THE SIMPLE AND THE COMPLEX Part I: THE QUANTUM AND THE QUASI-CLASSICAL with MURRAY GELL-MANN, Ph.D.

JEFFREY MISHLOVE, Ph.D.: Hello and welcome. I'm Jeffrey Mishlove. Our topic today is "The Simple and the Complex." With me is Professor Murray Gell-Mann, the recipient of the Nobel Prize in physics in 1969 for his theoretical work which led up to the idea of the quark. Professor Gell-Mann is on the staff of the Santa Fe Institute, a think tank in Santa Fe, New Mexico devoted to the problems of complexity. His distinguished career includes 38 years of work at Cal Tech in Pasadena in the field of theoretical physics, as well as distinguished work in the environment, in foreign policy, and in science policy. Welcome, Professor Gell-Mann.

MURRAY GELL-MANN, Ph.D.: Very nice to be here.

MISHLOVE: It is a pleasure to be with you. In your book *The Quark and the Jaguar* you are looking at the relationship between the most fundamental and simple known physical units and some of the most complex adaptive systems that exist, from human beings to galaxies, and you find, I believe, similiarities. If we look at a jaguar we can see qualities that are reminiscent or evocative of what we might see if we could see a quark.

GELL-MANN: Well, I would say it a little bit differently from that. What I try to do in the book is to trace the chain of relationships running from elementary particles, fundamental building blocks of matter everywhere in the universe, such as quarks, all the way to complex entities, and in particular complex adaptive system like jaguars. And it's not so much similarities but the relationship between them that I explore. How do you get from elementary particles, each of which is absolutely identical to all the othersof its type anywhere in the universe -- a thing that has no individuality -- to the richly diverse and individual and complex entities that we see around us, and which we are ourselves?

MISHLOVE: One of the issues that you raise has sometimes been called the problem of free will, because, as I understand it, science conventionally doesn't like to think about free will. It resembles the idea of teleology too much, which I think is a forbidden notion in science. You suggest that perhaps the principle of indeterminacy, which occurs at the subatomic level, might be related to the free will which we seem to experience, and I would presume other animals might experience.

GELL-MANN: Well, I mention that. I must say my remarks about free will are not the place where my knowledge and understanding are best revealed. But I don't actually adopt the point of view that our subjective impression of free will, which is a kind of indeterminacy behavior, comes from quantum mechanical indeterminacy. I just mention it as a logical possibility. I say it's much more likely that it stems mainly from other things, and from rather simple things like partial information. If we look at the way the universe behaves, quantum mechanics gives us fundamental, unavoidable indeterminacy, so that alternative histories of the universe can be assigned probability. Sometimes the probabilities are very close to certainties, but they're never really certainties. And often the probabilities are quite distributed. As a result the alternative possible histories of the universe form a kind of branching tree. Jorge Luis Borges in one of his marvelous imaginative short stories imagined someone building a model of the alternative branching histories of the universe in the form of a garden of forking paths. Now, what that means is that there is fundamental indeterminacy from quantum mechanics, but besides that there are other sources of effective indeterminacy. A famous one is the phenomenon of chaos, one that's recently become famous. Of course the word chaos is used in rather a vague sense by a lot of writers, but in physics it means a particular phenomenon, namely that in a nonlinear system the outcome is often indefinitely, arbitrarily sensitive to tiny changes in the initial condition.

MISHLOVE: Perhaps even quantum mechanical fluctuations.

GELL-MANN: Exactly. Perhaps even little quantum mechanical fluctuations could be amplified by the classical phenomenon of chaos, to make very large changes in the output. Since you never know the input exactly, that gives a second source of indeterminacy. The third source has been known for centuries and understood for centuries, and that is simply that in predicting things one always has only partial information.

MISHLOVE: Right. We can never make precise measurements, for example.

GELL-MANN: In my rather naive remarks about free will, which are not the central theme of the book by any means, I mention that probably all these sources of indeterminacy contribute to our subjective impression of free will, and that it's most likely more of the last kind than it is of the first kind. In other words, when human beings act in certain ways and it seems that the acts are not predetermined and therefore there's an element of free will, perhaps more likely we're acting from hidden motives than because we have a quantum mechanical random number generator concealed within us. But the main point I'm trying to make is not my personal speculation about which of these is more important, but simply that I think questions like that can be phrased as scientific questions.

MISHLOVE: Well, that's very important, because for a long time the very notion of consciousness or free will or mind was sort of considered an unscientific area to begin with.

GELL-MANN: Yes, and it still is by many scientists, I think. A friend of mine who lives in this area and is very interested calls it the C word. In fact mind he refers to as the M word, and many scientists don't want to use either of them.

MISHLOVE: And how do you feel about that?

GELL-MANN: Well, I think they're perfectly reasonable words that a scientist can employ. Mind, after all, is the name we give to the phenomenological aspects of what the brain and related organs do, and consciousness is a real phenomenon which we don't understand very well, but it's certainly there, exists in human beings, and probably exists to some extent also in other organisms. One thing it appears to be is the following -- that thinking appears to be a parallel processing operation, with many different strands, but at any moment the spotlight of consciousness seems to be on some particular strand. So it's sequential.

MISHLOVE: Consciousness seems to be sequential.

GELL-MANN: Consciousness seems to be sequential, a spotlight which is sequentially focused on one thing after another in this set of parallel-processing strands --

MISHLOVE: Whereas we know the brain can process lots of things at once.

GELL-MANN: Right. And some of that, I understand from psychologist friends, can be reduced to experimental considerations. When you think you're listening to several conversations at once, they tell me, you may really simply be time sharing -- that is, listening a little bit to this one, a little bit to that one. And since conversation is somewhat redundant, you can fill in a little bit between moments of attention, and therefore apparently follow several things at once, whereas really you're switching back and forth.

MISHLOVE: Like a time-sharing computer.

GELL-MANN: Right. But, they say, if the people are talking nonsense, then you can no longer do that.

MISHLOVE: Aha.

GELL-MANN: Because the nonsense no longer allows interpolation.

MISHLOVE: You can no longer track.

GELL-MANN: Exactly. So presumably it can be reduced in that way to something experimental. But exactly what it is and how it works, and so on, we don't know. But it's reasonable to guess that since complex adaptive systems probably are present on planets scattered throughout the universe, in many, many different parts of the universe, and complex adaptive systems have the wonderful property of exploring new possibilities and trying out new possibilities and spawning new complex adaptive systems, and so on, that most likely in very many places they have produced something like consciousness, whatever it is.

MISHLOVE: You're not one of those who would maintain we are alone in the universe.

GELL-MANN: I certainly don't think so. But of course that's just my personal guess, based on what scientific evidence exists. Our planet doesn't seem to be the result of anything very special. You know, there was a time, just before I started to study physical science, when astronomers thought that systems such as we have here in the solar system required a rare triple collision of stars. At that time one might argue that perhaps planets like this, suitable to the evolution of complex adaptive systems, were very rare. But then shortly after that astronomical theorists reverted to the old idea of the condensation of planets from dust, just like the central star. When you have gravitational condensations the central star, in our case the sun, condenses, and so do the planets. That's not a difficult process, and presumably happens all the time. Astronomers are just beginning to get observational evidence now of planets elsewhere.

MISHLOVE: Yes.

GELL-MANN: But of course they're not near stars like ours, and they presumably aren't relevant to this question of the evolution of complex adaptive systems.

MISHLOVE: Well, we may not have adequate instruments.

GELL-MANN: Exactly. That's the reason. Planets are too dim to be detected with existing equipment, far away, except in these very special circumstances where they're seen by their gravitational effect.

MISHLOVE: In principle you're saying they ought to be there anyway.

GELL-MANN: It seems very likely, theoretically.

MISHLOVE: And the same kind of process of complexification that led to the development of life and civilization as we know it on this planet is likely to occur on other planets that have similar conditions.

GELL-MANN: That's what I would conclude, but of course we don't know for sure. That's certainly what I would conclude.

MISHLOVE: I'd like to go back to the discussion of quantum physics, because certainly that's one of your fields of great expertise. In fact I know you are involved in developing what you call the modern interpretation of quantum mechanics, which is important for people, because so many of us hear over and over again about the mysteries of quantum mechanics, but nobody seems to be able to really quite interpret it.

GELL-MANN: Well, there is an interpretation, developed in the 1920s when quantum mechanics was new, that is generally taught. It's sometimes called the Copenhagen interpretation, after Niels Bohr.

MISHLOVE: It's a hidden variable --

GELL-MANN: No -- not hidden variable. And that interpretation, my friends and I believe, while not wrong, is approximate and special. It refers to a situation in which some phenomenon is being studied which is reproducible, can be produced over and over again in a laboratory, it's being studied by a scientist with a piece of apparatus who is outside the system, and then quantum mechanics gives probabilities for the various outcomes of this situation, reproducible situation, and those are essentially the same as the proportions of the different outcomes over a long sequence of repetitions. But that's very special, and what we who are developing, in different parts of the world, the modern interpretation of quantum mechanics want to see, is an interpretation that allows quantum mechanics to be applied to the whole universe -- quantum cosmology, it's called. And in that case, obviously, you can't have an observer outside; you can't have results that are reproducible, and so on. Also it would be nice for quantum mechanics to apply to situations where there is a lot of complexity and a lot of individuality. It must apply in those situations. So the old Copenhagen interpretation needs to be generalized, needs to be replaced by something that can be used for the whole universe, and can be used also in cases where there is plenty of individuality and history. And so those of us who are doing it are concentrating on histories, histories of the entire universe -- alternative histories forming a branching tree, with probabilities at each branching.

MISHLOVE: Now, let me just interject for a moment, because I understand the key issue here is whether these alternative branching universes exist ontologically, meaning really exist, or whether they exist sort of in theory only.

GELL-MANN: Well, I don't like to get involved in these philosophical issues very much. I think there's been a certain amount of confusion as a result of that sort of discussion. One of the pioneers of this modern approach was Hugh Everett III, who was a graduate student at Princeton in the late 1950s.

MISHLOVE: Who worked with John Wheeler.

GELL-MANN: Worked with John Wheeler, and afterwards went to the Pentagon, where he was a member of the weapon systems evaluation group, and I believed stayed with that group until he died rather young, unfortunately. Hugh Everett's work has been described by many people in terms of many worlds, the idea being that every one of the various alternative histories, branching histories, is assigned some sort of reality. And that has confused a number of people, and led some scientists, actually, to reject this kind of approach to quantum mechanics.

MISHLOVE: For that very reason.

GELL-MANN: Yes, it's confused them. For instance, one very distinguished physicist, student of quantum mechanics, has said that he doesn't like any such approach, because if it were right, then you should be encouraged to play Russian roulette for high stakes, since in one of the equally real worlds you would win. Well, it's kind of silly, because we experience, of course, at every branching only one branch, and to talk about the others being real is confusing.

MISHLOVE: But these confusions and paradoxes seem to come up everywhere in quantum physics.

GELL-MANN: Well, I don't think it's necessary. I think one can try to reduce the amount of confusion, and also to reduce the amount of nonsense that's talked about quantum mechanics. I have a chapter in my book called "Quantum Mechanics and Flapdoodle," because people have talked a great deal of nonsense about quantum mechanics.

MISHLOVE: But these people, as I understand it, are some of the great physicists. You mentioned Niels Bohr.

GELL-MANN: I didn't say that Niels Bohr had said anything foolish. I said that his Copenhagen interpretation may now be regarded as partial and approximate, but not wrong.

MISHLOVE: I understand that.

GELL-MANN: And not foolish, either.

MISHLOVE: I certainly didn't mean to imply that. I think we would agree that he's one of the founders of quantum physics, and he's universally honored. But didn't he say that if you look at quantum physics and you don't get dizzy by it, you don't understand it?

GELL-MANN: Let's see if I can translate the sentence carefully. If someone says that he can think or talk about quantum physics without becoming dizzy, that shows only that he has not understood anything whatever about it.

MISHLOVE: Now, I understand that your approach is to sort of reduce that situation.

GELL-MANN: Yes. That's what we're trying to do.

MISHLOVE: That must make every leader -- I'm trying to think of the right word, because you're certainly in the forefront of your discipline -- all of the founders of the field must be very uncomfortable with that.

GELL-MANN: Well, I don't think people are so uncomfortable, actually. It's not the kind of scientific work that brings a great deal of honor, because at first people say that it's silly or wrong or unnecessary, and if finally you get something straight in this sort of work, then people say they knew it all the time. Nevertheless, we do it, because we think it's important to try to straighten out these ideas, and in particular to see how the rich, complex world that we see around us, which is quasi-classical, emerges from quantum mechanics. And back in the 1920s physicists thought they had more or less licked that problem, but we believe that it requires a lot more work, really to understand the relationship.

MISHLOVE: You talked about chaos theory earlier, and I thought that was very striking, because in my understanding many of the people who talk about the relationship between the quantum world and the classical world, the world of our sensory experience, say, "Well, there really is no relationship. These quantum uncertainties and fluctuations have no influence or effect in the larger world." But to chaos theory there seems to be a mechanism.

GELL-MANN: Well, that's not the way most chaos theorists look at it, actually. But I think it's a pretty good description of some interactions between quantum fluctuations and chaos. The chaos can act as a magnifier of quantum fluctuations so that they can produce sizable effects in the world around us. But we know that that can happen often. In fact any experiment that measures a quantum effect is one in which the quantum effect is aligned with the behavior of some heavy, macroscopic object; that's how we measure it.

MISHLOVE: The measuring equipment.

GELL-MANN: Right, and that piece of measuring equipment, that heavy, macroscopic object, is correlated with the quantum fluctation. If the quantum event goes one way, the apparatus shows one result. If the quantum event goes another way, the apparatus shows a different result. So it's very familiar to have large-scale events around us controlled by probabilistic quantum alternatives. It's not unusual. And when Schroedinger wrote about his hypothetical cat -- a cat that was poisoned if a quantum event went one way, and was not poisoned if the quantum event went another way -- he was talking about the same kind of thing. Likewise, in principle, although it's not very nice, you could arrange for a city to be blown up by thermonuclear weapons if a radioactive disintegration were to proceed so that an alpha particle came out to the right, whereas if the alpha particle came out to the left the city would not be destroyed. Since the two are equally probable, and there's absolutely no way of predicting which way it will go, it's a clear case of a quantum probabilistic event being coupled to some macroscopic thing.

MISHLOVE: The paradox here, if I understand it, is that in quantum theory the probabilistic event is sort of viewed as a probability function, or sometimes I've even heard the term a probability cloud. It's as if both true and false are occurring at the same time.

GELL-MANN: Yes, and that's what I think is very misleading, and my colleagues think is very misleading. In the Schroedinger cat story, for example, the part I told is very reasonable and simply illustrates that a probabilistic quantum event can be coupled to some classical change in the heavy, macroscopic objects around us. That's fine. But the other thing people say is, "Well, suppose the cat is in a box, and the quantum event occurs, but you don't know which way it went, and the cat is dead if it went one way and alive if it went the other, and so until you open the box and see, well, the cat is in some sort of funny quantum-mechanical, coherent mixture of being dead and being alive. That's very strange and paradoxical and weird, and so on." It isn't really true.

MISHLOVE: That was the point Schroedinger tried to make.

GELL-MANN: Well, I don't know exactly what he was after, but it's a point that people have belabored after Schroedinger, and I think it's not really a very good way to look at it, because a live cat certainly is in interaction with its environment. It's not isolated.

MISHLOVE: That's right.

GELL-MANN: Even the dead cat is in interaction with its environment. It's decaying, emanating various chemicals. The live cat of course is breathing and in contact with its environment. Even if the cat is in a box, the box is in contact with the environment. It's being hit by photons from elsewhere in the universe. It's radiating a certain number of photons because it's not at absolute zero; if it were at absolute zero it would certainly not contain a live cat. And so on and so forth. Therefore, whatever it is that we're talking about, it's in interaction with other things, and those other things are being averaged over and integrated over and not seen. And under those conditions, the two situations, alive and dead, decohere, as we say. There is no interference between them; they are simply alternatives -- just like the alternatives at the race track when either one horse wins or another horse wins; there's nothing mysterious or peculiar about it. And when you open the box it's no different from the experience that you may actually have of going to the airport and accepting a cat box and not knowing whether the poor animal is alive or dead until you open the box. It's exactly the same. The two situations are on different branches of history. They are not coherent with each other because of the interaction with the rest of the world that's averaged over.

MISHLOVE: This is very deep material. I can't claim to understand everything that you've said, Dr. Gell-Mann, but it seems as if you're saying the environment itself is affecting the situation.

GELL-MANN: Well, that's how the alternatives become decoherent with one another.

MISHLOVE: What does decoherent mean? We only have a minute now.

GELL-MANN: It means that you can assign a probability to each alternative, and you don't have interference terms that prevent you from assigning those probabilities. In other words, it means that the situation is no different from that at the race track.

MISHLOVE: OK, and a quantum system is coherent, which means you can't separate it out.

GELL-MANN: If you treat a system in too much detail -- too fine-grained a history -- then you will end up with these interference problems, and you cannot assign probabilities to such fine-grained histories, and you mustn't do so. You cannot discuss them as alternatives.

MISHLOVE: I suppose in summary one might say that the fine-grained, quantum world is really very, very different from the coarse world.

GELL-MANN: And the coarse world is the only one that can be dealt with, and the only one that is dealt with. The other one is just in the background.

MISHLOVE: Professor Murray Gell-Mann, it's been a pleasure getting into the intricacies of the relationship between the very small and the very simple, which turns out to be enormously complex, and the very complex, which somehow seems to be simpler. It's been a pleasure discussing this with you, and I hope for those of our listeners and viewers who are intrigued by this discussion, you will stay tuned for Part 2 of our program on "The Simple and the Complex." Thank you so much for being with me.

GELL-MANN: Thank you.