CONVERSATION

Roger Penrose with Ranjit Nair

Roger Penrose is a distinguished physicist who has made path-breaking contributions in many areas of theoretical physics, including cosmology. In recent years, he has written two influential books on mind and consciousness in which he has attempted to throw light on issues in philosophy of mind from the point of view of recent work in physics and mathematics. Ranjit Nair explores these convergences.*

I. The Universe Outside

Singularities

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Nair : Could you tell us a little bit about the subject of black holes and the current state of black hole research?

Penrose : Well, there's a lot of very good evidence that black holes really are there. They occur when you have a large concentration of mass that falls together to such a concentrated configuration that light itself can't escape. There's a certain speed at which things can escape from a body and when you have a black hole, that speed gets up to the speed of light, so nothing can get out. When that happens, the material falls inwards to incredible densities and, according to our understandidng of physics, one reaches what we call a 'singularity' where the densities actually approach infinity and our present-day theories really give up. It's basically the end of the universe as far as the material which is falling in is concerned.

Nair: So you now believe that these entities, black holes, actually exist somewhere in the universe, that we haven't been sufficiently resourceful to pin them down?

Penrose : The evidence is very good now. I was just attending a lecture at a conference in Pune in which I think the evidence was extremely impressive that, in particular, in the centre of our galaxy, the Milky Way galaxy, there is a balck hole of a few million times the mass of the sun which is dragging material in, and the fact that it's a black hole seems strongly indicated by observations.

Nair : Would this then corroborate the picture of the universe that has emerged with the general theory of relativity?

Penrose : I think there is now a lot of very persuasive evidence; not only for black holes. There was also an origin of the universe in the sense that there was a region, if you extrapolate backwards in time, where our classical picture must give up because the densities were absolutely enormous: everything was on top of itself. Exactly what started off the bang, of course, is a problem beyond the scope of our present day physics but, nevertheless, the evidence that there was such a state seems extremly strong.

Models of Universe

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Nair : Could you comment on the standard model of cosmology, which is widely accepted these days, that posits the origin of the universe in the initial singularity which you just described?

Penrose : When Einstein came up with his field equations he very soon tried to consider how you might apply these equations to the universe as a whole. In particular, the Russian mathematical physicist Friedmann produced these particular models of the universe which are still the same models that are considered today. There are basically three models: the 'closed model' where the spatial universe is finite and closing in on itself, the flat model as far as space is like Euclidean geometry but the universe still expands—matter goes outwards in this, and what's called the 'open model' which has a different kind of geometry in the sense that it expands more rapidly. The evidence is pointing towards the third of these models. It's probably open—the universe expands most rapidly or continues to expand most rapidly. These three models are very well confirmed by observations: in particular, observation of the background radiation—the 3^0 K background radiation which is, roughly speaking, the flash of the big bang. Because it happened so long ago, and the universe was expanding, the tremendously hot initial universe has been cooled down to 3 degrees above absolute zero. But the nature of this radiation, which is an observed radiation, is that it is very very uniform indicating that the universe was very close to these models that Friedmann introduced many years ago.

Nair : So the existence of this relic radiation is an indication that we have got some elements of the theory right, but that still leaves open the question as to which one of these cosmological models is the right one.

Penrose : That's correct.

Nair : Your own preference, I take it, is for the open one.

Penrose : Yes, I have various sorts of ideological reasons for preferring the open one, but the evidence, as we've just been hearing at a meeting in Pune recently, is now rather in favour of this open model. The there are various different indications of this: for example, the lensing effects of distant galaxies—indications of the sort of flow of material which suggests where the mass primarily is in the universe. All these things fit together to provide a sort of picture which is beginning to come out of all this, seeming to confirm the open model. It's not conclusive yet and there's still scope for much argument. I'm sure there will be for many years.

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Nair : An open universe would be an universe that is infinitely extended.

Penrose : That's right.

Nair : But to a geometer presumably a closed model looks more aesthetic!

Penrose : Not really. You see, the open model is actually, from a geometrical point of view, the most interesting geometry. It's not a Euclidean geometry; its non-Euclidean geometry that was first studied by Gauss, Lobachevski, Bolyai, among others. Various people discovered that you could take the axioms of Euclid but exclude what's known as the parallel postulate. These geometries worked and were consistent. It now seems that these geometries are actually very beautiful; in many respects more beautiful than Euclidean geometry. As far as the aesthetic qualities are concerned, I would say the open universe is the most mathematically appealing; of course, whether that's a big consideration or not one might argue about.

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Nair : It's claimed by Stephen Hawking, on behalf of the closed universe, that one can in fact eliminate the initial singularity by a suitable mathematical trick.

Penrose : Yes, well, he has a certain view on how to deal with the initial singularity, but that's a particular standpoint which is not shared by everybody, and my own personal view is to go along a different line. I don't feel necessarily attracted by the closed universe and I have other considerations which lead me to prefer the open one—aesthetic considerations, if you like. Despite the close links between aesthetic values and truth in science, one has to be extremely careful about these things and, really, if the observations tell us one thing, we have to go in that direction.

'New Physics'

Nair: Could you talk a bit more about the nature of the initial singularity? One view of it is that it is a point at which the laws of physics—at least the known laws of physics—break down, that one needs new physics. Would that be your view?

Penrose: I think it would be anybody's view really that you do need new physics in order to try to cope with what was going on at the big bang, and the normal view is that this new physics must be the appropriate union

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between quantum mechanics and Einstein's general relativity. How you try to make that union of course is a very controversial question. You mentioned Stephen Hawking's approach; that's one approach. There are many other approaches. My particular view on this, which differs from most people's, is that it's not just a question of what people call 'quantizing' (quantizing a theory means bringing it under the umbrella of quantum mechanics). So the view is really that quantum mechanics is right and any other theory has to be brought within its scope. My view is different from that: I say that Einstein's general relativity on the one hand and quantum mechanics on the other are both excellent approximations to some other theory that we don't have. It's not just a question of quantizing general relativity; there will be give on both sides. You have to try and find some common features, some union, which incorporates both these theories as limiting aspects to this new theory.

Nair : In this projected marriage of quantum theory and relativity, it is not just relativity which has to give but also quantum theory.

Penrose : Exactly. It is more of an equal partners' marriage; not that one is imposesd on the other.

Nair : And in fact you believe that this particular unification will have relevance for quantum theory even in ordinary situations.

Penrose : That's right. This is another place where my own ideas differ somewhat from most people's. I think that this union between Einstein's theory and quantum theory will have a big impact on the way we use quantum

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mechanics. There has always been a big problem in quantum mechanics—its referred to as the measurement problem. In particular, there's the famous Schrodinger's cat which illustrates this problem. According to the rules of quantum mechanics, if you doggedly follow the equation of Schrodinger, you would come to the conclusion that, in certain situations, you could have a cat that is simultaneoulsy alive and dead. Schrodinger himself was saying, 'well, look, this is nonsense, cats don't do that'. Why is it they don't do that? Schrodinger would have said, 'don't believe my equation at the level of a cat'. But most physicists tend to say, 'well, we have to follow the Schrodinger equation whatever Schrodinger himself might have said'. My own opinion is to believe what Schrodidnger apparently believed, that the cat is either dead or alive, that it requires some deviation at some level from Schrodinger's equation, or else some interpretation which I find difficult to cope with. It seems to me there is a reality out there which is either a dead cat or a live cat, and that comes about through some deviation from Schrodinger's own equation at a certain level.

Nair : Do you believe that as far as microscopic systems are concerned, like atoms or electrons or particles of light, it is alright for them to be doing two different things like going through two slits

you can actually compute on the basis that this is a gravitational effect, that somehow it is part of this union between, on the one hand quantum mechanics, and, on the other hand, Einstein's general relativity

at the same time, but, as far as the objects in the everyday world are concerned, they have to be definitely at one place or the other?

Penrose : Yes, absolutely. To be a little more precise about this, I would say that you could have a macroscopic object (a big object) in a superposition, but that is an unstable thing; it will very rapidly become one or the other, and for anything the size of a cat it would be so rapid that you would never even consider it for a moment. But for a particle of intermediate scale (you could consider some tiny speck of dust or something), you could imagine whether that could persist in a superposition of being here and there. Quantum theory says it could, like the particle going through two slits; it does them both at once. In a sense it does both this and that at the same time. With a speck of dust you can start to ask the question, 'could a speck of dust be in this place and in that place at the same time'? My arguments would say that, at a certain level, you will start to see differences from the quantum procedure, and, at this level, you can actually compute on the basis that this is a *gravitational effect*, that somehow it is part of this union between, on the one hand quantum mechanics, and, on the other hand, Einstein's general relativity. This points to just the sort of level that one can start to predict a difference from how Schrodinger's equation would behave.

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Nair : So your view is that gravitation, which is one of the first forces to be understood within physical theory, in fact is not something that is relevant at just macroscopic or cosmological sales, but that it intervenes in a very fundamental way even at smaller scales.

Penrose : That's right. I think it's a thing that physicists often find hard to relate to because they think, 'oh well, gravitational forces must be very small in such situations'—which is absolutely true, but I'm not talking about that. It's the effects that the slight, very slight, curvatures of space-time have on the very structure of quantum mechanics, and, when you look at it very carefully, you find that there are effects which are of the sort that could be relevant in these situations. So it's a rather delicate thing; you think why isn't the gravitational effect so small that you can ignore it, and then you start to look at it carefully and you find that the way the numbers come together it's not small and that there could be a genuine influence on the way quantum mechanics behaves at the level of, say, something like a speck of dust. There are indeed experiments which I've suggested with some colleagues that, I hope, will be performed in the next several years which would test to see whether this is a real phenomenon or not.

II. The Universe Within

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Approaching Consciousness

Nair : Now, to change gears a bit, you have been currently engaged in discussions on the nature of the mind and its relation to physical theory. How is it that you came about pursuing this direction?

Penrose : I think I've been interested in these issues ever since I was a child. The particular view-point which I have been putting forward in recent years is one which I formulated I think, more or less, when I was a research student in Cambridge in the mid-1950s when I attended lectures on mathematical logic, on quantum theory by the great Paul Dirac and on general relativity theory by Hermann Bondi. So I think the basic ingredients which provide my present view-point were already present at that time.

Nair : In your view, mathematical thinking is something which has lessons for the very nature of consciousness.

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Penrose : Yes. Well, in these lectures on mathematical logic it was made clear—to me at least—that mathematical thinking is something which is not computational; a computer couldn't simulate the action of our thoughts in the special, rather limited area of mathematical thinking. So I formulated the view —which is basically based on the famous theorem of Godel which shows that in any system of rules you can always see how to go outside those rules—that we have to be doing something other than simply computing when we are trying to understand mathematics. And so, for a long time, I had this view and it also seemed to me that one shouldn't be trying to look outside science in order to see what could be involved in this idea, viz., that our thinking is outside computation. I suppose the other two areas, quantum physics and general relativity, were both things that I had some familiarity with since my time at Cambridge and realising the conflict and tension between these two theories made me believe that there is something beyond these theories. Something which, in the unification of these theories, could find the place where this kind of non-computational action would be a sort of boundary between the small-scale physics of the quantum world and the large-scale physics of the classical world. In that unknown boundary, we would find what we need at least to begin to understand what might be involved in our conscious thinking.

Three Worlds

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Nair: Before we actually examine some of the specific proposals that you have produced concerning the nature of consciousness, may I ask you how they relate to the traditional understanding we have of the mind-body problem following Descartes-Cartesian dualism? Indeed the mind was conceived of as radically distinct from matter in that it consisted of thoughts, ideas, sensations, etc., which could not somehow be reduced to the material motions of the brain. Would you comment on that?

Penrose : All right. Well, there's certainly something which seems to me very different between mind and what we think of as matter. Nevertheless, from what we know about, what we have definite evidence of, with regard to where mind seems to be in human beings and presumably

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other animals, it seems to be assoiciated with the action of the brain. So although there may be other things one has to consider, without understanding the physical actions of the brain we are not going to get very far in really appreciating what's involved in the mind. I think my position is different from the kind of dualism of Descartes, who seems to have these separate worlds. I mean I do think it's useful to think in terms of worlds which are in a sense separable, but neverthless, the connections between these are very profound and important. But I think of that as something which we can't study in isolation from other issues: primarily, what's involved in how the physical world operates and how it is that our own perceptions and, as I was commenting on before, mathematical resoning, seem to be something we need to go outside our present picture of the world in order to come to terms with? So here we have mathematics playing two roles: one, on how we understand mathematics, and, on the other hand, on how mathematics profoundly controls the way the physical world operates. So I think of it in terms of these worlds in a sense, the world of our mentality, the physical world and the third world being the world of absolutes—in particular, mathematical absolutes which one likes to think of as having a different kind of existence.

Nair : There is this particular idea of three worlds, and not just the two Cartesian worlds of mind and matter, which you have developed following, I believe, Karl Popper's suggestion that one should treat the world of ideas as an abstract world. For you, the world of abstract entities has almost as much reality as the world of mental states and of physical systems.

Penrose : Yes. I think where I would differ from Karl Popper—although as you said there are close connections with his view—is the way he thought of it; that somehow there was the physical world, the mental world somehow emerged out of that and then the world of ideas emerged out of our mental world. But there's a third link which he didn't seem to be so concerned with. This third link being how the world of physics, as we understand it, seems to depend so heavily on mathematics. So it's a sort of triangle rather than things emerging out of others. Being a mathematical physicist, I am impressed by the extraordinary way in which mathematics and physics relate to each other, and it would be quite impossible to think of how the physical world operates without this clear link between mathematics and physics. So I think of all these three; I regard them all as mysteries. I have no explanation for why there should be these links. But I think in order to study any one of them, we need to think of all this as a whole.

Truth, Beauty, Design

it really would not be possible to do mathematics in any creative way without having a sense of the aesthetic qualities of mathematics

Nair : In your books, you have this picture of these three worlds connected together in an almost impossible way …

Penrose : Yes!

Nair : … insofar as one maps into part of another which in turn maps into part of yet another which paradoxically maps into part of the first. This brings me to a question which concerns your interest in gemoetry, in designs, which I believe inspired Escher to produce some of his work, and that's an intereting link between the sciences on the one hand and the arts on the other. Would you comment on how you were drawn to the study of these objects?

Penrose : Well, certainly. I think I've always been intrigued by paradoxical things or seemingly paradoxical things. As you say, I draw these diagrams in a way which is deliberately paradoxical; that's really to reinforce the feeling that there really is something mysterious about all this. But I think paradox has always fascinated me; in particular, geometrical paradox and, as you say, I did at one stage involve myself with impossible structures. My father and I were both concerned with these things, and two of Escher's prints, 'Waterfall' and 'Ascending and Descending', were based on these impossible objects of ours. But geometry is something which has always interested me and

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also the whole issue in mathematics about how there is this interplay between truth and beauty, if you like. It really would not be possible to do mathematics in any creative way without having a sense of the aesthetic qualities of mathematics. So I think that it's absolutely fundamental, the aesthetic qualities are absolutely crucial to mathematical research.

Nair : Well, you just spoke a short while ago about the extraordinary way in which mathematics seems to be applicable to the physical world, and there is this statement by Eugene Wigner about the 'unreasonable effectiveness' of mathematics. Now you've made these observations about truth and beauty. Is beauty something which acts as a guide towards truth or is it integrally a part of the truth in so far as mathematical thinking is concerned?

Penrose : It certainly does act as a guide but I am inclined to think there is an intrinsic union, that there is something Platonic about the notion of beauty. Obviously, there are deeply personal aspects to beauty as well. In fact I wouldn't mind going along with the third link of, the third inhabitant of, a Platonic world, if you like, which is the issue of morality. So I think all these things are interconnected and, in scientific research, one often sees the close connection between beauty and truth. I think one can't really separate them.

Nair : So your view is of a harmony of some kind between the Kantian ideas of truth, beauty and goodness?

Penrose : Yes. I think the connection betwen truth and beauty tends to be more, the deeper one goes. There are many things which are true and not beautiful, but when you get down to the fundamentals of what's going on, then I think one tends to find this closer link between truth and beauty.

Nair : In your particular work on general relativity, which was path-breaking, the first major advance since Einstein, were you guided by considerations of beauty?

Penrose: Oh yes. The arguments that we both, Stephen Hawking and I, used were very much large-scale arguments. We didn't spend a lot of time solving equations. They were very much geometrical considerations where visual and aesthetic values played an important role. So I think that's certainly true.

Nair: So it's this feeling for the larger picture that has actually taken you out of the confines of mathematical physics into the larger arena where you address questions like the relationship between mind and matter?

Penrose: Perhpas so. I've certainly always been intrigued by this connection between truth and beauty in mathematics and issues of this nature, whether there is something deeper in these inter-relationships.

Scope of Computation

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I would spread outwards to say okay, other aspects of our conscious thinking also cannot be part of computational activity

Nair : But you know, for the layman, mathematics is a specialised art and it is not something that is accessible to everybody. There are people who are good at it, and there are people who are not good at it, and it might seem rather strange to make a case for the nature of consciousness based on the nature of mathematical thought given that it is not accessible to everyone.

Penrose : Yes, that's true and in a sense I apologise that many of my discussions are based on mathematical considerations. I think the answer to that is—in fact it's rather surprising—that mathematics is the area where one sees most clearly that one has to go outside the computational models. But I suppose it is partly the reason that mathematics is such a precise subject, that one can make clear statements. With many things it is really almost impossible to make a definitive statement: to say this or that is outside the scope of computation. Whereas in mathematics, one can make a clear statement that this (admittedly very limited area of our conscious activity, namely, understanding mathematics) is beyond the scope of purely computational activity. And from there I would spread outwards to say okay, other aspects of our conscious thinking also cannot be part of computational activity.

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Nair : Would you briefly paraphrase the central argument of your books, which derive from a theorem in logic (Godel's incompleteness theorem) that you've interpreted in a paticular way?

Penrose: Yes, well the basic argument is that mathematical understanding—I would like to use the word 'understanding' as the key word in my own considerations—is beyond the scope of any computation. Take any computer activity, no matter how clevery it can perform elaborate functions; there is no understanding present in that activity. Understanding requires awareness; it's one feature of our awareness, and that's the only thing I can get a real handle on. But from there I would say it is unrerasonable to draw a line between our understanding of mathematics, and our understanding of other things; for example, the appreciation of a musical sound or a beautiful scene or feeling of pain. All these qualities are more obviously outside computation. And so it's hard to draw a line between that and mathematical understanding, and I wouldn't draw a line either between human consciousness and animal consciousness. It seems to me that animals show enough similarity to ourselves, that they also, I would say, clearly exhibit some form of consciousness.

Nair : Your argument is not that somehow mathematical understanding is definitive of consciousness in any way ...

Penrose : Oh absolutely not.

Nair : ... but that it is something that is amenable to a particular form of argument.

Penrose : Exactly, that's right.

Nair : In fact one might think of mathematics as something that can be performed by a calculating machine while feelings, ideas, and so forth, are distinctively mental, psychological. But you are saying that even mathematics, which we might think of as something performable by means of some calculating device, isn't really possible in those terms and there is this theorem which establishes that.

Penrose: That's right, that is basically the viewpoint, yes.

The Local End

if one assumes the normal thing about energy and the equations of general relativity you would, in the middle of this, reach a region where the equations of classical physics, or of Einstein's general relativity, come to an end

Nair : Well, if I might just steer the discussion once again towards the scientific contributions that you've been associated with—the work on black holes. How did you come to apply your specific techniques, the global methods in general relativity, to this whole area? I mean there was a whole traditon since Einstein of just calculating solutions of the equations and so on, which seemed to get nowhere until you came on the scene.

Penrose: To some extent it was my background in pure mathematics. I didn't start with physics, I started with mathematics. I was worrying about the problem of the universe as a whole and the steady state model, the continual creation model of Bondi, Gold and Hoyle, the idea that perhpas the universe was always there and never had a beginning. And I was rather attracted by that idea, but I was also attracted by Einstein's general relativity. In trying to see whether they could be brought together, I developed certain arguments which were of a global topological character, rather than trying to solve differential equations. And then, a little later, these same ideas were applied to the problem of the collapse of a massive star to form a black hole. What I was able to show was that if one assumes the normal thing about energy and the equations of general relativity, that if you had a collapse which reached a certain point, a point of no return, no matter how irregular that collapse was, you would, in the middle of this, reach a region where the equations of classical physics, or of Einstein's general relativity, come to an end and you have an end of the universe in any black hole. Then you can turn the argument around, as Stephen Hawking did first in a clear way, and show that the same arguments can be applied to the big bang; so that each of these things, the beginning of the universe where we have this situation where equations of classical physics break down, and the end, the local end if you like, where those people who are unfortunate enough to fall inside a black hole, would reach their own local end of the universe.

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Ranjit Nair is a philosopher of science at NISTADS, New Delhi.

* Roger Penrose, *The Emperor's New Mind*, Oxford University Press, Oxford, 1989.

Roger Penrose, *Shadows of the Mind: a search for the missing science of consciousness*, Oxford University Press, Oxford, 1994.

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