"I visualize a time when we will be to robots what dogs are to humans, and I'm rooting for the machines," says the founding father of the electronic communications age

INTERVIEW

CLAUDE SHANNON

Much to his discomfort, Claude Shannon, at seventy-one, is a living legend. What Louis Armstrong was to jazz, Shannon is to the electronic information age: a founding father who laid down its most important principles. His contributions are saluted by the world. Diplomas and prizes stretch along a wall and up a spiral staircase in his home. There would be a Nobel too, if one existed in mathematics. But Shannon has shunned fame. His face is so unfamiliar that when he arrived at a recent conference in Brighton, England, devoted to the field he founded, he was hardly recognized. In the dining hall a man cried excitedly, "Do you know who's coming? Claude Shannon!" as Shannon sat at the next table.

Not that Shannon is unsociable. Spared the cross fire of media inquiry, he cannot resist a joke, gadget, or prank. He is vividly remembered at Bell Labs for riding a unicycle up and down a long corridor, juggling all the while. One

PHOTOGRAPH BY BRIAN WOLFF

plaque on his wall is from the Whammo Company for his rocket-powered Frisbee.

Playful prankster or not, Shannon's discovery lit a beacon, and for decades engineers have steered into the future by its light. As a twenty-two-year-old MIT engineering student in 1938, Shannon first soared to prominence for his M.A. thesis, which Howard Gardner, the Harvard mind theorist, calls "possibly the most important master's thesis of the century." Shannon's brilliant, prizewinning paper demonstrated that the strict logic of Boolean algebra could symbolically represent the relay switching circuits used in telephone exchanges. (Boolean algebra is a branch of mathematics that represents relationships symbolically.) Essentially, "If the alarm clock rings and it is Monday, then you have to go to work" is the linguistic equivalent of "If switch A is closed and switch B is closed, then current flows to the motor." Shannon saw, then, that the relationship between electronic switches and currents could mimic the intellectual processes of symbolic logic and higher math. The insight was heroic. "You could now use mathematics to calculate if a design was correct, instead of using trial and error," notes Marvin Minsky, MIT's artificial intelligence guru.

Ten years later, while working at Bell Labs, Shannon published *The Mathematical Theory of Communication.* This masterwork provided electronic communications with a set of general theorems that formed the groundwork of "information theory." In a single stroke Shannon spelled out the principles of the signaling of information in concise, elegant math. It was a contribution of comparable significance to Newton's laying down the laws of motion for mechanics. Suddenly engineers had a language to deal with the major puzzles of telephone and radio communications: how to measure information and thereby fully exploit the capacity of telephone wires, microwaves, or fiberoptic cables as channels of communication.

What astonished engineers was Shannon's proof that however "noisy" a communications channel, you could always send a signal without distortion. If the message is encoded in such a way that it is self-checking, Shannon showed, signals will be received with the same accuracy as if there were no interference on the line. A language, for example, has a built-in error-correcting code. Noisy party conversation is intelligible partly because half the language is redundant. The extra symbols enable you to fill in what you miss.

Over the next 25 years Shannon's powerful codes yielded superaccurate communications hardware. Drag a knife point across the surface of a compact disc and error-correcting codes will mask the flaw, thanks to Shannon. *Voyager II*'s beaming back detailed pictures of Uranus and its ten newly discovered moons 1.8 billion miles to Earth is a tribute to Shannon's inspiration. So are the picture-perfect digital TVs and VCRs and compact discs on the home market. Information theory spurred the digital revolution, where information is sent in discrete bits rather than in the wave form of "analog" signals because Shannon's error-correcting codes work naturally in digital.

After writing his Ph.D. thesis at MIT on the mathematics of genes and heredity, Shannon joined Bell Labs in 1941 and during World War II worked on cryptography. A theorem of Shannon's was behind the SIGSALY telephone, the huge speech-scrambling apparatus that allowed Churchill to speak to Roosevelt from a special, toilet-size booth. Its coding system remains uncracked. Much to the regret of colleagues at Bell, Shannon returned to MIT in 1956. "It was a big loss," says Edgar Gilbert of Bell Labs. "He would grasp the essence of a problem immediately and come up with a totally different idea that shed a great deal of light on it."

Made Donner Professor in 1958, Shannon gave "beautiful" lectures, took a few

"Many things I've done I've never written up. Just lazy, I guess. I have a file upstairs of unfinished papers. But that's true of most of the good scientists I know."

select graduate students in tow, and refined information theory. By the mid-Sixties his preference for working at home became the rule. Borrowing Shannon's long-deserted office, a friend once found a sizable uncashed check more than a year old. Shannon retired in 1978, wealthy from investments in technological companies, some founded by his friends.

Not just a theorist, Shannon has always been fond of inventing and building gadgets and machines. His mechanical white mouse that, decades before the microchip, could learn its way through a maze has become legendary. A "mind-reading" machine anticipated whether a challenger would choose heads or tails. Colleague David Hagelbarger actually invented the prototype, but Shannon's stripped-down version, he says, outsmarted his own "more conservative and pompous design." Shannon's prankish side came out in the design of Hex. This machine, which played a board game, cunningly concealed the fact that it had an unfair advantage.

A visit to Shannon's large house, down a shady lane a few miles from MIT, suggests that his home life has not been dull. The house is filled with musical instruments—five pianos and 30 other instruments, from piccolos to trumpets. The chess-playing machines include one that moves the pieces with a three-fingered arm, beeps, and makes wry comments. A chair lift he built to take his three children 600 feet down to the lakeside has been taken down now that they are grown.

Shannon's lifelong fascination with balance and controlled instability has led him to design a unicycle with an off-center wheel to keep the rider steady while juggling, and a tandem unicycle that no couple has yet managed to ride. Today Shannon's keenest passion is juggling. In his toy room is a machine with soft beanbag hands that "juggle" steel balls. But his juggling-model masterpiece is a tiny stage on which three clowns juggle 11 rings, 7 balls, and 5 clubs, all driven by an invisible mechanism of clockwork and rods.

When writer Anthony Liversidge visited, Shannon was just back from Kyoto, Japan, where he had given a speech and collected an award in company with French composer Olivier Messiaen. He was quick to show off family photos, a computer printout of his stock portfolio, and all his toys. Betty Shannon, a math graduate who met her husband at Bell Labs, was his partner in the constant merriment.

***Omni*:** How many balls can you juggle?

Shannon: Four. At five I don't last very long! I get them up there, but catching them is a different matter!

***Omni*:** Did your genius come unannounced, or was there science and invention in your background?

Shannon: My grandfather was an inventor who had some patents—a washing machine, stuff like that. He was also very interested in determining the exact turn of the century: Was it 1900 or 1901? He owned a farm and was always inventing farm machinery. My father, Claude, was judge of probate in Gaylord, a little town of about three thousand in Michigan. If you walked a couple of blocks, you'd be in the countryside. Here is a picture of me playing the E flat alto horn in the town band. Here's my mother, who was principal of the high school in Gaylord. She was very intelligent. My father was clever mathematically and knew what he was talking about, although he didn't work in the field.

There was not much scientific influence from my father. He was a little distant, although he helped me when he could. I used to work with Erector sets. A friend of mine and I had a telegraph system between our houses, half a mile away, and we built the parts for this line for Morse code signaling. Later we scrounged equipment from the local exchange and connected up a telephone. I was always interested in building things that had funny motions, but my interest gradually shifted into electronics.

***Omni*:** Funny motions?

Shannon: Yes, like those dancers in burlesque theater I saw as a young man! They had an especially interesting motion. Cheap joke!

Omni: When were the Erector sets?

Shannon: In the seventh grade or so. After Betty and I got married, I said I'd always wished I'd had a number ten Erector set [the most complex set available]. She gave me one for Christmas!

Betty Shannon: I went out and got him the biggest Erector set you could buy in America. It was fifty bucks, and everyone thought I was insane!

Shannon: Giving it to a grown man! But it was really extremely useful—I used it to try out different ideas. Now I have a number ten Meccano [British version of an Erector set] and two others as well. I am always building totally useless gadgets just because they're fun to make. They have no commercial value but may be amusing.

Omni: Their "uselessness," then, doesn't really bother you?

Shannon: That would be the *last* thing! Here's a picture of me riding a unicycle and juggling at the same time! That was more than thirty years ago. You wouldn't believe the number of unicycles we have in our garage, along with similar wheeled vehicles of very odd types.

Omni: You once created quite a stir by juggling while riding a unicycle through the corridors of Bell Labs!

Shannon: Yes, I did! Those people are very far-out, but this was something that had never happened in the halls before. I worked at Bell Labs for fifteen years and then was a consultant. I found it very good. To begin with, you could work on your own ideas. They didn't come and say, "Work on this!" At least, not to me. The people in my mathematics research group were all very bright and capable, so I got a lot of interaction [feedback, discussion] about things I was working on. Had I been in another company aimed more at a particular goal, I wouldn't have had the freedom to work that way.

Omni: William Shockley, one of the inventors of the transistor, was at Bell Labs when you were there. Did you know him well?

Shannon: I walked into his office and he had this little object on his desk. I said, "What's that?" "It's a solid-state amplifier," he said, explaining that it amplified like a vacuum tube. This was the transistor in its first state. Right there I got a grasp of its importance because of its small size. I consider Shockley, his team, and John Bardeen to be the creators of the most important invention of the century.

I did most of my best work while I was young. Looking at the history of great scientists, such as Newton or Einstein, you find that their greatest creative work was done usually between twenty and fifty.

Omni: Did you always feel that you were destined for fame?

Shannon: I don't think so. I always thought I was quite sharp scientifically. But scientists don't generally get the press of politicians or authors. They have a limited audience of mainly other scientists. Even so, I thought my paper on switching was quite good, and I got a prize for it. I thought my information paper was very good, and then I got all kinds of acclaim for that, I tell you—a wallful of prizes and stuff in the other room. Ha-ha-ha! And sometimes I get asked to make speeches. I really don't like giving speeches, but sometimes, I suppose, I owe it to my public, so to speak!

Omni: Why not make the same speech over and over again?

Shannon: I sort of do, but I forget it and have to write it again. It's no fun to make the same speech twice. I spent quite a time trying to write a speech for the Japanese. What the hell did I say? I don't remember! Ha-ha-ha! I guess it went down well. Everything was translated into three or four languages. Most of the audience was Japanese, and I was speaking in English. Being very polite people, they would have clapped if I had read the Lord's Prayer.

During my little speech in Brighton last year, I was getting no reaction at all from the audience, so I pulled out these three balls and started juggling. Suddenly everyone looked up. There was great excitement, though that's the most trivial thing in the world!

> *"This motorized pogo stick is gasoline driven and has a piston that fires each time it comes down. You go along at great velocity, but I found it very uncomfortable."*

Omni: Have you ever analyzed juggling mathematically?

Shannon: I wrote a paper for *Scientific American,* which I'm still revising. My theorem relates how many balls you are juggling to how long each one is in the air. In uniform juggling, the ball stays in the air the same amount of time, and when it hits your hand it stays there for the same amount of time. I visualize a person with not just two, but several, hands juggling. You could even have several different people juggling simultaneously. My theorem relates five quantities: the number of hands; the number of balls; the time your hand is empty; the contact time; and the flight time of the balls. These five things all connect in a very simple relationship, which would be exciting to nobody except a few mathematically inclined jugglers. Ha-ha! Juggling relates to patterns. There's a topology and a combinatorial aspect to it that mathematicians find interesting.

Omni: Would your theory lead to a way of juggling more objects than ever before?

Shannon: The more balls you juggle, the higher you have to throw them in order to get more time. This theory indicates how much higher you have to throw the balls, depending on the number you are juggling. I've measured jugglers with a stopwatch and observed how they juggle seven balls, a very hard thing. They have to throw them very high. I even put metallic strips on jugglers' hands and had them juggle metal-covered balls so they'd close a contact when holding the balls. Then I ran these data into electronic clocks that measured the time, and checked this all out.

Omni: Why haven't you commercialized your three juggling clowns?

Betty Shannon: Oh, fiddle!

Shannon: Well, there wouldn't be too much of a market.

Betty Shannon: We don't believe in commercializing fun.

Omni: You have quite an array of computerized chess machines in your toy room. Do you still play chess?

Shannon: I don't play at all.

Betty Shannon: He used to play very well. Good enough to play Mikhail Botvinnik in Moscow. Claude, by God, got the exchange [got ahead]. Botvinnik was worried. Botvinnik finally pulled it off, but it was really very close.

Omni: Where did you find all your chess machines?

Shannon: At this store in Los Angeles.

Betty Shannon: Claude went hog-wild!

Shannon: Yes, I actually bought one of each. Ha-ha!

Omni: Do you find it depressing that chess computers are getting so strong?

Shannon: I am *not* depressed by it. I am rooting for the machines! I have always been on the machines' side. Ha-ha!

Betty Shannon: Some people get livid when he says that.

Shannon: I am not depressed by machines getting better. Whether people will be replaced by machines that have gotten smarter in all things, I can't say. Within a century or so, machines will be doing almost everything better than we can. They already do factory work better than we can, but the highly intellectual stuff is going to come later. It gets harder and harder as you get higher and higher in this game.

Omni: Do you agree with Norbert Wiener's denial of any basic distinction between life and nonlife, man and machine?

Shannon: That's a heavily loaded question there! I am an atheist to begin with. I believe in evolutionary theory and that we are basically machines but of a very complex type, far more so than any machine that man has made yet. So that's both a yes and a no. *Mechanical* doesn't just mean that metal and gears are involved, of course. We are the extreme case: a natural mechanical device. I see no God involved.

Omni: Will robots be complex enough to be friends of people?

Shannon: I think so. I myself could very

easily imagine that happening. I see no limit to the capabilities of machines. As microchips get smaller and faster, I can see them getting better than we are. I can visualize a time in the future when we will be to robots as dogs are to humans.
Omni: Can you imagine a robot president of the United States?
Shannon: Could be, but I think by then you wouldn't speak of *the United States* anymore. The world will have a totally different organization.
Omni: Is it a big leap from the pedestrian routines of today's chess computers to machines that could grapple, seemingly in a creative, intuitive fashion, with the problems of higher mathematics?
Shannon: I see computers proving theorems that have been sitting around that nobody's proved. I don't yet see them *creating* theories, that is, discovering a new branch of mathematics, as many great mathematicians have in the past. That's a broader, wider thing—more like writing a play—and will be a lot longer in coming.
Omni: Is your famous proof that a reliable circuit can be built from unreliable components relevant to the brain's operations?
Shannon: The brain can suffer all kinds of damage and yet can still handle things pretty well. It must use some redundancy to take care of faulty operations, such as the death of certain neurons. The modern desk computer generally has no redundancy, so if one part gets into trouble, that will show up in later operations. That we manage to live in spite of all kinds of internal troubles suggests the brain's design involves a great deal of redundancy or parallelism of multiple units.
Omni: Your paper shows that if the relays closed only sixty percent of the time when triggered, you could still have highly effective circuitry. Could the brain be using such an approach?
Shannon: That the brain has ten billion neurons probably means it was cheaper for biology to make more components than to work out sophisticated circuits. Yet I am totally astounded at how clever and sophisticated some of the things we see in human or animal bodies are. Such long-term, sophisticated changes could be what happened in the brain, but an easier way would be to use paralleling and multiplication to reduce errors of individual neuron operation. And when it all gets going, we have these clever people like Einstein.
Omni: Some recent experiments with rats suggest that the brain responds to stimulation even in old age, and there isn't an obvious reason why the brain shouldn't operate as well later.
Shannon: Did they ask those rats a hard mathematical question? Bit of an extreme extrapolation to humans, especially to people who are creative when they are young and all that.
Omni: How did you get to MIT?
Shannon: After I got my bachelor's from Michigan, I wasn't sure what to do. This little postcard on the wall said MIT wanted a research assistant to run the differential analyzer, a machine Vannevar Bush had invented to solve differential equations. I applied for the job and spent the next four years at MIT.
Omni: What in fact makes up the differential analyzer?
Shannon: The main machine was mechanical, with spinning discs and integrators, and there was a complicated control circuit with relays. I had to understand both and work on them. The relay part got me interested. I knew about symbolic logic and realized that Boolean algebra was just the thing to take care of relay and switching circuits. I got all the books I could on symbolic logic and Boolean algebra, started interplaying the two, and wrote this master's thesis. That was the beginning of my great career! Ha-ha-ha!
Omni: You saw the connection between a relay circuit and Boolean algebra. That was quite an inspiration!
Shannon: Oh, it's trivial—once you make it! The connection is not the great thing. The more important, hard part is working out the details, like how to interleave the topology of the switching circuits and how contacts within the circuits are connected with the Boolean algebraic expressions. That was a lot of fun, working that out. I had more fun doing that than anything else in my life. It worked out so well that when I finished, it was shown to people there. Vannevar Bush, then vice president and dean of engineering at MIT, was very impressed and wrote a recommendation to get it published.
Omni: Was your basic insight that yes/no can be embodied in on/off switches?
Shannon: It's not so much that a thing is "open" or "closed"—the "yes" or "no" you mention. The real point is that two things in a series are like the word *and*, whereas two things in parallel are like the word *or*—"this *and* this" versus "this *or* this." Some contacts close when you operate the relay; others open. All those things together form a complex connection between Boolean algebra, if you like, or symbolic logic, and relay circuits.

People working with relay circuits knew how to make these things, but lacking a mathematical apparatus like Boolean algebra, they weren't very efficient. Much of my work used this math to minimize circuitry, to get the smallest number of contacts.
Omni: A supposedly major mathematician criticized your treatise *The Mathematical Theory of Communications* as lacking mathematical honesty because your results weren't proved, he said, with mathematical rigor—i.e., with the complete generality mathematicians like. How did you react to his hostile review?
Shannon: I didn't like his review. He didn't read my work carefully. You can write mathematics line by line, with each tiny inference indicated, or you can assume the reader understands what you are talking

about it. That's what I did. I was confident I was correct—both intuitively and rigorously. I knew exactly what I was doing, but maybe it takes people a little brighter to understand it. You can always find new proofs of things, better proofs, shorter proofs; and some of those things went on later at MIT.

Omni: What impact did your information theory have on the field of communications engineering?

Shannon: On the philosophical level, one is able to understand the communication process by measuring information in so many bits or choices per second. On the actual operational level, it enables you to combat noise and send information efficiently by working out the right amount of redundancy to decode at the receiving end, despite noisy communication.

Omni: In the Fifties you criticized people for applying your ideas to fields other than line communications. Recently, in the book *Grammatical Man,* Jeremy Campbell has again suggested that they may be widely applicable. Are you as skeptical now as you were then about such attempts?

Shannon: I am, and always was, interested in information theory in the narrow sense of communication work. It's possible to broadly apply the term *information theory* to all kinds of things, whether genetics or how the brain works or this and that. My original ideas were related to coding information for transmission, a much narrower thing. But some of these applications may be valid. For example, animals and humans transmit information along nerve networks. And the nervous system isn't very precise and accurate. It is a noisy, redundant system.

Something similar happens in the social system, where we have lots of aids to communication. If you're talking to me, I might say, "What?" This is a feedback system to overcome some of the noise and get correct transmission. I see it like that frequently, all over the place, mostly crude systems—not scientific or mathematical.

Omni: Does information theory hint at how complex life forms might have evolved, seemingly in the face of the second law of thermodynamics, which says order is slowly disintegrating?

Shannon: The evolution of the universe is certainly a very puzzling thing, to me as well as to everybody else. It's fantastic we've come to the level of organization we have, starting from a Big Bang. The second law of thermodynamics is not so simple as to say that from that Big Bang you couldn't get anything more than disorganization. There's a lot of energy there, so you can get local organization at the cost of overall increase of entropy. I've puzzled many hours about the gradual organization of life, the structure of knowledge, and all the things we humans have. It's the most incredible thing! I'm not a religious man, and it would not help if I were!

Omni: Would you say information theory is a substitute for belief in a God?

Shannon: I certainly would not! While I may be a proponent of information theory and a great believer in it, other theories can be developed to show how an overall increase in entropy as time goes on can produce order in certain subsets of the universe. The steam engine, for example, uses disorganized heat energy to produce organized mechanical energy but only at a certain cost. Entropy is the overall "price" the universe pays to produce all these wonderful things.

Omni: Has your ambition waned at all?

Shannon: I was never motivated by the notion of winning prizes or the desire for financial gain. My motivation in science has always been curiosity about something: How is it put together? What laws or rules govern this situation? Are there any theorems one can prove about what one can or can't do? After I had found answers, it was always painful to publish, which is where you get the acclaim. Many things I have done and never written up at all. Too lazy, I guess. I have got a file upstairs of unfinished papers! Ha-ha-ha! But that's true of most of the good scientists I know. Just knowing for ourselves is probably our main motivation.

"The simplest mirrored room is a cube where you'd see an infinite series of yourself receding into the distance. But tetrahedra would yield more interesting patterns."

Omni: Your success in the stock market obviously hasn't diminished your desire to work hard.

Shannon: Certainly not—and we were very successful, too. I even did some work on the theory of stocks—again not published, although everybody wants to know what's in them! Ha-ha! Some twenty years ago I gave a talk at MIT outlining some math on this subject. To this day people ask about it. Just last year when we were over in Brighton, more than one person came up and said, "I heard your talk at MIT about the stock market!"

Omni: Your stock market success was based on mathematics?

Shannon: Mathematics and some good friends! More important thing, that. One of my good friends since college days was Henry Singleton, head of Teledyne. When he started his company he asked if I'd like to invest. We put as much as we could into Teledyne, and it has gone off like crazy. That was in 1961. We had already had one good experience with Bill Harrison, because Harrison Laboratories merged with Hewlett Packard in 1953. We've had quite a few things like that. We do study graphs and charts, but the mathematics is not as important, in my opinion, as the people and the product.

Omni: What was the lecture at MIT about?

Shannon: The best way to balance a portfolio; the optimal amount you should have in different stocks to maximize the logarithm of the current value of the portfolio. But if you make money, it becomes very painful to sell that stock because you have to pay a capital gains tax. This tends to negate all the theoretical thinking! People always look at the stock price when they should study the basic company and its earnings growth. There are many problems with stochastic prediction [involving random probabilities] of stochastic processes, especially in relation to the earnings of companies. When we consider a new investment, we look carefully at the earnings of the company and think a lot about the future prospects of the product. We're fundamentalists, not technicians.

Omni: Haven't you been lucky?

Shannon: Far beyond any reasonable expectations. Economists talk about the efficient market, where everything is equalized out so that nobody can really make any money. But I don't believe that's true. These are our current stocks [Shannon produces computer listings]. The annual growth rates are punched out every night by our machine, a prehistoric Apple II that Steve Jobs [one of Apple's founders] wired together himself.

The annual compounded growth rates of our stocks here since we bought them, most quite a few years ago, are thirty-one percent a year, eleven percent, one hundred eighty-five percent, thirty percent, thirty-one percent, one hundred eighty-one percent, ten percent, eighteen percent, one hundred fourteen percent, twenty-one percent, two percent, and twenty-seven percent. Ha-ha! That's our holdings—the whole list.

Omni: Which companies do you see as the big gainers there?

Betty Shannon: Ecology, a spinoff from Teledyne, has gone up like crazy. But we've only had it for a year and a half. The other is Kyocera. I bought it because the man who runs the company donated the Japanese prize that Claude recently was given. When I looked at the thing, it sounded interesting. And he sounded like a real hotshot laddie, so I went out and bought a little bit, and it's been going *zoomp*! That's luck! Kyocera makes ceramics—all kinds of electronics.

Shannon: We've held Teledyne for twenty-five years, and it's compounded twenty-seven percent a year. The difference between going up twenty-seven percent and ten percent, like you might get in a bank, is incredible over a twenty-five-year span. [$100 compounded for 25 years at 10 per-

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cent is $1,083.56; compounded at 27 percent, it's $39,364.72.—*Editor*]

Omni: Is there a future to using math to predict fluctuations in stock prices?

Shannon: I think it is easier to predict which of the companies are going to succeed than to predict short-term fluctuations, things lasting only weeks or months, which they worry about on *Wall Street Week*. There is a lot more randomness in that unpredictable things happen that cause selling or buying pressure. If you get into the short-term thing, you keep paying short-term capital gains. With a long-term thing, you may never pay taxes because you keep it forever.

Omni: Given your fondness for gadgets, it seems odd that you don't relish playing with computers.

Shannon: Feeding programs into a computer is kind of dull. Designing computers is more to my taste, but I haven't felt much like it lately. I guess I've had a bellyful of that general game. I do like the physical aspects of these things, but mathematics itself involves symbolics. I've often worked on problems and theorems that never had a physical object.

Omni: Did you make the motorized pogo stick hanging in your garage?

Shannon: I bought it from a guy in New Jersey, who made it. It's gasoline driven and has a piston that fires each time it comes down. You go along at great velocity. Ha-ha. But I found it very uncomfortable. It was quite a shock each time the piston exploded.

Omni: What became of your project to use a computer and radio to win at roulette in Las Vegas?

Shannon: The thing worked very well here in the house. The roulette wheel—a real professional one—is up in the attic now. The predictor would indicate which half of the wheel the ball was going to fall into. It had a much better than fifty–fifty prognosis. Two thirds of the time it would predict the right half of the wheel, so you would win at a very good rate if you kept playing.

This partly depends on the fact that wheels in Las Vegas and elsewhere are tilted. We examined many wheels and could see some of them were tilted quite strongly. If you play any of these, there's a strong probability that the ball will fall out in a certain segment of the outside of the wheel. And you can tell quite well how long it will take for that to happen. The wheel is going around one way, and the ball is going around the other; so by timing the spinning of the wheel, you can determine where it's going to be when the ball falls in. It's a very simple dynamic system with little friction.

Omni: Wouldn't you have to consider the strength of the croupier's throw?

Shannon: Our device timed both the wheel and the ball. The person standing there would press a button when the wheel was spun and the double zero went by a certain point and again when the ball was thrown, passed a certain point, and came around again to that point. So even if the croupier threw the ball at different speeds, that was calculated into the prediction. Both the speed of the wheel and the moment the ball left the croupier's hand were evaluated by our little computer. But we had a lot of practical problems, and we never really made any money. Had we been willing to spend another month cleaning up details, we probably would have won.

Omni: You once wrote that the redundancy of a language determined whether it could have crossword puzzles; and since English has a redundancy of about half, it couldn't be used for three-dimensional puzzles. Right?

Shannon: Yes. You can't build big ones in three dimensions. There are so many constraints among the letters of a single given word that tie it together. In English it gets even harder to find other words that will tie it together in a two-dimensional pattern. A fortiori, if I may use another English word—ha-ha—it gets even harder to tie them together in three dimensions.

Omni: If you were funded, could you build a robot that rides a bicycle?

Shannon: Oh, I have already built little bicycle riders. I have one four inches high that rides a tiny two-wheeled cycle. That's almost trivial. I worked on a little mechanical unicycle but never got that working.

Omni: Is it true you investigated the idea of mirrored rooms?

Shannon: Yes, I tried to work out all the possible mirrored rooms that made sense, such that if you looked everywhere from inside one, space would be divided into a bunch of rooms, and you would be in each room, and this would go on to infinity without contradiction. That is, you'd move your head around, and everything would look sensible. I think there were seven rooms. I planned to build them all in my extra room here and give people an exciting tour. The simplest case would be a cube where you would just see an infinite series of yourself receding into the distance. All of space would be divided sensibly into these cubical patterns. But other ones, like tetrahedra [four-sided solids] and so on, yield much more complex and interesting patterns. I will build them if I can finish all my other projects!

At the moment I'm working on another juggling machine, which might juggle five balls. I'm using an air hockey table [a game in which pucks travel on cushions of air] and plan to juggle discs by tilting the table.

Omni: What would you say is your secret in remaining so carefree?

Shannon: I do what comes naturally, and usefulness is not my main goal. I like to solve new problems all the time. I keep asking myself, *How would you do this? Is it possible to make a machine to do that? Can you prove this theorem?* These are my kinds of problems. Not because I'm going to do something useful.