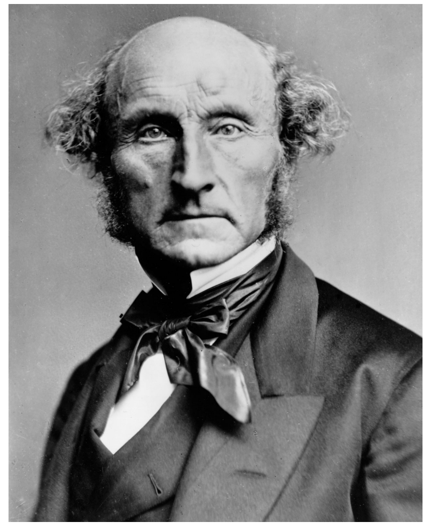
Kant's causality

Immanuel Kant (1724-1804) contradicted this position and asserted that we observe certain regularities in nature and construct causal connections, because such connections actually exist in nature. In his famous book *Critique of Pure Reason* (1787), he took the principle of causality to be required for the mind to make sense of the fact that certain sequence of events always obey a specific order in time. Whereas we can have the sequence of impressions that correspond to the sides of a house in any order we please, the sequence of impressions that correspond to water drops moving downwards in the Niagara Falls cannot be reversed: it exhibits a certain temporal order (or direction in time). This temporal order by which certain impressions appear can be taken to constitute an objective happening only if the later event is taken to be necessarily determined by the earlier one (i.e., to follow by rule from its cause).

It is ironic that in spite of taking this scientific position, Kant divided the world into

[1] In philosophy, the word "necessity" implies something that will necessarily happen, not in the sense of the word "need".

two types of entities: the knowables (things for us, or *phenomena*) and the unknowables (things in themselves, or *noumena*). He ascribed the principle of causality only to the phenomena. It took the scientific world quite some time to come to the realization that everything in the material world are knowable. We may not know everything at any given point of time. But science progresses on the basis of the confidence that everything is knowable, and the way to know what we don't know today is to look for the causes of every phenomena.



John Stuart Mill (1806-1873)

Mill's causality

Unlike earlier philosophers, who concentrated on conceptual issues, John Stuart Mill (1806-1873) concentrated on the problems of actually determining causal connections. Mill argued that causality could not be demonstrated without experimentation. His four general methods for establishing causation are:

1. *The method of concomitant variation*: Whenever A varies, if B varies in some particular manner (that is, if A goes up B always goes up or always goes down), then A is either a cause or an effect of B, or is connected with it through some fact of causation;

2. *The method of difference*: If an instance in which the phenomenon B occurs and an instance in which it does not occur, have every circumstance in common except one (say, A), then A is the cause, or an indispensable part of the cause of B;

3. *The method of residues*: Suppose a phenomenon A has many aspects (say, P, Q, R, and S) and through previous research it is known what can cause P, Q, and S. Therefore the residue in the phenomenon is R. Now, in the condition prevailing immediately before the occurrence of A, if there is some aspect which is known to be not a causative agent of P, Q, and S, then it may be the cause of R. Thus, the method is to subduct from any phenomena such part as is known by previous induction to be the effect of certain antecedents, and the residue of the phenomena is the effect of the remaining antecedents;

4. *The method of agreement*: If two or more instances of a phenomenon under investigation have only one circumstance in common, the circumstance in which alone all the instances agree, is the cause (or effect) of the given phenomenon.

To illustrate, suppose one morning four patients report indigestion to a doctor. Upon investigation, the doctor finds that the four people spent the day in different circumstances, but all four of them went to a marriage party in the evening. The doctor would conclude that the indigestion is caused by something eaten at the marriage party. This is the method of agreement.

The doctor goes out and finds more people who went to the marriage party, but many of them did not fall ill. Upon questioning, he finds that the four patients ate dal, potato-chips, fish-fry, prawn curry, chicken curry, curd, and sweets, while the party-goers who did not fall ill ate most of the above but did not eat prawn curry. He would then conclude that the culprit is the prawn curry. This is the method of difference.

The doctor then investigates further by questioning the four patients. He finds that the patient A only tasted the prawn but did not eat much. He is feeling uneasy, but is not really ill. Patient B ate one serving of prawn curry and is ill. Patients C and D really liked the prawn curry and had extra helpings, and are severely ill. This would again point to the fact that the prawn curry caused the food-poisoning. This is the method of concomitant variation.

The doctor has years of experience, and knows that there are different manifestations of indigestion. He also knows which food items can cause which external symptoms. Only, he does not know the effect of consumption of stale prawn. Today the patients are complaining the usual symptoms of diarrhoea, and in addition they are complaining nausea. The doctor then concludes that the "residual" effect, nausea, is caused by the prawn which was not cleaned properly prior to cooking. This is an application of the method of residues.

These are mundane day-to-day examples. But a little reflection will reveal that all modern experimental designs to detect causality are based on one or more of these methods.

The modern concept of causality

After these seminal contributions, many other scientists and philosophers of science tried to enrich the idea in various ways. But the groundwork laid by these philosophers has continued to this day, with rectification of the shortcomings of their ideas.

First, out of Aristotle's four causes, only the material cause and the efficient cause are recognized by modern science. The formal cause has been included in the concept of efficient cause (in the sense that the form of the sculpture lies in the mind of the sculptor).

Second, out of Hume's propositions, the criterion of precedence is accepted with a small correction: Without going into debates about microsecond and picosecond separation between the cause and the effect, we simply say that the effect cannot precede the cause in time. The idea of contiguity could not stand ground in view of the exceptions cited earlier. The idea of constant conjunction had to be abandoned when it was recognized that a causative factor (say, a virus) may not always produce the effect (a disease) because of the influence of other factors. Hence the notion of constant conjunction has been replaced by statistical testing of causal connections.

Third, science has unequivocally rejected Kant's idea of "thing in itself" to be by nature unknowable. It has accepted his idea that phenomena in nature have objective causal connections, and that causality is not a mere mental construct. Science works by looking for these objective causal connections working behind the occurrence of every phenomenon in nature.

Fourth, modern science does not accept the idea of plurality of causes. Plurality of causes is a common sense opinion which means that a given effect or phenomenon may have been the result of multiple or alternative causes. This is not a scientific viewpoint. Modern science says that for every effect there is a single cause. If A and B together cause C, then A and B are not called causes individually; they are called “factors” affecting the phenomenon. The cause in this case encompasses both A and B. The immediate antecedent of C, the collection of all the conditions occurring immediately before the occurrence of C will be called the cause of C.

It is surprising to note that this idea was also first introduced by Galileo. As we have seen earlier, he was the main figure in the scientific renaissance of Europe, and was responsible for the introduction of the objective method in scientific pursuits, and for placing on a firm ground the heliocentric picture of the solar system. Naturally it is expected that he would have something to say about the problem of causality. However, we do not find a treatise of the subject in his writings. But in the book “Dialogue Concerning the Two Chief World Systems” we find glimpses of his thoughts and can piece together his position on the problem of causality.

In this book he states that “from one uniform cause only one single uniform effect can follow” (passage 515) and that “there is only one true and primary cause for one effect” (passage 488). He did not elaborate what he means by “uniform cause” and “uniform effect”, but he seems to oppose the idea of plurality of causes behind any effect. Further, he says “Thus I say if it is true that one effect can have only one basic cause, and if between the cause and the effect there is a fixed and constant connection, then whenever a fixed and constant alteration is seen in the effect, there must be a fixed and constant variation in the cause” (passage 517).

Thus, Galileo viewed cause as the set of necessary and sufficient conditions for an effect. If A and B are causes of C, then C will occur whenever both A and B occur; on the other hand, if only A or only B occurs, then C will not occur. C occurs if and only if both A and B occur, and so A and B put together constitute the cause of C.

It is a pity that this position of Galileo went unnoticed for a long time, and scientists went on arguing on what constitutes cause of an event, while they were actually trying to identify the “factors” included in the cause. For example, we now realize that the “operational causality tests” proposed by Mill are actually the ways to locate the “factors” included in the cause of a phenomenon.

Determinism

The idea of determinism was a natural outgrowth of mechanical materialism that developed following Newton’s work. In the Newtonian formulation, one can predict the motion of a body (say, a planet) by writing down the differential equation governing its motion, measuring the state (the position and the momentum) at an initial time, and solving the differential equations starting from that initial condition. Thus, the dynamical status of a body at any time can be predicted using the information about the dynamical status at an earlier time. This implied, in turn, that the state of a system is *determined* by the state at an earlier epoch.

Notice that this is a stronger statement than saying that the state of a system is *caused* by the state at an earlier epoch. It additionally implies that, given the existence of the factors causing the change of a system, the resulting state is uniquely determined by antecedent state. That is, given a specified way things are at a time t, the way things go thereafter is fixed as a matter of natural law.

Perhaps the most elegant definition of strict mechanical determinism was given by the famous French physicist Pierre-Simon Laplace in his book “A Philosophical Essay on Probabilities” (1814). Laplace said,

“We may regard the present state of

> the universe as the effect of its past and the cause of its future. An intellect which at a certain moment would know all forces that set nature in motion, and all positions of all items of which nature is composed, if this intellect were also vast enough to submit these data to analysis, it would embrace in a single formula the movements of the greatest bodies of the universe and those of the tiniest atom; for such an intellect nothing would be uncertain and the future just like the past would be present before its eyes."

This has come to be known as Laplace's "Demon," which, in possession of the information about the initial condition of all bodies in the universe, would be able to predict all events at all times in the future. How much information would be required for this, or how much computation power must the demon have—are all besides the point. The main point is that the future state *in principle* can be computed using the information of the initial state, which implies that the future state is *uniquely determined* by the initial state. In the language of Bertrand Russell, "The law of universal causation $\cdots$ may be enunciated as follows: given the state of the whole universe, every previous and subsequent event can theoretically be determined." This is the main assertion of mechanical determinism. In some scientific literature it is designated as "hard" determinism.

Probability

The idea of probability stands in sharp contrast to the above idea of determinism. The theory of probability developed out of gambling in the 17th century when mathematicians like Fermat, Pascal, Huygens and Bernoulli considered mathematical ways of predicting the outcome of games of chance.

Pierre-Simon Laplace (1749-1827)

Where chance occurrences are involved, it was not possible to pinpoint the precise outcome, and so the mathematicians tried to work out the odds of getting a particular result. The theory of probability developed out of this effort.

For example, in a game of Ludo, the probability of getting a 'six' in a throw of die is $1/6$, because there are six sides of the die and they have equal probabilities of facing up when the die is cast. What is the probability of getting three sixes in three throws of the die? This is $1/6 \times 1/6 \times 1/6 = 0.00463$, by the law of multiplication of probabilities. Noticeable is the fact that you get the probability as a number, not as a nebulous concept like "what will most probably happen". And when you can quantify the probability as a number, you can do many things with it.

For example, when a pollen is released in water and is observed under a microscope, it is found to move in a zigzag fashion—a phenomenon known as the Brownian motion. Einstein explained it in terms of the random impacts of the pollen with water molecules, which are all moving at high speeds due to thermal motion. Since we do not know from which direction and with what velocity the next water molecule will collide with the pollen particle, we cannot say how it will move at the next instant. It depends on chance factors. But, using the rules of probability, Einstein managed to calculate the distance by which it is likely to move in a given amount of time. This was tested by experiment, and was found to be statistically true.

Thus, the theory of probability was making inroads into mainstream physics, especially in the field of statistical mechanics. But it was soon realized that the idea of determinism (as it was understood then) was at odds with the notion of probability. The motion of a tossed coin is governed by Newton's laws; and so if we know the exact condition of a coin toss, we should be able to calculate whether it will be head or tail when it falls to the ground. In that case we would not need to think in terms of probabilities. Similarly, if we know the exact position and momentum of all the water molecules in the drop of water, the conditions of each impact with the pollen can be calculated and the motion of the pollen can be exactly predicted. Thus, if everything is deterministic, we would not need the notion of probability at all.

Still, in practice why do we need the notion of probability? It is because of our lack of knowledge about the exact condition prevailing before an incident happens. The need for probabilistic understanding, therefore, stems from *our* lack of information. This is one interpretation of probability.

Thus, we see that the idea of mechanical determinism was in contradiction with the idea of probability. That is why, when the theory of probability was finding more and more acceptance in the description of physical phenomena, some people declared that determinism is dead.

Predeterminism

But the view of strict determinism that evolved from mechanical materialism had even more serious problems. If the state of everything in the universe is uniquely determined by the state prevailing in the past, it implied that the present is predetermined by the past. That past, in turn, is predetermined by the even distant past. Thus, everything that is happening in the world now is fatalistically predetermined by the condition of the particles constituting the universe at a far distant past. Thus, mechanical determinism also implies predeterminism.

This is obviously an unacceptable position. If true, it would imply that the fact that you are now reading this article, the thoughts going on in your mind, the discussions that happened over a cup of tea—all these are the consequence of the positions and momenta of the particles of the universe a thousand years in the past. Obviously absurd.

What exactly went wrong?

Enter the quantum

Towards the early part of the 20th century, there was an explosion in physics. We came to know that the atom is not the smallest constituent of matter. We learned about the sub-atomic particles like the proton, neutron and electron. We learned that light has a dual character—in some situations it behaves as particle and in some situations it behaves as wave, producing interference and diffraction patterns. Then de Broglie showed that not only light has this dual character, *all* particles also behave like waves (for example, electrons also exhibit a diffraction pattern). He thus generalized that matter as such has dual character. Schrödinger found out the equation that these waves obey. Then Heisenberg told us that the position and the momentum of a particle cannot both be measured with infinite accuracy; if you measure one accurately there will be some uncertainty in the measurement of the other.

It is not possible to give a detailed account of these momentous developments within the scope of this article. So we will focus on the specific issue that concerns us here, namely, the status of determinism.

The basic formalism of quantum mechanics was developed in the 1920s and 1930s, but people have since been debating about its concept and implications. However, over the years many experiments have been conducted, and the predictions of quantum mechanics have always come out to be true. If we take a theory's ability to correctly predict the behaviour of things in different circumstances as its test for truth, we can say today that quantum mechanics has passed that test.

This has necessitated certain change in our mental picture of what a particle is. We often intuitively equate the character of a micro-particle with that of a piece of stone—only the former is small and the latter is big. The character of a piece of stone is that it is "localized", meaning that at any point of time it is at a definite position. It is "there" at a point, and it is "not there" at the other points. It now appears that we have to abandon this picture when we deal with micro-particles. They are, in some sense, "there" not just at a point, but over a range in space, much like a fuzz (see Figure 1). The extent of its being "there" varies from point to point, that is, the "density" is different at different points. And beyond a certain (small) range, this density is practically zero.

Figure 1: Left: the classical "point" picture of a particle, right: the quantum "fuzzy" picture.

In classical mechanics, the "state" of a particle is given by its position and momentum, and if these (and the forces acting on the particle) are known, the future state become determined, and can be predicted using the laws of classical mechanics. In contrast, for micro-particles the state is not given by the position and momentum. Instead, it is given by a single complex number which has different values at different points in space and at different instants of time. This is called the wave-function, denoted by the Greek letter Ψ (psi). This wave-function determines the "density" at different points in space at any given time. When the particle interacts with something—another particle or a measuring instrument—the interaction always occurs locally, that is, at a specific point. The density actually specifies the probability of finding the particle at a given point in space at a given time, when such an interaction happens.

This makes the probabilistic description inevitable in describing micro-particles. Earlier people believed that we have to take recourse to probability because of our lack of information, that is, we have to talk in probabilistic terms because we do not know where exactly the electron is located. In this view the electron has a definite position at every point of time, that is, there is a well defined trajectory; and only because we do not know it exactly we have to talk in terms of its probability of being at a specific location in space at a certain time. But now we realize that this picture is not correct.

The behaviour of the electron is *inherently* probabilistic; it is fundamental—something that is not born out of our inability to find its location. This means that the probabilistic description is objective, not subjective.

The same is true for its velocity also (scientists talk more in terms of the product of its velocity and its mass, that is, its momentum). The velocity of a particle also does not have a definite value. It is also distributed as a fuzz. The uncertainty principle says that the fuzziness of the position and the fuzziness of the momentum cannot both be arbitrarily small. If one has less fuzziness (that is, one is more localized) the other has more fuzziness. This has nothing to do with our inability to measure the position and momentum of the micro-particle. This property is not subjective. It is objective. This is how the particles actually are.

It may be noted that many authors write about the uncertainty principle in terms of the Heisenberg-Bohr interpretation. This interpretation talks in terms of *our* observation. How do we observe something? By shining light on it. So if we want to see an electron we would shine a light on it. But since the particle is so tiny, the light would disturb its position and momentum. If we want to observe the position more accurately, we have to shine a light with lower wavelength. Since lower wavelength means higher energy, that would disturb the velocity of the particle more strongly. According to Heisenberg and Bohr, this brought in the uncertainty in the position and momentum. Notice that the whole interpretation depends on *our* ability to observe. Hence there is a subjective element in it. In contrast, the modern interpretation of the uncertainty principle is objective, and does not depend on our ability to observe.

If we adopt this objective view of probability, its contradiction with determinism disappears, for now determinism has to be understood in terms of the probabilistic description. Determinism asserts that the future state is determined by the past state. In classical mechanics, the “state” comprises the values of the position and the momentum of the particle, which were expected to be determined by the state in the past. But in quantum mechanics, the state is given by the wave-function. So determinism would assert that the future wave-function of the particle should be determined by the past wave-function. This is exactly what happens, as the wave-function obeys the Schrödinger equation.

But the probabilistic description also says that the exact location of the particle is not given by the past. The past only determines the probability distribution. The particle could actually be at any place where the probability is non-zero.

If a quantum system is in state A, from there it could go to state B, C, or D. Which state it will actually go cannot be predicted with certainty. But the state A deterministically dictates the *probabilities* of going into state B, C, and D. The system transits to one of these states strictly following the law of probability. Because of the fundamentally probabilistic nature of the micro-particles, the problem of pre-determinism disappears.

Thus, if you sharply ask the question “Why do you need probabilistic description of physical phenomena?”, there can be two types of answers. The first one will say that the world is strictly deterministic (in the sense that everything is determined uniquely by the preceding events), but since we do not know the values of all the variables, the best we can do is to obtain the probabilities of getting different end-results. If we knew all the variables and parameters needed for the prediction, and if we had the necessary computing power, we could have calculated the outcome with certainty. This is the stand of statistical mechanics, a very successful branch of physics.

The other answer to the question will be that nature is at a fundamental level probabilistic. For a given cause there can be multiple possible outcomes, and any of these could actually materialize. Our inability to predict which one will actually materialize is not due to our lack of information, but because it is unpredictable at a fundamental level. But the probability of each outcome is deterministically given by the cause. That is why scientists can calculate the probability of each outcome and check against experiment. This is the "objective" interpretation.

Both the interpretations are perfectly scientific, and necessary in specific circumstances. In the case of a coin toss, we need the probabilistic prediction because of our lack of information about the condition of the throw. Here the first interpretation prevails. In the case of a micro-particle, it is fundamentally impossible to predict the position. That is not due to our lack of knowledge of the initial position or momentum. But the probabilities of finding the particle at different locations is given by the wavefunction, which, in turn, is deterministically given by the earlier wavefunction and the forces working on the particle.

Now, if we add the "lack-of-information" interpretation of probability with strict mechanical determinism, we still have the problem of pre-determinism. Predeterminism disappears only if we add the objective interpretation of probability. It is in this sense that quantum mechanics has given us a more enriched version of determinism free from predeterminism.

Over the past 30 years another development has happened in classical mechanics which has shown why determinism should not imply pre-determinism. The development of chaos theory has shown that there are conditions under which a very minute difference in the initial condition of a system may lead to widely different future states. This does not require the participating bodies to be micro-particles: such situations occur in the motion of gross bodies, even in planet-size objects. Moreover, it has been found that such situations are not rare, and in fact, are quite prevalent in nature. And such tiny perturbations in the state of a system are always there in a natural system. Therefore, even though the system may evolve deterministically following the governing equations, the future state is not uniquely given. Here also the problem of pre-determinism disappears.

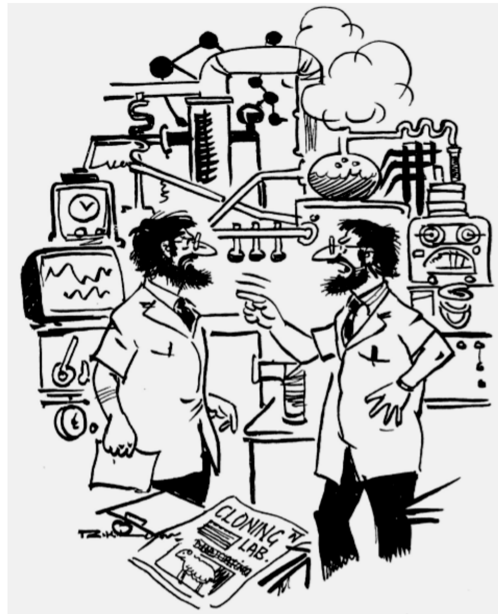
Conclusions

Both the ideas of causality and determinism are fundamental to modern science. But the content of these notions, and their technical meanings, have evolved over the years to take a modern form. And in the meantime we have seen scientists as well as philosophers pronouncing the demise of both in the light of certain discoveries in science. But when the initial mist is cleared, the recent developments have enriched our understanding of both of these concepts.

Planck felt that causality is a "heuristic" principle in the sense that it is futile to try to "prove" causality. Unless we believe there is a cause and effect relationship inherent in all events in the world, one can do no science—for the whole of science evolved out of our attempt to find the cause of things happening around us. Einstein was also of the same opinion.

The early idea of mechanical and strict determinism was flawed because it implied pre-determinism. But the idea was immensely influential and many eminent scientists erred when they placed determinism as contradictory to the idea of probability, and tried to defend determinism by repudiating probabilistic description of the microworld. Now we know that the probabilistic description is fundamental, and determinism and causality are not at odds with the notion of probability. In fact, when we understand causality and determinism in this light, these notions emerge as much more powerful in understanding the ways of nature. □

The earlier installments can be found in the website http://www.breakthrough-india.org/archive.html



That's what you say? I say I am the original and you are the duplicate · · · !