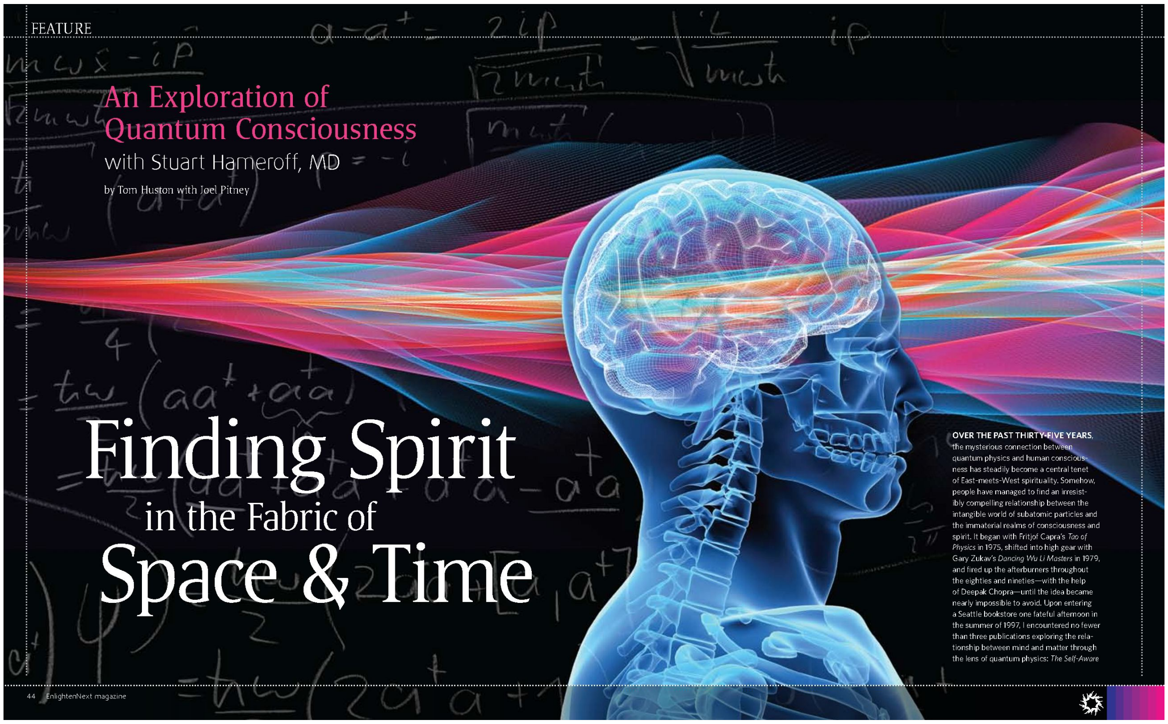
Finding Spirit in the Fabric of Space and Time



An interview with **Stuart Hameroff** by **Tom Huston** with **Joel Pitney**:

Over the past thirty-five years, the mysterious connection between quantum physics and human consciousness has steadily become a central tenet of East-meets-West spirituality.Somehow, people have managed to find an irresistibly compelling relationship between the intangible world of subatomic particles and the immaterial realms of consciousness and spirit. It began with Fritjof Capra's *Tao of Physics* in 1975, shifted into high gear with Gary Zukav's *Dancing Wu Li Masters* in 1979, and fired up the afterburners throughout the eighties and nineties—with the help of Deepak Chopra—until the idea became nearly impossible to avoid. Upon entering a Seattle bookstore one fateful afternoon in the summer of 1997, I encountered no fewer than three publications exploring the relationship between mind and matter through the lens of quantum physics: *The Self-Aware Universe* by Amit Goswami, *The Spiritual Universe* by Fred Alan Wolf, and Issue 11 of this magazine, whose cover posed the question "Can Science Enlighten Us?"

I eagerly bought the first two, but after skimming through the magazine, I decided to leave it on the rack. Already a firm believer in the physics-equals-mysticism idea, I found*EnlightenNext*'sspecial brand of playful skepticism off-putting. Why did they doubt, when the evidence was so clear? It was obvious that the deeper dimensions of consciousness and the deeper dimensions of matter converged in the mysterious realm of quantum physics. Right?

Not necessarily. I soon realized that just because the nature of consciousness is mysterious and the nature of quantum physics is also mysterious, *it doesn't mean that both mysteries are ultimately the same thing*. By the time the enormously popular film *What the Bleep Do We Know!?* hit the scene in 2004, launching the physics-and-consciousness idea into a whole new quantum orbital, I was working as an editor for *EnlightenNext* and took it upon myself to review the movie with a newfound appreciation of the many subtleties involved. As it turned out, as far as I and my fellow editors were concerned, the supposedly perfect marriage between quantum physics and consciousness was probably little more than wishful New Age thinking. And when it came to the more serious scientific suggestions that physics had something to say about consciousness, we generally found the arguments less than persuasive.

But that was before we met Stuart Hameroff.

Although he holds the title of Professor Emeritus of Anesthesiology and Psychology at the University of Arizona and spends much of his time in surgery at the University of Arizona Medical Center, Hameroff is best known for his work in the arena of consciousness studies. In 1994, he founded the Toward a Science of

Consciousness conference series, bringing together the world's leading experts on consciousness every two years in Tucson, Arizona, to explore various shades of something called the "hard problem"—how and why subjective mind appears to arise from objective matter. And for nearly twenty years, Hameroff has collaborated with Oxford mathematical physicist Sir Roger Penrose to develop (and defend) a quantum-physics-based theory of consciousness that is impressive, original, and ambitious, to say the least. The theory is a fusion of Hameroff's and Penrose's distinctly different areas of expertise: Hameroff's studies of tiny structures called "microtubules" within human brain cells and Penrose's work on the relationship between quantum physics, gravity, and the geometry of space and time. In some sense, their work could be considered a "grand unified theory" of quantum physics and consciousness—a theory somewhat more sophisticated than anything you're likely to find in the spiritual section of your local bookstore. After interviewing Hameroff, I found myself questioning my previous dismissal of what I've come to call "quantum mysticism." And I'm sure others will find his arguments equally illuminating.

That said, consider yourself warned: The interview that follows is not an easy read. In fact, it may require more than one careful reading before the different threads that Hameroff lays out begin to stitch themselves together in your mind. But the payoff is worth the effort. I'm not sure if I agree with all of Hameroff's conclusions—and he himself insists that his theory has yet to be proven—but I do know that his arguments for a relationship between quantum physics and consciousness are among the most persuasive I've ever heard.

MYSTERY OF THE MICROTUBULES

ENLIGHTENNEXT: *You're best known as one of the world's leading proponents of a quantum-physics-based theory of the mind. How did you first become interested in the mystery of consciousness?*

STUART HAMEROFF: I got interested while in college in the late 1960s. Studying mostly science and math, I took a course called Philosophy of Mind and was intrigued with how difficult was the problem of explaining how conscious experience arises from the pinkish-gray meat we call the brain. And I remained interested through medical school, being drawn toward fields having to do with consciousness—psychiatry, neurology, neurosurgery. But one day, while doing a research project in a cancer lab in the early 1970s, I was looking at cells dividing—mitosis—under a microscope, observing how the DNA-containing chromosomes were separated and pulled apart into perfectly equal mirror images of each other. The tiny strands and little machines moving the chromosomes were called microtubules and centrioles (which were themselves composed of microtubules). The dance of the chromosomes had to be perfect, because if they divided unequally, abnormal cancer cells could result.
Most of my research colleagues followed the trail of the chromosomes and went into gene-based research. But for some reason, I became fixated on how these little molecular machines knew exactly what to do and how they were choreographed. I wondered how they were organized and guided, and whether there was some intelligence, if not consciousness, at that level. Around the same time, it was discovered that these same microtubules existed in all cells—especially neurons—as major components of the cell skeleton, or structural scaffolding. Being highly asymmetrical, brain neurons are just full of microtubules. So it occurred to me that microtubules, which seemed to display some kind of intelligence or consciousness in cell division, might have something to do with consciousness in brain neurons. Maybe in addition to being the cell's structural support, microtubules were also the cell's on-board computer.

After medical school in Philadelphia I gave brief consideration to a full-time research career, but decided to take a clinical internship in Tucson, Arizona, to figure out what I wanted to do next. I was leaning toward neurology, but then met the chairman of anesthesiology at the new University of Arizona medical school hospital who was in need of residents for his fledgling program. He was a Boston-trained Texan named Burnell Brown, and he showed me around the operating rooms at the new hospital, explaining how anesthesiology was important, paid well, and could be fun. As he came to know my interests, he told me that if I really wanted to understand consciousness, I should figure out how anesthesia works, because anesthesia selectively erases consciousness while sparing other brain functions. He also showed me a paper written by a colleague of his in 1968, suggesting that if you apply the gases used in anesthesia to microtubules, they depolymerize—they fall apart. So there was a theory that anesthesia worked by causing brain microtubules to fall apart. It turns out, fortunately, that that's not true. You need about five times the amount of anesthesia for microtubule de-polymerization than you need to cause somebody to lose consciousness. But it showed that anesthetics do affect microtubules, which further suggested that microtubules might have something to do with consciousness.

EN: *What, exactly, is a microtubule?*

SH: First and foremost microtubules are the rigid structural support defining the shape of all animal cells, but continually moving and rearranging. The rearrangements account for all cell growth, development, movement, synaptic regulation—pretty important stuff. Each microtubule is a molecular assembly, a cylindrical polymer composed of many versions of a single, peanut-shaped protein called tubulin. Each of these tubulins can flex into alternative conformational shapes, and can also have genetic and other types of diversity, but are overall similar. The tubulin proteins self-assemble into hollow cylinders whose walls are elegant lattices which are both hexagonal and helical, the helical winding patterns having beautiful Fibonacci geometry. I became somewhat obsessed, enchanted really, with the structure of microtubules. These self-assembling and unassuming cylinders somehow accounted for cell growth, movement, and function. Their actions reminded me of the "Indian rope trick" where the Fakir tosses up a rope, climbs it, and then disappears. Except there's no Fakir, just self-assembling proteins forming the cytoskeleton, the bone-like structural support or scaffolding, inside all animal cells. Like a building assembling itself, brick by brick. And the more asymmetrical a cell is, the more it needs the structural support. So neurons with their long axons and dendrites have lots of microtubules. If you look inside a single neuron, you see hundreds of microtubules composed of something like one hundred million tubulin protein subunits. You could say that neurons are actually *made of* microtubules. So I just figured that if microtubules were organizing complex activities during rudimentary cell division, then they might be doing something similar in brain neurons related to consciousness.

EN: *Interesting! Most people think that consciousness arises from activity between brain cells, or neurons, but you're saying, well, no, it may actually be these extraordinarily tiny structures* within*neurons that provide the real physical basis for consciousness.*

SH: Yes, exactly. Most views consider the brain-as-computer, with neuronal firings acting as "bits." Neurons are seen as simple fundamental components of brain information processing, able to perform simple logic functions. But I began to think the mechanisms for consciousness went deeper. A couple of other things helped lead me in this direction. The first was that I looked at single-celled organisms like paramecia. A paramecium is one cell and therefore has no neurons or synapses. But it swims around, finds food, avoids obstacles and predators, finds a mate, has sex, and can learn. It seems to have some intelligence. Not necessarily consciousness, but the single-celled creature definitely has cognitive functions—"cognition" meaning sensory processing, control of behavior, and so forth. It has intelligence and yet no neurons nor synapses. It does, however, have microtubules, and organelles called cilia composed of microtubules which act as both sensors and motors. This suggested to me that a paramecium might use its microtubules to process information and organize its behavior. And if paramecia did so, why wouldn't neurons?

The second thing was that, around the time I learned about microtubules, I also began to read about computer switching matrices, lattices, and networks. The structure of microtubules consisted of a cylindrical lattice of tubulin proteins. Each of these could switch between different conformational states, and be programmed by genetics and other factors, and be influenced by lattice neighbors, like gates and switches in computers. This was more support for the notion that microtubules might be acting not only as bone-like support, but also as molecular-scale computers, the intelligence system inside cells.

EN: *So you basically started to realize that there's actually a lot more activity—and maybe even* conscious *activity—going on inside the brain than most people imagine?*

SH: That's right—I saw more intelligence at a deeper level inside neurons, specifically in microtubule computation. Most views saw the brain as a computer with one hundred billion simple, dumb neurons interacting together to produce something intelligent and conscious. I thought each neuron at the level of its microtubules had significant information processing and intelligence. I had a hunch that microtubules were "Nature's computers."

So I started working with engineer and physicist colleagues to model and simulate tubulin states in microtubule lattices. We assumed each tubulin could be in two alternative states correlating with its dipole, and that neighboring dipoles interacted, or computed according to rules set by the microtubule geometry—very much like cellular automata, self-organizing computers. We also assumed the computational interactions were synchronized by coherent excitations on the scale of nanoseconds. Based on these assumptions, I worked with my colleagues Rich Watt, Steen Rasmussen, Jack Tuszynski, et al., and showed that microtubules were well suited to be efficient computational devices. Based on about ten million tubulins per neuron and nanosecond-range computations, we calculated that microtubules within each neuron in the brain could perform roughly 1016 operations per second. That was twenty years ago. Recent evidence has shown slightly slower coherent microtubule excitations of about one-hundred nanoseconds, and ten times more tubulin per neuron, so a revised estimate would be about 1015 operations per second per neuron for microtubule information processing. So instead of each neuron registering as a single bit in the computer of the brain—a one or a zero, firing or not firing—there was another layer of microtubule processing deeper inside each neuron, raising the potential computational complexity of the brain tremendously.

This was in the 1980s and early 90s, and I was going to a lot of artificial intelligence and neural network conferences where they were trying to model and simulate the brain as many simple neuronal switches. The Singularity people are still trying to do that. Considering brain computation strictly at the level of neuronal synaptic interactions, they estimate one hundred billion neurons per brain, each with up to one thousand synapses per neuron, and up to one-hundred operations per second per synapse. This gives roughly 1016 operations per second for the entire brain. Using Moore's law for the minaturization and speedup of computer components, they were forecasting brain equivalence—and hence consciousness—in a few decades.

That 1016 was familiar. It was what we had calculated for one neuron at the microtubule level. I was saying, "No. Each of your simple switches is incredibly complicated. You have to take into account this added computational complexity. Each neuron has 1016 operations per second. The computational capacity of the brain is squared!" They didn't like that very much. If correct, it pushed their goal of simulating a human brain way down the road. So I became kind of unpopular among that crowd.

But then one day someone said to me, "Okay, let's say you're right. Let's say each neuron has all this enormous added computation going on. How would that explain conscious experience? How would that explain why we have feelings, why we see red, why we feel pain? How does that explain *consciousness*?" And I realized I didn't have an answer to that, which brings us to what the Australian philosopher David Chalmers famously dubbed the "hard problem" of consciousness research.

EN: *The question of how we get mind out of matter.*

SH: Exactly.

ROGER PENROSE & SCHRÖDINGER'S CAT

SH: Fortunately, someone suggested that I read a book by the English mathematical physicist Sir Roger Penrose called *The Emperor's New Mind*. So I did, and it was really amazing. The book's title was intended as a slap in the face to artificial intelligence theorists because they maintained that if you had sufficiently complex computation in a computer, it would be conscious. But Roger argued—in a somewhat obscure mathematical direction called Gödel's theorem—that consciousness involves something noncomputable, that *understanding*, or*awareness*, is not a computation. Something else is involved. So after ruling out the idea that consciousness was strictly a computation, Penrose then offered a mechanism for consciousness that involved something so far out of left field that most people considered it—and still consider it—rather bizarre. And that has to do with quantum physics, and in particular, quantum gravity.

Reading *The Emperor's New Mind,* I was floored with the breadth and subtlety of Penrose's knowledge, much of which I didn't understand. I *did* know that anesthetic gases exert their effects by quantum forces, so consciousness having something to do with quantum physics made sense to me. And I had this gut feeling that he was onto something. He at least had a mechanism for consciousness. It was based on a particular type of quantum computation in the brain having something to do with quantum gravity—the fabric of spacetime geometry. I learned that quantum computation required information, e.g., "bits" of 1 or 0, to exist for a time in quantum 'superposition' of coexisting possibilities—quantum bits, or "qubits" of both 1 *and* 0. After interacting/computing the qubits then reduce, or collapse to bits, e.g., 1 or 0 as the answer. Roger was proposing a new explanation for the reduction, or collapse based on quantum gravity, and associated with consciousness. But on the brain side, he didn't have a strong candidate for a qubit, suggesting possibly superpositions of neurons both firing and not firing.

I said to myself, well, maybe tubulins are qubits and microtubules are the quantum computers Penrose is looking for. So I wrote to him and we soon met in his office at Oxford.

Roger is a gentle, unassuming man, despite being incredibly brilliant and highly acclaimed. He mentioned he was going to a consciousness conference at Cambridge, and had me do almost all the talking. So I just started talking about microtubules and showed him the 1987 book I'd written on the subject. He listened intently, asked questions and was particularly taken by the Fibonacci geometry of the microtubule lattice. After several hours, he finally said, "Well, that's very interesting." I said goodbye and didn't think anything was going to come of it. But about two weeks later, I was having dinner with some friends in London and they said, "Guess what? We were at this conference at Cambridge and Roger Penrose was talking about you and your microtubule stuff." Soon after that, I received an invitation to a conference in Sweden that Roger was attending, and we struck up a friendship and decided to start developing a formal model of consciousness based on his theory of quantum gravity and the possibility of quantum computation in microtubules in the brain. I also invited him to speak at the first Tucson conference, Toward a Science of Consciousness in 1994.

EN: *Pretend I don't know anything about quantum physics. Could you explain what a quantum superposition is? And how it relates to consciousness or microtubules?*

SH: Quantum means, literally, the smallest fundamental unit of energy, like a photon—an indivisible unit of light. But behavior at the quantum level is bizarre. It's so bizarre, it's like another world. In fact reality seems to be divided into two different worlds—the classical world and the quantum world. The classical world is our everyday familiar world, in which Newton's laws of motion, electromagnetism and other basic physics pretty much describe everything very well. If you throw a ball, its trajectory, speed, location and so forth can be easily predicted. But as we go to smaller scales—let's say, for argument's sake, atoms and smaller—we enter a world where completely different physical laws apply, and predictions become a lot more difficult. For example, at the quantum level particles can be in two or more places or states at the same time. Instead of being either here or there, particles can be both here *and* there simultaneously, more like smeared-out waves than particles, and governed by a quantum wave function. And when pairs of superpositioned particles are separated, they remain somehow connected. This is called entanglement, or what Einstein called "spooky action at a distance." But we don't see this other world. And some say that's because quantum superpositions collapse, or reduce to classical systems—the wave function collapses—only when consciously observed.

EN: *This means that a human observer is required to collapse a state of superposition?*

SH: In one interpretation of quantum physics, yes. The Danish physicist Niels Bohr popularized this model, which became known as the Copenhagen interpretation. Early experiments seemed to show that if a machine measured a quantum system, the results in the machine remained in superposition until observed by a conscious human, that consciousness "collapsed the wave function." This put consciousness outside science, but allowed Bohr and others to continue experiments without worrying about any deeper meaning for reality or consciousness.
If you take Copenhagen to its extreme, you might suppose that if you're sitting in a room and there's a picture hanging behind you, then the picture may be smeared out in multiple places at once until you turn around and look at it. In other words, anything unobserved would be in a wave-like state of quantum superposition. That idea is pretty bizarre, however, and Erwin Schrödinger, another early quantum physics pioneer, thought it was downright silly. So he came up with his famous thought experiment, called Schrödinger's Cat, to try to demonstrate how nonsensical it was.

But the question raised by Schrödinger's thought experiment remains: How big can a quantum superposition get? Can isolated quantum systems be amplified so that something as large as a cat can be in two states simultaneously? There's still no answer to that, but the question has led physicists to come up with alternatives to the Copenhagen interpretation—different models of wave function collapse that don't necessarily require a conscious observer.

A QUANTUM OF CONSCIOUSNESS

EN: *And you prefer one of these alternatives to the Copenhagen interpretation?*

SH: Well, yes, Roger's theory is one of the alternatives—the only one incorporating consciousness. The others include the multiple-worlds view in which each possibility in a superposition branches off to form a whole new universe. Despite the mess of an infinite number of overlapping universes, this is actually a popular view among physicists. Another view is Bohm's interpretation that pilot waves guide quantum particles in choosing their classical states and paths. And then there's decoherence, in which any interaction with the classical environment disrupts quantum states—quantum systems must remain isolated from the classical environment somehow. But what about quantum systems which *are* isolated from environment, and may grow or evolve to a larger scale?

Roger proposed that in such cases, if decoherence can be avoided long enough, the wave function eventually proceeds to a certain point at which it *self-collapses*, or reduces due to an intrinsic, objective threshold in the fabric of spacetime itself, what Roger called objective reduction, or OR.

To understand this, go back to the multiple-worlds view. Every superposition is considered a separation in the underlying structure of spacetime, or fabric of the universe, with each branch of the separation evolving separately—resulting in two different universes. The universe divides like a living cell into two nearly identical copies. Roger agreed that superpositions are indeed separations in the underlying spacetime fabric, or geometry of the universe. He pointed out that Einstein's general relativity meant that matter was equivalent to curvature in spacetime, so that a particle in two places is the same as simultaneous spacetime curvatures in opposite directions—a bubble in the underlying fabric of reality. But in Roger's view these separations, or bubbles, are unstable—even if decoherence is avoided. Rather than evolve to form a new universe, the spacetime separations eventually reach an objective threshold for self-collapse, or quantum state reduction, and choose one bit of reality or the other. And when that happens, he argued, this self-collapse—OR—resulted in a moment, a fundamental unit or quantum, of conscious awareness.

The objective threshold for Roger's OR self-collapse and consciousness was given by a very simple equation, very similar to the equation relating wavelength and frequency in photons in the electromagnetic spectrum. The wavelength of a photon is inversely related to its frequency by a constant—the speed of light. So the shorter the wavelength of a photon, the higher will be its frequency and energy. High energy X-rays have shorter wavelength and higher frequency compared to visible photons or microwaves. For fundamental units, or quanta of consciousness, Roger used a similar equation related to quantum indeterminacy, $E= h/t$. E is the size of the superposition, as well as the energy and intensity of the conscious moment, and t is its wavelength, or duration. h is Planck's constant, putting it all in the quantum realm, or more precisely on the edge between the quantum and classical worlds. So the larger the superposition E, the shorter the t, or wavelength, and the faster the system will reach OR threshold for self-collapse and a conscious moment. And the larger the E, the greater also is the intensity of the conscious experience. This gives a quantum of consciousness, or actually an entire spectrum of quanta-conscious moments.

Penrose turned the Copenhagen interpretation around. Conscious observation doesn't *cause* quantum wave-function collapse, as the Copenhagen interpretation says. Rather, he suggested consciousness *is* the wave function collapse, or at least one particular kind of collapse. It's a quantum collapse that gives off fundamental units of conscious awareness, just like an electron orbital shift gives off a photon of light. And like photons, quanta of consciousness come in a spectrum of different intensities, frequencies and qualities.

EN: *Wow! In this interpretation of quantum physics, superpositions naturally collapse themselves? And those collapses somehow produce consciousness?*

SH: Yes, if decoherence or measurement doesn't occur first. And that's a fairly tricky thing, otherwise we'd have consciousness all over the place. If E is very small, t will be very long. So if an electron with a very small E in superposition were isolated from environment, it would have a conscious moment only after a very long time t—something like ten million years. And it would be a very low intensity experience—rather dull. A large superposition E, if isolated, would reach threshold quickly with a high intensity experience. We think the brain has evolved to isolate large superpositions E, but otherwise it's very difficult to isolate large superpositions. So consciousness can happen whenever $E=h/t$, but in the universe it is fairly rare.

So how does it happen in the brain? That was kind of my job to figure out when Roger and I began to formalize our model in the mid-90s. I showed how synaptic inputs could tune, or 'orchestrate' OR-mediated quantum computations in microtubules, hence our theory became known as orchestrated objective reduction, 'Orch OR'. There was the obvious issue of decoherence in the warm brain which I suggested was avoided by coherent biochemical pumping, microtubule resonances, ordered water and actin gelation encasing microtubules. Over the years we've had a lot of criticism about this, but recent evidence has clearly shown quantum coherence in warm biological systems. Another biological issue was how a quantum state isolated in microtubules in one neuron could extend to those in other neurons, for which I suggested gap junctions—window-like connections between neurons. In recent years, gap junctions have been shown to mediate gamma synchrony EEG, the best measurable correlate of consciousness. We also addressed how tubulin states could be regulated by weak quantum forces, be isolated from environment yet interact with it causally, and how it all fit in modern neuroscience.

So we had a reasonable story for how OR events—Orch OR—could happen in microtubules throughout wide regions of the brain. And when these collapses happen again and again, you get a series of conscious moments that is your experience of a stream of consciousness. So consciousness consists of a series of discrete events, yet is experienced as continuous. This is kind of like a movie appearing to be continuous yet being composed of individual frames, only with a movie you have an outside observer. In Orch OR, the frame itself has the observer built into it. The conscious moment and the quantum wave-function self-collapse are one and the same—a ripple in the fundamental level of the universe.

What is fundamental spacetime geometry? If we were to shrink smaller and smaller, much smaller than atoms, the medium of spacetime would appear smooth and featureless until we eventually reached the incredibly tiny Planck scale—the basement level of the universe—where patterns and webs of information exist. What it might look like is approached theoretically through geometry arising from string theory, twistors, spin networks or quantum gravity. Roger is one of the world's experts in these areas, and he suggested that information embedded at this level, and repeating holographically, contained mathematical truth, as well as perhaps other Platonic values. Roger suggested that pure form and truth arise from information intrinsically encoded in the universe. This led to his noncomputability.

When superpositions decohere, or are measured as in standard quantum physics, the quantum possibilities collapse or choose a definite state randomly—like flipping a coin. But when decoherence and measurement are avoided and OR conscious threshold is reached, Penrose suggested that the choices of definite states—the conscious choices we make, or perceptions we experience—are not chosen randomly from among possibilities, but are influenced, or guided, by Platonic information embedded in spacetime geometry. He called this influence noncomputable because the Platonic influences were outside the system, built into the universe. Consciousness does sometimes involve choices or perceptions which appear to be noncomputable, e.g., intuition, instinct, divine guidance, enlightenment, or "following the way of the Tao."

EN: *So according to Penrose, gravitational effects at the quantum level are causing wave functions to collapse automatically, emitting little bursts of consciousness that somehow result in our own continuous, moment-to-moment experience of being conscious, aware, and alive?*

SH: That's right. I don't know how familiar you are with the early-twentieth-century mathematician and philosopher Alfred North Whitehead, but his thinking was very much along these lines as well. He said that consciousness was a sequence of what he called "occasions of experience occurring in a wider field of proto-conscious experience." In his view, the universe isn't made of things or particles. It's a *process*. It's made up of events. In the early nineties, physicist Abner Shimony pointed out that Whitehead's occasions of experience are very much like quantum wave-function collapses, or quantum state reductions, so our view seems pretty consistent with Whitehead's. But what about his "wider field of proto-conscious experience"?

When Roger and I first came out with our theory, we didn't directly address the hard problem—why we have conscious experience. But when the *Journal of Consciousness Studies* did a special "hard problem" issue in 1996, we took a stab at it. And we basically followed Whitehead, saying that the "wider field of proto-conscious experience" was the fabric of the universe at the Planck scale—quantum gravity, or fundamental spacetime geometry—and that OR events were "occasions," or ripples, occurring in that wider field. Fundamental properties of matter such as spin, mass, and charge are irreducible components of the universe that are somehow embedded in this Planck-scale geometry. So Roger and I proposed that the primary components of consciousness, of awareness, or at least their precursors—are also fundamental, irreducible, and built into the basic structure of the universe. After all, why should precursors to matter be present at that level but not the precursors to mind?

EN: *Good question. You're saying it's possible that at least some basic level of consciousness may be as fundamental to the universe as the laws of physics?*

SH: Yes. The laws of physics must include consciousness, or its precursors. I wouldn't say the universe is conscious, just like I wouldn't say the universe is entirely yellow, or purple, or wet or whatever. But under the right conditions, any of these can be true for small regions of the universe. The un-collapsed, still-superpositioned precursors of consciousness are somewhat like dreams. When OR occurs, the universe—at least a tiny portion of it—wakes up.

GAMMA FREQUENCY & ALTERED STATES

EN: *We began by talking about microtubules, so please tie these together for me. How do these quantum wave-function collapses relate to what is happening with the microtubules in the brain?*

SH: Well, the best measurable correlate of consciousness is a type of EEG—that is, electroencephalography, or brain-wave measurement—called gamma synchrony at around forty times per second, discovered in the 1980s in Germany by Wolf Singer. Typically with EEG you get a mess of squiggly lines, but if you break them down into frequency ranges you get various types of waves—delta, theta, alpha, and beta. These indicate electrical waves in the brain ranging from zero up to about thirty hertz, or thirty waves per second. But Singer discovered a higher, perfectly coherent frequency that came to be known as gamma synchrony, which ranged from thirty to ninety hertz, or even higher, though forty hertz is typical. Gamma synchrony is the best marker we have for consciousness in the brain. This suggests that conscious moments, or Whitehead “occasions,” occur roughly forty times per second.

EN: *You’re saying that by monitoring someone’s brain with an EEG, researchers have been able to isolate a certain frequency of activity that only correlates with conscious experiences?*

SH: There has to be a critical amount of it, but yes. And it can occur in different parts of the brain, kind of moving around. For example, if somebody smells a rose, they have this gamma synchrony in the olfactory cortex, the part of the brain dealing with smell. If you’re having visual consciousness, you’re going to have gamma synchrony in visual cortex, and in frontal cortex. For sexual pleasure, there is gamma synchrony in a part of the brain called nucleus accumbens, and so on. Gamma synchrony goes away with general anesthesia while other brain neuronal activities continue.

So Roger and I proposed that gamma synchrony correlates with OR quantum-state self-collapses happening roughly forty times per second among coherent, organized networks of the brain’s microtubules. Using $E=h/t$, we set time t as twenty-five milliseconds, the time duration for forty events per second, and calculated E in terms of superpositioned microtubule subunits. We came up with roughly nanograms of superpositioned tubulins, occupying roughly one hundred thousand neurons worth of microtubules, a number which matched other estimates for consciousness coming from conventional approaches.

Now, I should note that the frequency of conscious events can vary. In heightened or altered states, we seem to be having more conscious moments per second, which would mean that our perception of the outside world would be slower. For example, in a car accident when the car is spinning, people often report that time seems to slow down and the outside world appears to be moving half as fast as it usually does. This could be because their rate of gamma synchrony is changing from around forty hertz to eighty hertz. And similarly, someone once asked the great basketball player Michael Jordan in his prime how he was able to outperform the other team so well. He said when he’s playing well, it’s like the other team is in slow motion. So maybe Michael Jordan was experiencing sixty, seventy, or eighty conscious moments per second and the opponents were only experiencing something like forty.

We also see it in meditation. Buddhist texts describe flickering in pure awareness which have actually been counted—something like six and a half million in a day, which comes out to be in the gamma synchrony range. A few years ago, the Dalai Lama sent some monks to a lab in Wisconsin. They found that while meditating, the monks had the highest gamma synchrony ever recorded. They were actually operating at about eighty to one-hundred hertz, with control subjects at forty. And even at baseline, before they would meditate, the monks showed an unusually high rate of gamma synchrony. Years of meditating had changed their brains so that they were just normally in this higher-frequency gamma range. That suggests they’re having a richer and more intense conscious experience more frequently than the average person. You could perhaps also say they were having higher energy, frequency and intensity OR conscious moments, or quanta. They go deeper into the quantum world.

THE SPIRITUALITY OF SPACETIME GEOMETRY

EN: *Okay, I have a question about this. If consciousness is arising as a certain frequency of quantum collapses in the brain, then your model could still be considered materialistic, right? Consciousness is still ultimately a byproduct of brain activity, just pushed down to the level of what you’re calling quantum spacetime?*

SH: Hang on a second! Material means "matter." Matter derives from something more fundamental, which is quantum spacetime geometry, twenty-five orders of magnitude smaller than atoms. So this goes way below the scale of matter. Matter is … immaterial.

EN: *Can you elaborate?*

SH: Basically, if you think of mind and matter and the relation between them, there are a number of different philosophies to choose from. First you have dualism, where mind and matter don't relate; there's a brick wall between them. Next, you have ordinary materialism, the conventional view that says that matter creates mind. Then you have idealism and various mystical approaches, which say that mind creates matter. And there's panpsychism in which mind and matter are the same. But in my opinion, none of these work. They all have problems. So the final choice, I think, is what's called *neutral monism*, which has been put forth by such figures as Bertrand Russell, William James, and Baruch Spinoza in Western philosophy, and various nondual positions in Eastern philosophy. Neutral monism says that there's one common underlying entity that gives rise to, on the one hand, *matter*, and on the other hand, *mind*. In our model, that underlying entity that gives rise to both matter and mind is quantum spacetime geometry. If you have a superposition which decoheres, you get matter. If you have a superposition which avoids decoherence and evolves to reach threshold for a conscious event/quantum, you get both matter and mind. In the Vedic traditions, you could call spacetime geometry Brahman, the underlying ground of being. You can call it whatever you like—spirit, the cosmos, quantum gravity—whatever it is that gives rise to both mind and matter and underlies all of reality.

EN: *So you're saying that based on your model, reality could be seen as being fundamentally spiritual?*

SH: First let me say that Roger doesn't relate his work to spirituality. But I personally have nothing to lose, so I figure, why not? I recently wrote a blog about this topic after speaking at an atheist conference, which I called "Being the Skunk at an Atheist Convention." Richard Dawkins, Patricia Churchland and other atheists were there bashing religion. I said I didn't hold with any organized religion, but that based on what we know of quantum physics and consciousness, we have to take seriously the scientific possibility of spirituality. Needless to say, they didn't like that very much. In defining spirituality I mentioned three things. The first was an interconnection among living beings, and the universe as a whole, and I said that this could be possible through quantum entanglement, the intimate connection between quantum particles seemingly beyond the limitations of space and time. The second was some kind of divine guidance or cosmic wisdom influencing our choices due to Platonic values embedded in fundamental Planck scale spacetime geometry. And finally, there was the possibility of consciousness persisting outside of the body, or after death.
About ten years ago, several studies about near-death and out-of-body experiences came out of Europe. Both involved several hundred patients who had cardiac arrests, and they found around seventeen percent of the patients had these near-death or out-of-body experiences. Then the BBC did a show about it called "The Day I Died," in which they asked the researchers who did the studies if they could explain these experiences scientifically. And they replied, "We have no idea. Why don't you ask Penrose and Hameroff ?" Anyway, Roger declined comment, but I said, well, under normal conditions, consciousness is happening at the level of spacetime geometry in and around the microtubules in the brain. However, when the blood and oxygen stop flowing and quantum coherence in brain microtubules stops, then the Planck scale quantum information isn't destroyed. It continues to exist at the Planck scale, and can leak out or dissipate but remain entangled as a certain pattern, at least temporarily. So if the patient is revived, the quantum pattern gets drawn back into the microtubules inside the brain, and the patient reports having had a near-death or out-of-body experience. If the patient actually dies, then it's conceivable that the quantum information can remain entangled in some sort of afterlife state. And perhaps the information can get pulled back into a new creature, a zygote or embryo, in which case you'd have something like reincarnation.

Now, I'm not offering any proof that this happens. I'm just providing a plausibility argument. I'm saying here's how it could happen based on the Orch OR model.

EN: *Let's see if I've got the gist of your theory straight. Essentially, you're saying that at least some basic degree of consciousness is woven into the fabric of spacetime itself, and it's the coherent quantum activity among the microtubules in our brain that allows us to amplify or strengthen the basic universal consciousness that's already there?*

SH: Yes. Or simply to gain access to it, connect to it, become one with it. Quantum processes in brain microtubules make this connection in a way that also involves cognition, computation, and intelligence.
Most people think that consciousness emerged over eons as a byproduct of random mutations and the inherent complexity of natural selection, but I look at it the other way around. I think the fundamental field of proto-conscious experience has been embedded all along—since the big bang—in the Planck scale, and that biology evolved and adapted in order to access and connect to it. When someone meditates or becomes enlightened, they're moving more deeply into that quantum realm. If you meditate and attain what people call nothingness, it isn't actually nothingness. I think it's spacetime geometry with its Platonic wisdom. You move more deeply into the basic fabric of the universe and actually become more consciously a part of it.

In fact, the Kabbalah says that we have this world of wisdom and light and then we have the world of aggravation and strife, and that consciousness dances on the edge between the two worlds. I think that's very close to what's happening, with the classical world being filled with aggravation and strife, and quantum spacetime geometry being filled with wisdom and light. OR is a process literally "on the edge" between quantum and classical worlds, converting quantum possibilities to classical reality. Spiritual practices allow you to dive deep and become immersed in the quantum Platonic world of spacetime geometry. You could call it God if you wanted to.

I should add that our theory has many, many critics. One argument against us has been that the brain is too warm for quantum effects, and that decoherence would prevent superpositions from reaching threshold for consciousness. But evidence in the past few years has shown that quantum coherence and superposition play major roles in living systems at warm temperatures, for example photosynthesis in plants. If plants can avoid decoherence, the brain is likely to have evolved a similar capability. So I'm betting on our side. If the quantum consciousness hypothesis is proven, it will give credence to the spiritual dimension of life. It will undermine materialism and atheism. I think it will rightfully justify faith and hope.