THE QUANTUM MIND*

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When did consciousness arise? Basically there are three possibilities for the origin of consciousness in the universe. Number one, which is the most popular I would say amongst scientists, certainly, consciousness emerged as a property of biological complexity at some point during the course of evolution. And we can argue about when.

Number two is a more religious view that consciousness has been in the universe all along, for example, as the ground of being or God as suggested by spiritual approaches, and/or in the fine structure of spacetime geometry. Now, I will argue that that last clause in the fine structure of spacetime geometry is more or less equivalent to the ground of being or God to some extent as suggested by spiritual approaches.

The third is a little bit different from number two in that sense that the precursor of consciousness has been in the universe all along with consciousness emerging during evolution as quantum biomolecular processes in the brain connecting to the fine structure of spacetime geometry. So number three is kind of a combination of one and two. Now let's consider where and when.

This allows me to walk around a little bit. Here are a number of possibilities. The earth formed about four and a half billion years ago and life started about three and a half billion years ago, and for a long time not much happened. And then eukaryotic cells developed, if you believe Lynn Margulis with the symbiotic merger of spirochetes with cytoskeletal structures in with prokaryotes, but still not much happened until about 540 million years ago. And then in a fairly brief 10 million years, all the animal phyla evolved rather quickly.

This is known as the Cambrian evolutionary explosion. I wrote a paper suggesting that consciousness emerged here in the Cambrian evolutionary explosion where the organisms were fairly simple organisms at the beginning and then wound up with mammals by the end of the 10 million years. Now, some of these creatures are still around. And give us, for example, this urchin over here is still around in the form of Actinosphaerium, and I happen to know about this organism. It's got these oxoniums coming out, which are sort of precursors of neurons, and if you cut a cross-section of them, you'll see that they are these double spirals of microtubules. Each of these circles is a microtubule on end, and this whole thing is made of polymerised microtubules.

If you anaesthetise this creature with anaesthetic, the microtubules depolymerise. And that gave rise to a theory in 1968 that anaesthesia worked by

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depolymerising microtubules, although it turned out to require quite a bit more to depolymerise than it does to cause anaesthesia. But it does show that microtubules are sensitive to anaesthesia. Now, the same microtubule structures here are found inside neurons. Here's a synapse, two synapses, and in the dendrite and there are also axons, where we find these microtubules.

Microtubules have been around a long time. And they led to the Penrose Hameroff Orch-OR Theory of Quantum Computation in Brain Neuron Microtubules, where inside a neuron we have microtubules and each of their sub-units acts as a quantum bit, or qubit, giving rise to global quantum coherence. I will talk about that later. I just want to briefly give you a glimpse of that.

Let's go back more or less to the beginning of the study of consciousness. The Greeks, Plotinus, I used to think Plato said this but somebody corrected me, observed that reality, his version of reality, is merely a representation in his brain. Light bounces off the tree, goes to his eyes, and he has a representation of the tree in his head. And you can see even with the Greeks the tradition of using the word «bing» to denote phenomenal conscious experience began. That's a joke, but you'll see in the course of this lecture I'll use bing to indicate the hard problem of phenomenal experience.

Now, the representation of reality in our head may poorly represent actual reality. We don't really know. And this is exemplified by Plato's cave allegory, where these guys could only see two dimensions and for them, that was reality. Two dimensions was all there was, and that was perfectly fine. And so he's getting bing out of a two-dimensional shadow world, suggesting that there may be a deeper reality for us that we're not normally seeing.

Descartes picked up on this idea that reality is a construction in the head and observed that for all we know, we could be a mere brain in a vat fed information by an evil genius. So here's a brain in a vat who's being fed information and he or she thinks I'm walking outside in the sun, when he's actually in a vat. And this has been the script for many science fiction movies. And this led Descartes to say that we're only certain that we're conscious. I think, therefore I am.

For Descartes the observer was an immaterial soul hovering above his head, through the pineal gland gained entrance, and it's the soul that had the conscious observation. The bing experience, according to Descartes. Of course this is Cartesian dualism, where mind and matter are separated irreconcilably as if separated by a brick wall. Now, Greeks including Aristotle suggested that the brain, actually Aristotle said the heart, but we'll cut him some slack and give him credit for saying the brain, projects mental qualities out onto the world. So the bing is projected out onto the world and this is a form of idealism where mind generates matter.

Another view in Eastern philosophy is that consciousness pervades a deeper level of reality. Bing is pretty much everywhere, and when you meditate you get in touch with it. And this is a form of pan-psychism where mind and matter are more or less equivalent and/or can be considered a form of neutral monism. We heard about monism yesterday. I don't know if anybody mentioned neutral monism, which was started by Spinoza; also William James and Bertrand Russell, where there's some underlying deeper reality which gives rise to matter and mind. And so this is neutral monism. We'll come back to this point, because this works very well with the quantum paradigm.

And finally, the most popular view, materialism or reductionism where matter generates mind: brain equals mind equals computer. This would be the most popular view amongst scientists, certainly, and is pretty much the basis for modern science's understanding of brain function. It doesn't quite explain consciousness, however. But let's look at this, because I think we can learn a lot from what's perceived. Modern science sees the brain as a computer in which nerve cells over here and synapses, we can't really see in the connections between the nerve cells, act like nodes and switches in a computer matrix over here; essentially the same thing.

Descartes came up with a scheme for organising consciousness based on a theatre analogy. And he said that the contents of consciousness are like a play on a stage, with actors, props, script, and so forth going into determine what's on the stage, which is then viewed by the audience, the observer sitting out in the theatre. Now, of course Descartes didn't have to worry about the audience too much because he had the soul hovering above his head, but the rest of us worry about who the audience is and who the observer is.

But this architecture was very useful. It was picked up by Simon and Newell, who developed computer architectures based very much on Descartes' theatre metaphor, which was called the global workspace or the CPU where various forms of inputs went into this, and then an output to a monitor which somebody could watch. But it's very similar to the Descartes' theatre.

And finally in the 1980s, a number of neuroscientists including Bernie Baars, Gerald Edelman, Giulio Tononi, Sean Joe Dehain, Kirk and Kolk and others, cast thalamocortical oscillations as the version of Cartesian theatre or the global workspace, where sensory inputs and various other inputs went into the thalamocortical system which arose to cortex and then feed back to thalamus. And this reverberation was thought to be the site of consciousness, bing, and that's pretty much the modern view among neuroscientists; Global Workspace Theory, thalamocortical oscillations.

However, this is based strictly on sensory stimuli and arousal, bottom-up and top-down. What about mental states without sensory inputs and arousal? Task for example, task-free stimulus independent thought, internally generated states, mind wandering, episodic memory, meditation, daydreaming, these don't require sensory input. And it turns out that we spend about half our time in these mind wandering or similar modes. Marcus Raichle described this as default mode networks, so the brain's dark energy in this paper, and there's been a lot of work since showing these particular brain areas that are active when we're not in our sensory processing mode; when we're mind wandering or daydreaming.

The default mode networks mediate episodic memory, if you just remember something, introspection, self-referential thought, daydreaming and so forth. Thinking about consciousness, meditation, maybe the Jamesian fringe, that's outside of consciousness, a Freudian id; maybe also context and filling in for sensory processing. So these are different from what we do just processing information from the outside world, and Raichle showed that there are two types of networks that are anti-correlated. So we're either in our mode of processing sensory information, or we're in our daydreaming mode, and we toggle or flip back and forth.

These blue spots are low activity in the default mode networks and down to here, this person has gone into high activity in the default mode networks. So between this and this, they've switched from, say, paying attention and processing sensory information in the here and now, to daydreaming and mind wandering, and this happens on an average of every 10 seconds. Very roughly. So aside from conscious versus non-conscious distinction, we know that the brain operates in these two distinct modes. Attention-based sensory processing, task performance, thalamocortical…

Let's say you're driving your car in heavy traffic. You're paying attention. So that's… that would be this. And then you're on a smooth road and nothing's happening, and you're daydreaming about something else, you go into this other mode of mind wandering, episodic memory, internally generated states, and the activity has shifted. The conscious activity, whatever it is, has shifted to the default mode networks, different regions of the brain. And these flip back and forth between the two on the order of very roughly every 10 seconds. These are the anti-correlated networks.

That doesn't really tell us about consciousness because the default mode networks can either be conscious or non-conscious, and the sensory processing can be either conscious or non-conscious. What it does tell us is that consciousness may involve a self-organising neuronal processing in the brain moving back and forth between these two networks. So one moment it's in the sensory processing mode, and the next moment it's wandered off into the daydreaming mode.

So how do we picture this? We know that the brain has various types of functions, sensory perception, behaviour, learning, memory, sleep, and so forth. You can read them, and all of these may be at one point non-conscious or at other times conscious. When they're non-conscious, they're known as the easy problems of Dave Chalmers; or the zombie modes; or the autopilot, as if we're on autopilot. So you know what an autopilot is. The pilot can press a button and go wander off, flirt with a stewardess, or have a meal, or take a nap, go to the bathroom, and everything's fine. The plane's flying on autopilot until there's some turbulence, and then he comes back and takes over. We'll come back to the autopilot.

Now, these same functions can also be processed consciously. Sensory perception, controlled behaviour, can also be conscious. So the bing can occur in different parts of the brain at different times. And usually not all of these things are going on at the same time, but we can have these different modes shifting back and forth from moment to moment as consciousness moves and redistributes through the brain. So this is I think an important point that consciousness actually moves around the brain, and wherever it is, that's what is brought into consciousness. And it moves around the brain in a zone of gamma synchrony EEG.

Now, gamma synchrony EEG is the best correlate of consciousness. We get beautiful pictures out of FMRI, and they show us the anatomy beautifully, but they don't have any temporal resolution, and they don't really help us in terms of what consciousness is, it just tells us where. So as you know, EEG recorded from the scalp or brain surface gives a bunch of squiggly lines, which if you do a Fourier transform, you break into frequency modes, and gamma 30 to 90 hertz, used to be called coherent 40 hertz, but it can be 30 to 90, correlates best with consciousness. Particularly when it's from one part of the brain to the other, that's the best marker of consciousness; so coherence in the gamma synchrony.

Gamma synchrony also can correlate with elevated states of consciousness. In this famous study by Lutz et al in PNAS, they study Tibetan monks who had been chosen by the Dalai Lama for being the best meditators. They had the highest gamma synchrony ever recorded. Instead of 40 where you and I probably are, they were 80 to 100, even at rest before they started meditating. And then when they meditated they went even higher in terms of frequency, amplitude, and coherence. The controls were college kids they taught to meditate for a couple days. They had gamma and they had bing, but not nearly to the degree as the monks. So it's a marker of also level of consciousness.

It also tells us that consciousness is momentary, for example, at 40 cycles per second or 40 moments per second. And a sequence of moments causes each other, each one lasts only a short period of time, and advanced meditators are able to detect the transition from moment to moment. And one described them as 1/64th of a snap of a finger. So whatever time that is, I'm not sure, that's how long a moment of consciousness lasts.

Other Buddhists actually quantified the number in a way, I don't know how they did it. But, for example, they counted six and a half million conscious moments in 24 hours, which is actually one 13.3 milliseconds, or 75 hertz, and Chinese Buddhists as 50 per second. And both of these are in the range for gamma synchrony. So it's pretty convincing that Buddhist texts from thousands of years ago and modern electrophysiology both give this idea that we have conscious moments roughly 30 to 90 per second. James also described consciousness as specious moments in a stream, and Alfred North Whitehead had occasions of experience. So Whitehead also had discreet conscious moments.

How do we get conscious moments and experience out of neural function? Here's a brain cell, the Hodgkin-Huxley neuron, which tells us how membrane depolarisation occurs due to ion channels opening and closing. The dendrites integrate information, have greater potentials. There's a trigger, all or none, and then a spike travels to the next set of neurons.

Here is a network of toy neurons where we have inputs going over here, each one of these guys use either white or black depending on whether it's active or not. And one is active and zero is not, so we've inputs coming over here. We have rules by the synaptic plasticity. This is typical neural net stuff, and I'm just using it to illustrate a point. And we have outputs here, here, and here. If we let it run and change the inputs, we just get different outputs. And do some fairly efficient computing on the neural… neuron to neuron basis. I think Giorgio talked about this yesterday. And this is pretty much the standard paradigm in neural science in terms of how the brain and neurons compute.

But where is consciousness? Where is the bing, and specifically where is the synchrony? Because in this type of network, there's no synchrony. Synchrony is something else. Presumably that explains non-conscious processing, so we can explain the computerised non-conscious activities of the autopilot by that type of network. But where's the conscious pilot? Maybe somebody like John Travolta shows up. Maybe he's not the best paradigm of being conscious, but the point is that consciousness can move around the plane and resume control of the cockpit.

How do we find something that moves around the brain and can correlate with consciousness? Well, here's another toy neuron. Here's the three dendrites in a cell body. Here's the axon. And these three guys, these three dendrites, receive information… integrate information and trigger a firing here, and here's the chemical synapse that we've all come to appreciate over the years. But there's another type of connection in the brain called a gap junction, electrical synapses, and this type of connection synchronises this membrane and this membrane. So this causes synchrony including gamma synchrony. So these types of connections, cortical interneurons, glia, and other neurons, connected by gap junctions, are active synchronously in the gamma range and correlate with consciousness.

If we have neurons connected dendrite to dendrite by gap junctions, as we see here, as opposed to axon to dendrite as other types of networks… these sideways connections, anywhere they're synchronised, like the dancers holding hands with kicking up their legs, the Rockettes. Anywhere you look in this system, you're going to see synchrony and coherence. And so this accounts for gamma synchrony throughout wide regions of the brain, if not the entire brain. So here's a type of gamma gap junction suggesting some kind of quantum tunnelling between the two.

So we go back to our network and now we put in gap junctions, here, and allow them to open. And what happens is, as they grow larger, they reach a threshold, and we start to get synchrony, which correlates with consciousness. And we know that gamma synchrony correlates with consciousness, so we have bing in a zone of gamma synchrony moving around the brain. And I think this is how consciousness moves as a causal agent, as a mobile agent, moving around the brain and wherever it goes, that's where consciousness is. And I published this in a paper called the Conscious Pilot, the conscious pilot being the zone of synchrony moving around the brain, dendritic synchrony moves through the brain to mediate consciousness, earlier this year.

Two examples of this are that gap junction-mediated gamma synchrony in the olfactory bulb mediates conscious smell. This is the only sensory modality that doesn't require the thalamus. Signals from the odorants come through the nose directly into the brain into the olfactory bulb and there gap junction mediated gamma synchrony occurs, which correlates with conscious smell. And there are the references for that.

One other example is that conscious feelings of pleasure and reward correlate with gap junction-mediated gamma synchrony in dopaminergic nucleus accumbens and other areas, prefrontal cortex, nucleus accumbens, ventral tegmentum. And gamma synchrony mediated by gap junctions in these areas correlate with pleasure. Now, we know that dopamine is involved and that this may be the final common pathway for all forms of pleasure and reward, but the gap junction-mediated gamma synchrony is right in there also. It can occur regardless of what the neurotransmitter is.

I would say consciousness moves around the brain in the zone of gamma synchrony, why is it conscious? Is it complexity? So many neurons, so much computation? Not necessarily. For example, consider a single cell paramecium which can learn, avoid predators, find food, find mates, have sex. It has no synapses. It is only one cell. Here's a paramecium that bumps into something and backs up, it goes another way. If you suck it into a capillary tube, it escapes faster and faster each time. It can avoid predators. And it can find a mate, and here's actually two paramecium having sex. And they actually fuse and become one for about a minute, and then swim off and go their separate ways.

We don't know that this is conscious, obviously, but it could be. And what better way to promote evolution than to have sex, feel good and cause organisms to want to do it? So the point is that this creature does this without any synapses. I don't think it is right to say that consciousness and cognition emerge from complex interaction among neurons when we have single cells like a paramecium that can do complex things. Not necessarily conscious, but certainly cognitive. And I always ask my AI friends to simulate a paramecium before they worry about a brain. So far nobody's been able to do it.

This suggests that cognition, if not consciousness, can occur at multiple scales and I just want to mention something, we'll come back to this later. Scale-free dynamics, otherwise known as fractal, as something like a hologram, where there's self-similarity across various scales, and frequency size, and energy. And this is found widely in nature and in many systems in the brain in EEG activity, in saccade movements in the eye and in other functions. So there may be this hierarchical scaling going on and I'll come back to that in a little bit.

To give you an example how that would work each… if you imagine these are neurons, each one of them is connected in a small world local network but also larger world, large scale networks. So neurons can participate in different scale networks, and then we go inside neurons and it gets even more interesting. So this is just the scale free idea that found in inner spikernels, EEG saccades, eye movement, and neuronal structure nested networks. We have networks inside networks, with time scales from tens of seconds as in the switching between the default modes and the sensory modes, down to EEG and tens of seconds to 1,000 hertz. Consciousness and memory have long been considered holographic by Pribram, Lashley and others.

Let us look inside the neuron to the microtubules and see if the scale of reactivity can extend down there. This is the structure of a microtubule and some of you may know that I got obsessed with microtubules when I was in medical school 38 years ago. And I got the idea that they were organising things and might be acting like computers. And if you look at their structure, they're made of these peanut-shaped tubulin proteins which can switch between states. This is also a quantum state and this could process information.

I spent a number of years working on models of information processing and microtubules including one very good paper with Steen Rasmussen, who was here yesterday, showing that they could function as cellular automata or molecular automata and process information based on dipole-dipole couplings. This is the game of life, which is a form of molecular… cellular automata and this is kind of a similar one in microtubules except based on the structure and the dipole coupling strings among the neighbouring tubulins.

We showed information processing like this, which meant that each neuron having something like 10^8 of these sub-units switching at 10^7 could have 10^{15} operations per second per neuron, whereas most people in AI were talking about that same number for the entire brain. So we weren't very popular among AI people arguing for pushing the goal-post for brain equivalents way, way downstream. So it does increase the brain, the information capacity per neuron and per brain, although it doesn't necessarily solve the problem of consciousness.

Microtubules are also involved in Alzheimer's disease, which as you know takes away memory and cognition and eventually consciousness. And basically it's because the microtubules more or less disintegrate because of these Tau proteins which are attached to them, which get hyper-phosphorylated. And when the microtubules fall apart, you lose memory, you lose cognition, and eventually consciousness. Now, one interesting point is what Tau does. Tau is hyper-phosphorylated and causes the microtubules to fall apart, but under normal circumstances what does it do?

It turns out that Tau acts as a traffic signal for motor proteins transporting synaptic materials. So here's a neuron here, here's a cell body, this is the axon. Here's a dendrite and we've zoomed in one little piece of the dendrite, and see a microtubule inside of it, and so kinesin is moving material this way to a synapse and it has to branch. And so the question is: how does the kinesin know where to drop off its cargo? It's kind of like FedEx or some postal service, it needs to have an address, it needs to drop things off at a particular synapse, and it turns out that Tau tells the kinesin when to get off and where to drop its material in a particular synapse. And so then the question is, how does the Tau know where to bind on the microtubule? There would have to be some kind of information embedded in the microtubule for the tile to know where to bind.

I will say one more thing about memory. The basic idea in memory is synaptic plasticity. If synapses become more sensitive, that enhances activity and that's learning. In long-term potentiation, which is a model for memory, part of it is calcium comes in and activates the enzyme called CAMK2, which is a snowflake-shaped enzyme which then gets stuck on microtubules and are transported somewhere; and phosphorylates something within the neuron, which records long-term memory. The question is what is phosphorylated to recall to record long-term memory?

We looked into this about a year ago. This work was done by Travis Craddock and Jack Tuszynski in Canada collaborating with me. When the CAMK2 is phosphorylated and activated by calcium, it transforms. Like in the movie Transformers, where it changes shape, and extends six arm and six legs. I think they're both legs. Legs going up and legs going down, to form this nano-robot or nano-poodle some people call it, funny looking thing, which is able to phosphorylate and record memory inside the cell.

There's six of these kinases coming down and each one can phosphorylate or not, and therefore conveys a bit of information. And so you have six bits, or a byte of information for each set of six kinase domains, and this shows where the phosphorylation sites are, and somehow these sites phosphorylate a substrate and memory is encoded or stored. Well, we thought, well, maybe they're binding to microtubules, so we did a comparison based on size and geometry. And here is a microtubule at 20 nanometers, and here's tubulin on the sub-unit of five nanometers, with the phosphorylation sites. And then we asked, well, how does the CAMK2 line up with the size and geometry of the microtubule? And the answer is perfectly.

So here's a microtubule A lattice, it's a piece of a microtubule here and here. This is the B lattice. And this is the CAMK2 with the top cut off. And overlying here you see that it matches up perfectly for both the A lattice and the B lattice. Therefore these CAMK2 kinases can phosphorylate microtubules and this is what it would look like for a CAMK2 occupying six sites on a microtubule. And here we show the nitty gritty details of the phosphorylation mechanism at the level of the amino acids.

Finally the encoding capabilities from one little patch of a microtubule, from one CAMK2, depending whether it's binary, trinary, and a couple other assumptions, this gives you 64, 2^6 possible bits per byte. This is 500 and this is 5,000. So the amount of information capacity able to be phosphorylated onto microtubules is enormous. We published this in the Journal of Integrative Neuroscience not too long ago.

Here we have microtubules inside a neuron, and this is an electron micrograph, some of these have been. The tops have been ripped off. But you can sort of see the tubulins there. They're interconnected by microtubular associated proteins, so you have a network of these microtubules inside neurons. So it's sort of a fractal scale-free dynamic going down inside. So let's go back to the basic idea of the microtubule as computer, with the tubulins switching states and possibly being in superposition of both states. So the control of the state is proposed to be by what are called hydrophobic pockets, regions of the protein which have non-polar amino acids that… which is where anaesthetics bind. Anaesthetics bind on these little pockets and prevent the protein from doing its dynamics, and ultimately block consciousness. And we'll come back to that.

These hydrophobic pockets are formed by folding by these non-polar amino acids conglomerating with each other in the interior and forming a secluded environment. And when Steen was talking yesterday, I was trying to make the point that what he's talking about in terms of the olive oil is actually a very small part of the phase diagram of a body. If you took any of us and grind us up in a whirring blender and then looked at solubility zones and what in our bodies would act as a solvent for different solutes, you could see all the different solvents here. These two areas, the aliphatic and the aromatics, are where anaesthetics bind; and also are non-polar and therefore optimal locations for quantum processes.

They bind by the van der Waals force, the van der Waals-London force between neutral, non-polar atoms or molecules. This happens to be neon, but it could be the non-polar amino acids. So you start with eight of these electrons that are balanced and then the electrons in one repel the electrons in the other, they form little bar magnets or dipoles, which then attract each other. And this is the van der Waals-London force. And a lot of the other… and it also shows how… membranes can form and even… and proteins can form. And anaesthetics bind by these same van der Waals-London forces between non-polar, polar, but polarisable electron clouds.

Here's the basic idea that the electron clouds are flipping back and forth, controlling the protein, and controlling the switching. Now, it's actually, as you might imagine, much more complicated. This is more work from Travis Craddock showing the location of the aromatic rings, just of tyrosine in the purple, and the indole or tryptophan in the blue, and there's actually pathways going through that can conduct quantum information, but I'll come back to that later. So it is a bit more complicated than having just one or two aromatic rings. So the idea for anaesthesia… well, the idea is that the electrons flip back and forth, control the state of the protein. And anaesthetics get in there and block that activity, and therefore block the activity of the proteins.

These structures, the opposite of the anaesthetic effect are drugs and molecules which get into those hydrophobic pockets of receptors, and enhance the electron resonance energy, and are hallucinogenic or psychoactive. And this includes serotonin, which is a neurotransmitter, dopamine, and chocolate, which is psychoactive as well as far more psychoactive compounds like LSD and DMT, which is characterised by Rick Strassman as the spirit molecule, because it induces what he interpreted as religious experience, I guess. But the point is that these work by the same sort of van der Waals-London forces by promoting the activity rather than impairing the activity.

It also gets us to the quantum level because the London forces are actually quantum processes. And so we've gone from the scale of the whole brain down to the level of quantum and we still haven't found consciousness, so let's keep going and see if we can come up with something. We have to deal with quantum mechanics now. Nobody really understands quantum mechanics. As Richard Feynman famously said, anyone who claims to understand quantum physics is either lying or crazy. But let's just see what we can say about it.

The world appears divided into two realms, described by two different sets of physical laws. Quantum is immaterial, it can be below the level of matter; co-existing possibilities, non-local, unified, connected, may have some ultimate truth, deeper levels of reality, spirit-like. Classical, which is our Newtonian world that we're familiar with, is material, Newtonian, definite, macroscopic, local, predictable, disconnected, maybe postmodern you might say; boring in some sense.

Four features of the quantum world. Quantum particles can exist in multiple possible states or locations simultaneously. This pointer could be here and here at the same time. Quantum particles which become separated remain connected over distance and time, this is quantum entanglement. So if I had two of these and separated them, and sent one over there and one over there, and measured one over there, if you went over there it would instantaneously react. Einstein didn't like this and predicted it would fail, but it didn't. It worked out. I'll come back to that.

Multiple particles can condense into one unified entity, quantum coherence, and uncertainty. So just to give some illustrations, for superposition, behaving like waves or multiple locations, here's an electron not over time but at one moment of time where it's in concentric rings inside this quantum well. That is one electron occupying these different rings. And here's an electron with a spin-up and a spin-down, which can be in both spin-up and spin-down at the same time. Quantum superposition.

Now, the superpositions also lead to entanglement and this is what Einstein didn't like. Here's two complementary, let us say electron spins. Spin both up and down, both up and down but they're complementary. You split them up, you send one to, say, Barcelona and you send one to Valencia, and you make a measurement in Barcelona. Instantaneously the one in Valencia has the opposite or complementary state. If this is down, this is then up. If this is up, this is then down, instantaneously many, many miles or kilometres apart.

Einstein predicted this wouldn't work, and so he published the EPR paradox in 35 with Podolsky and Rosen, describing an experiment. In 1985 this experiment was done by Alain Aspect, and it was shown to actually work. And since then, it has been done thousands and thousands of times. Zeilinger has done it between mountain peaks in the Canary Islands, fibre optics under the Danube, off of satellites, and so forth, and it works every time, it seems.

How does that happen? And the only explanation is that when you make a measurement here, the quantum information goes backward in time to where they were together, and then out this limb to carry this correlation. And backwards in time is allowed in quantum physics. And it has been done between satellites or as Zeilinger has done it, so distance doesn't seem to matter. Non-local action at a distance, what Einstein called spooky action at a distance.

The third aspect of the quantum world is that objects can condense into unitary objects, quantum coherence of Bose-Einstein condensation, governed by one wave function. If one component is perturbed, everybody feels it. So in this ring here, all these molecules or whatever they are, are perfectly in lockstep. They are acting like one entity, whereas the guys outside of it are random and chaotic. So this is like a laser, a Bose-Einstein condensate, where all of the components act the same, precisely the same. And this unity has been thought to mediate the unity of consciousness. Of course, there's only one of us inside our brain.

These quantum effects are using quantum information technology, quantum computers where information is represented not only as bits of one or zero, but also quantum bits of one and zero, superposition one and zero. The cubits communicate and collapse to an answer. Quantum cryptography, where the quantum states are transmitted by non-local entanglement. This is now used commercially. And quantum teleportation, where you communicate a state of a particle by non-local entanglement, destroying the original, and transporting it somewhere else.

I think most of us have probably watched Star Trek and saw beam me up, Scotty, which was presumably a form of teleportation. Nobody's done it for a whole person, and probably never will, but they have done it for small quantum particles and quantum objects. It does happen, although it may be limited.

But why don't we see quantum superpositions in our world? We only see one of these. We don't see things in multiple places in the same time. This question has been around since the turn of the last century, and your answer depends on your interpretation of quantum mechanics. It's almost different religions, actually. Now, one is that conscious observation collapses the wave function. This came from Niels Bohr and Eugene Wigner, who noticed that if a machine observes a quantum superposition, the results in the machine seemed to stay in both possibilities until a human actually looked at the results. They said that consciousness collapses the wave function; conscious observation.

Schrodinger didn't like that, he thought it was kind of silly. And so he came up with another thought experiment called Schrodinger's cat, where a quantum particle out here, outside this closed box, for example, a photon going through a half-silvered mirror, 50% probability. Since it is a quantum property, quantum particle, it both goes through and doesn't go through. It enters the box and doesn't enter the box. It releases the poison and doesn't release the poison. It kills the cat and doesn't kill the cat. Schrodinger said, if this interpretation is correct, until someone opens the box and looks, the cat is both dead and alive.

It was obviously bizarre but it was a pragmatic solution for Bohr, who wanted to do experiments. But it put consciousness outside of science. Consciousness became something weird, outside of science, you just bring it in when you need to collapse the wave function. We don't really know what it is. The other problem is that nobody's determined how big a quantum system can be, whether something as large as a cat can actually be in two states at the same time.

Another view of what happens to superpositions is the multiple worlds or parallel universe idea, where every time there's a superposition, there's a separation in reality, underlying fabric of the universe separates and branches off and forms a whole new universe. Here we see multiple overlapping universes, and this is actually a very popular idea, because it works out mathematically and is unmessy except for the infinite number of universes. There's also decoherence, which is what happens when the environment interacts, but we're talking about things that are isolated from decoherence.

And finally Roger Penrose came up with an idea that brought consciousness back into science. He said that a superposition will continue until it reaches an objective threshold for quantum state collapse, a reduction called objective reduction. And he defined the threshold as $e = h/T$, where e is the amount of superposition, so a larger superposition would have a greater e, and T is inversely related. So a large e will have a short T, and vice-versa.

For example, an electron, something very small in superposition isolated from decoherence, would eventually reach T after 10 million years. A long time. Something very large, like nanograms of tubulin in our brain, reaches threshold in 40 times a second, 25 milliseconds. So a large system such as the brain has evolved can have this happen fairly frequently. Roger proposed in his 1989 book, The Emperor's New Mind, that this was the origin of consciousness for reasons that get into Gödel's Theorem and many other things. And it is a relatively rare occurrence on the edge between the quantum and classical worlds, and is equivalent to consciousness.

He's saying that the superpositions are happening in the brain and the self-collapse is happening in the brain, so unlike the Copenhagen interpretation where consciousness is outside and collapses the wave function, the superposition, the dead cat and the live cat, are inside the head or inside the brain. We have a superposition of both or multiple possibilities, which go along and reach threshold and self-collapse, and we have a moment of consciousness. And that happens over and over and over and over again. That's the basic idea.

He was saying, it bears repeating, that consciousness is an actual physical process, a sequence of quantum state reductions connected by $e = h/T$ to an objective threshold to give rise to bing. In other words, consciousness is built into the universe, it is because that is what causes the collapse. Well, actually, I should explain that. Why does that cause collapse? Penrose took the problems of superposition seriously. Rather than trying to find a pragmatic solution, he asked the question, what does it mean for something to be in two states at the same time, or two places at the same time? Well, he went back to Einstein, who showed that the universe has an underlying structure which curves. Einstein talked about this for big objects like the sun, so the light would curve around the sun and you could see it. Arthur Eddington did that experiment proving that spacetime curved.

But Penrose said it also holds for small objects, small curvatures. For example, a tubulin protein in two different states is a curvature. So here we've taken spacetime into just two dimensions. We've got three dimensions on one axis; three dimensions of space, one axis of time. The tubulin, or anything in one particular conformation is curvature into the screen, and tubulin in another conformation is out towards us, and flipping back and forth is actually flipping between two curvatures in space-time geometry.

Now, if you have superposition, you have both of these, and you have a curvature towards us and away from us. You have basically a bubble or separation in underlying spacetime geometry. And this is what the multiple worlds theory says, too, that a superposition separates reality and branches off to form a whole new universe. But Penrose said, no, these separations are unstable, and after a certain time, T, they will collapse to one or the other, at this given time, T. And when that happens, that's consciousness. So it's like the multiple worlds except there's a threshold built in, because the separations are unstable. So when this happens, when T is reached, bing happens at this self-collapse, and either this one or this one is chosen.

Now, the other thing he put in, which is pretty significant, is that the choices of this one or this one are not random as they are with decoherence or measurement, but are influenced by information embedded in the universe; what he called platonic values. Here is quantum superpositions preceding and then a threshold is reached here, and the cycle begins again, in a piece of microtubule. And in our model the quantum states spread between neurons through gap junctions by tunnelling and therefore can go throughout the entire brain.

That is a summary of the model, the quantum computation and brain microtubules, which gives among other things the possibility for real time causality and free will. We were talking yesterday about the fact that activity that seems to correlate with consciousness happens after we've responded, so that people, most neuroscientists and philosophers say that we act unconsciously, on autopilot, and have a consciousness that's epiphenomenal and illusory after the fact. But with quantum you get the backward time effects, and I'll talk a little bit more about that in a second. It gives you the possibility for real time causal efficacy and free will. It also makes a connection to quantum space-time geometry.

Now, by the way, this is a picture from 1994, there's Roger, there's Dave Chalmers, there is me about to fall into the Grand Canyon there. We went there after the first Tucson conference, and this is where we started seriously developing our model. So the basic idea is we have a protein qubit which correlates with the spacetime qubit so a quantum computation happening in the microtubule in the brain is actually happening at the level of spacetime geometry in the brain, because spacetime is everywhere. You can't get away from it.

One conscious moment would look something like this. The quantum computing is in here, reaches threshold, there is an objective reduction and a moment of consciousness here at 25 milliseconds. It needn't be exactly that. Here it'd be normal experience, a series of these conscious moments at 40 hertz. If you add anaesthesia, they stop. If you're excited, they happen more frequently. Let's say you go from 40 to 60 to 80 hertz, maybe like the monks. If you're in an altered state, it goes even higher and faster, and your perception of the outside world would slow down. And you don't go to baseline, so you merge quantum information, dreamlike information, with consciousness in altered states. And dreaming would be something like that.

Here is the 25 milliseconds; bing, bing, bing, every 25 milliseconds. And notice that quantum information is sent backwards in time, so this can get us out of the problem of consciousness being epiphenomenal because of the backward time effects. Now, critics jump up. We have been criticised severely ever since even before we published our first paper, by critics who say all kinds of things. Including, well, everybody knows the brain is too warm, wet, and noisy for quantum effects because if you build a quantum computer in the laboratory, you have to do it at absolute zero to avoid decoherence.

We said, well, biology is pretty smart. Billions of years of evolution figured it out. They kept on criticising us, which was fine. But then the data started to come in, and show that actually warm temperature is not a problem for quantum coherence or quantum properties. For example, this paper in 2003 studied quantum spin transfer between quantum dots. So the green and the red are the quantum dots, and they're connected by benzene rings. The exact same structure that's found inside proteins, that is found in the hydrophobic pockets that are mediating the switching in tubulin. And if you measure the quantum spin transfer from dot to dot through the benzene, you get quantum interference. You get quantum superposition and quantum effects. And if you do that as a function of temperature through the benzene ring, you go from absolute zero. At about 70 kelvin there is a big jump and it persists out to brain temperature. So this quantum process is actually driven, and enhanced, and requires heat.

In 2007, papers started coming out about quantum coherence and warm temperatures in photosynthesis. And it turns out that plants utilise photosynthesis, they collect sunlight and transfer the energy to another part of the cell, by electron quantum coherence. With the electrons occupying all possible routes at the same time, so quantum coherence superposition in photosynthesis, providing all the food we eat or animals eat, which we then eat. This is really the key to life right here. Here's an article, Nature's hot green quantum computers revealed.

And the other thing that's even more exciting for me, anyway, is the work of Anirban Bandyopadhyay at the National Institute of Material Sciences in Tsukuba, Japan. He hasn't published this yet, but he's talking about it at meetings. He's being very careful. And he's already published in Nature, so he's got a lot of credibility. But basically Pokorny discovered megahertz coherence in microtubules, and using megahertz coherence to excite the microtubules, Anirban found quantum conductance in topological qubit at room temperature in microtubules. That hasn't been published yet, but when he does, it'll be very good news for our model.

Just to sum up where we are with the model, we've been criticised incessantly, but we're still out there. And actually things seem to be breaking in our direction in terms of incoming data. But it's still just a theory. I think it's the most complete theory, especially with the conscious pilot involved. Just a couple other things about it, is that, let's say you're making a decision, how would that look in terms of spacetime geometry?

You see a woman across the street, is it Amy, Betty, or Carol? Were you trying to decide what they had for lunch, shrimp, sushi, or pasta? So this could be algorithmic processing, but it could also be a superposition of all three possibilities. And for some reason, some intuition, you're not quite sure why, you decide that's Carol. Or, I think I just feel like having sushi. So this type of choice could be made by objective reduction with influence by these platonic values, which I'll come back to.

Now, the hard problem Steen Rasmussen was talking about the hard problem, of how you solve Chalmer's hard problem of phenomenal experience, and what we say is that the essence of experience is encoded in fundamental spacetime geometry. The conventional view would be, she looks at the rose, and there's a pattern of activity in her brain, and that gives rise to bing. What would we say is that happens, but also the essential feature of the rose is a pattern in spacetime geometry. Much more than three qubit, but and when, by entanglement, that is reproduced in the head, in her brain, so she has the exact same spacetime geometry configuration and captures the central phenomenology of the rose by having the same spacetime geometry. Essentially it's like having the rose inside her brain.

So again, why would that be conscious, though? And a number of people, including Penrose, and Freeman Dyson said that mind and intelligence are woven into the fabric of the universe suggesting that qualia, the essential features of conscious experience, might be part of the universe. So what is the fabric of the universe? Well, if we go down in scale, down every ten orders of magnitude, orders and orders of magnitude starting at the level of atoms, so from our scale down to atoms everything's kind of smooth and featureless until we get to the Planck scale, at 10^{-33} centimetres, where we have information, and coarseness, and irregularity.

Another way to look at it is starting on the level of protein to atoms, everything's kind of smooth and featureless. When you get down to about 10^{-32}, 10^{-33}, we start to see patterns and information irregularities. Now, what that looks like, actually, nobody knows for sure, but it's been approached a number of different mechanisms, through string theory, and loop quantum gravity. And the best guesses are the fine structure of the universe looks something like this. And they're actually pretty similar.

In both of them, you get down to volumes that have, on an average, once Planck length on a side. They could have multiple edges and multiple lengths, so the number of different voxels is vast, and so the way this is put together non-locally and holographically gives rise to spacetime geometry. Now, Penrose, Dyson, David Bohm, and we're going to hear about him in a moment, precursors of consciousness, life, and platonic values may be irreducibly embedded at this level, like mass, spin or charge. This is consistent with Buddhism, Vedic teachings, Shamyana teachings, the Akashic record in Hindu teachings. And again, Penrose said that platonic values are embedded in the Planck scale geometry, and influenced the choices, so that the choices can be influenced by platonic information.

To illustrate that, here's a robot windsurfer who's sailing, let's say to A, but the platonic values and spacetime illustrated by the wind here is going to push him or her to A or C every once in a while. You could think of this in the way of divine guidance or the way of the Tao, if you just allow yourself to be mindful and not act rashly or reflexively, you can be influenced by, you call it intuition, call it insight, call it whatever you want. But it could be platonic information embedded in the universe.

Now, is this really feasible? Information from the Planck scale? Actually, yes. Recently it's been shown that there may be information coming from the Planck scale already. There's a big gravity wave detector in Germany, British Germany GEO600 experiment, looking for gravitational waves from super-dense astronomical objects, which they haven't found yet. But they have encountered inexplicable noise which repeats at multiple spatial temporal scales, like the scale-free dynamics, and this guy Craig Hogan actually predicted that this would appear and then sure enough it did. And he says that the noise is coming from Planck scale fluctuations, and they suggest the universe is a giant hologram. And this information repeats in a self-similar way every three orders of magnitude from the Planck scale on up to getting within near the biological levels, and near to actually microtubule dynamics.

That is the model. I begin to wrap up here and put it in the context of spirituality, just to look at the distinctions between the quantum world and the classical world. The quantum world is multiple coexisting possibilities, the classical world definite. The quantum world, deep interconnectedness, isolated, disconnected, timeless, flow of time, access to universal mind in the dark, spiritual question mark, material. I think this is… this best fits with neutral monism, and I showed a picture of neutral monism earlier, where instead of some unspecified deeper reality, we have Planck scale space-time geometry, which ultimately does give rise to everything.

And depending on how the quantum collapse occurs, if it occurs by decoherence or measurement, you get matter. If it occurs by Penrose's objective reduction or by Orch-OR you get matter and mind. So this is how consciousness can arise in the context of neutral monism from one underlying entity, namely quantum spacetime geometry. The other thing it suggests is that consciousness is on the edge between the quantum and classical worlds, because you have the quantum world which self-collapses and more or less creates the classical world, so it's a process on the edge. I use the yin yang to illustrate this. Consciousness is literally on the edge between the quantum and classical worlds.

I want to talk a little bit about near-death and out-of-body experiences, because I'm in clinical medicine, and we hear about this a lot. And there have been a number of studies which show that when patients have cardiac arrests, 17% is the number I keep hearing, report near-death and out-of-body experiences. And actually people can have those spontaneously without near-death. And the phenomenology is a white light in a tunnel, that's very, very common. In some cases actually, out-of-body experience, so like this picture, she's waving goodbye to her body. And if the patient is resuscitated or revived, they go back inside and say, hey, I was floating around on the ceiling. And if they die, well, we don't know. But this has been reported so many times that it's really difficult to ignore.

Last year there were two studies that addressed this problem. One was by Lakhmir Chawla at George Washington University, who was studying terminally ill patients who were on ventilators and support for their blood pressure, pressers. So they were getting IVs to maintain their blood pressure and heart, and they were on a ventilator machine to breathe for them. And for various reasons they were hopeless and they and their family decided to terminate, to pull the plug if you will.

And Chawla has a protocol for allowing patients to die with dignity, and he used a brain monitor called a BIS or another called a SEDLine, that gives the EEG information zero to 100. And we use this in anaesthesia all the time. And 80 to

100 is where awake people are, where hopefully most of us are now. 80 to 100. Between 40 and 60 is where you want to your patients under anaesthesia. If they're between 40 and 60, the manufacturer will tell you that they won't remember and they're not conscious. And down here they're pretty close to brain dead.

In Chawla's study, and also in another study by David Owyang on patients who were allowed to die before giving up their organs, they put this brain monitor on and this is typical of what they found. They are down around zero, and by this time the heart has stopped. There's no blood pressure. And the BIS number, the brain monitor level has gone to zero, and then there's this burst of activity, which in this case lasts 20 minutes. Now, these lasted 90 seconds to 20 minutes. This is the longest one. And notice they are up around 90. They're up between 80 and 100, which is an indicator of being awake, of being conscious. And in one study they looked at the raw data, and it showed gamma synchrony EEG, suggesting that there was some kind of awareness.

Whether there was or not, we don't know, because these patients died. That was the point, their support was being withdrawn, but Chawla wrote about that, that this could be the near-death phenomenology, the… maybe even out-of-body experience. And who knows, maybe it's a sign of the soul leaving the body, we don't really know. But it's a mystery as to how the metabolically dead brain, which is acidotic, hypoxic, ischemic, has this burst of activity which is coherent and global. It can't just be a spasmodic discharge as some people said because the whole… it's coherent over the entire brain, in this case lasted 20 minutes. So we're going to be hearing more about this, because a number of other people are doing these types of studies on end-of-life brain activity. This is a quick video. I'm not sure it's going to work.

Basically that was a TV show called Miracle Detectives, which is going to be on the Oprah Network, and they were investigating a reincarnation case, and they asked me if or how it is possible that there could be life after death. Basically what I said was, under normal circumstances, consciousness is occurring in spacetime geometry in the brain, around the microtubules. When the blood stops flowing and the coherence is lost, the quantum information isn't destroyed, but can leak out or dissipate to the universe at large, but remain entangled as a soul, if you will, and persist indefinitely or go back in the body as a near death experience or maybe even reincarnation.

That gives rise to what could be called a quantum soul plausibility argument, where consciousness is seen as quantum entanglement and fundamental spacetime geometry. And this paradigm gives the following, which I think relate to spirituality: A connection among living beings and among living beings in the universe by entanglement; near-death and out-of-body; the possibility of afterlife and reincarnation; and the capability for wisdom and platonic ethical values in the universe to influence our choices.

Coming back to the original question, the origin of consciousness, the three possibilities, I would say I favour the last one, which actually kind of encompasses all three. I think the precursor of consciousness has been in the universe all along, but then at some point we animals developed the capacity for Orch-OR, or OR, to have conscious moments connecting to the fine structure of spacetime geometry. Which means that consciousness is really a self-organising process at the fundamental level of the universe.

He final point is a theory I just want to mention by Paola Zizzi, an Italian astrophysicist, who was studying the big bang and the period of rapid cosmological inflation. And during the big bang the universe expanded very rapidly for a very brief period of time and then stopped expanding rapidly and has been expanding slowly ever since. She used $e = h/T$, the equation for Penrose's objective reduction, using e as the mass of the universe, and as you might expect at a very short T, something like 10^{-33} seconds, which is when inflation ended. So she proposed that during the big bang, the universe had a cosmic conscious moment, which was dubbed the big wow by somebody else. In other words, it was an OR event that occurred at the origin of the universe.

I want to mention the conference we're having in Stockholm in May. Roger Penrose will be there and Deepak Chopra. We're going to have sessions on brain fields, consciousness in the universe, quantum biology, anaesthesia, end-of-life brain activity, transcranial therapies, time, backward time effects, and many others; and the varieties of religious experience, consciousness, reality in the universe.

To close, let me just say that I would say the precursors or components of consciousness, proto qualia or proto-conscious qualia, have been the universe all along as irreducible components of Planck scale geometry, along with mass, spin, or charge. They just came along with the territory. Quantum processes in biology evolved to best access and select proto-conscious precursors, so we do it better than lesser developed animals, I would say. And consciousness as a process rooted in fundamental spacetime geometry, plausibly allows for non-local conscious awareness, and spirituality and something like the quantum soul.

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