Oral History of Judea Pearl

A.M. Turing Award Winner, 2011

Interviewed by:
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Brock: Well, I'm very pleased to say that I'm sitting here with Judea Pearl on July 26th, 2022 in Los Angeles. I'm David Brock. And this is an oral history interview as part of the ACM History Committee's Turing Award Project. So, Professor Pearl, thank you once again for agreeing to do this with us. And to begin at the beginning, I believe you were born in Tel Aviv in September of 1936.

Pearl: Perfect, yes. I remember that it was Tel Aviv, 1936.

Brock: And could you tell us a little bit about your family background and how your family came to that area?

Pearl: Okay, my family came from Poland. My father and his family came in 1924 when it was open border. It was in the first few years of the British Mandate, and they really encouraged Jewish immigration to Palestine at that time. My father and his family came there and established a Biblical town, in the sense that they bought the land from a real estate agent in Jaffa, and they found a place seven-and-a-half mile northeast of Jaffa called Ibn Ibraq, which was the Arabic name for an ancient Biblical town named Bnei Brak. They found it -- to be a few hut-houses and a few scattered trees according to the newspaper at the time. And they tried to establish a religious cultural town, okay? Which was unique at the time. Agricultural town, yes. And they grew radishes, and they grew cows and they sent my grandfather to Damascus to buy good cows, not those cheap local cows. And he returned bloody with one cow, and so on -- there are long stories of how they established my hometown. There wasn't a hospital in my hometown, so my mother went to hospital in Tel Aviv to give birth to me. Well, my mother, I should say came later in 1935, where Hitler’s hand was already on the wall and millions of Jews flocked the British consulate in Poland to get a certificate to come, but the British locked the door in 1935 already. They only gave 15,000 certificates per year, and she managed to come because my father went to Poland as a British subject, so he was able to bring a bride. He was a very sought-after bachelor having British subject status. And so, despite his dark skin <laughs> and his, I will say, lack of education. He wasn't academician. He was a farmer, right? He actually went to Poland to find a princess, which was my mother. So, she managed to come back in 1935. I say "come back" because she left her family over there and their fate was dictated by the British White Paper. She lost all her family there.

So, I was born in 1936 in that town, and I was treated with a silver teaspoon in my mouth because I was supposed to be the New Jew, who doesn't know about antisemitism, who doesn't know about the Diaspora, I was going to be the embodiment of the Free Jew. So, I haven't learned about the Holocaust and what's going on in the war during which I grew up. When I was about, I would say six or seven years old, I found my mother crying in the kitchen. And I said, "What's going on?" She said, "Well, you know, there's a war in Europe." I said, "So what? Wars come and wars go," and we go on. And she said, "No, this is a different kind of a war." And I couldn't understand what she's talking about. I understood it only later. But to come to back to the topic, I was really treated as a prince. Not only me, my whole generation were treated as special, because we grew up in the period where there was a new nation born. And everything that was done there was with the idea that, "We are creating here a model society which never existed before and it's going to be a light for the nations." And it turned out to be a light to the nations, but that's a separate story. <laughs> We will go there later.

So, and I got a very, very good education. Excellent education. Because my teachers were professors that came from Germany, from Heidelberg and Berlin and they couldn't find a job in academia, so they became teachers in high school, and they saw in us the embodiment of their dreams, of their scientific dreams. So, they invested in us everything that they had. And they had a lot! Each one of them was a polyglot, who could talk without notes on any subject, from the economy of Manchuria to the proof of Pythagoras' Theorem, okay? So, I was lucky with the rest of my generation to have this educational experiment, which was unprecedented.

Brock: Do you think that those professors of yours from high school shared that same-- in addition to kind of shifting their attention to you as their new pupils, you know, with the change in their careers-- do you think that they also shared that same sense that your family and your community had about this generation of young Israelis?

Pearl: Oh, of course!

Brock: Yeah.

Pearl: I should say everybody in that period was fully active in the act of creating a new state. There were, when I was born, there were-- I would say about 450,000 Jews under the British Mandate at that time. And we all had one mission. To get the European Jews out of Europe. One mission. And to build in the infrastructure for a new state. The infrastructure was already prepared in 1935 when I was born. I didn't see any deficiency in any of the infrastructure capabilities or facilities that you have today in California. In the sense that education, water supply, electricity, health care -- all the facilities were already created. Government structure, okay. Everything was available, ready for a new state. And everyone's mind, okay, was focused, directed, committed I would say, to one and only one mission. That is, to create a model state, to create a home for the people who were stranded in Europe. We used to sing in the bus as we went to summer camp. We used to scream and scream, "Down with the British government! Down with the White Paper! Hebrew state!" And "Free immigration." <speaks Hebrew> I can cite it to you in Hebrew if you want to hear the screaming of 11 year old boys in the bus, okay? <sings in Hebrew> Okay? You can cut it off. <laughter>

Brock: No, absolutely won't cut that off. What was the language spoken in your household?

Pearl: Oh, the language was very interesting. My language was Hebrew. Everything was in Hebrew. Yiddish was another language spoken by the old people who couldn't make the transformation. Spoken by my parents, too, when they didn't want us to understand. But I learned to understand Yiddish very quickly. They spoke then Polish when they really didn't want me to understand what they're saying. So, that was the language. The language in school was Hebrew. That was a decision that was made already in 1913, I should say, when the Technion was founded. They had a committee, plus they had a controversy that everybody took part of, how should they teach technical material, okay? You know, there were no technical terms for things like electron and proton and neutrinos. And the country was in uproar and the decision was made in 1913 to teach in Hebrew. Even in the Technion. Even though most of the teachers were German and spoke only German. Actually, the Technion was not established until 1925, okay. The building was built in 1925, but the decision was made in 1913 that the language will be Hebrew. And indeed, I learned all the terminology. Some of the terms were translated into Hebrew, like transformer was *shanai*, and other things. Transistor remained "transistor" because I think the Hebrew name was too cumbersome. So, a few terms remained in English and all the classes were in Hebrew, yeah. Now, to come back to your question, our teachers were devoted and committed to this idea that they are preparing a new generation and that the future of the model state lied in science. More generally, in excellence in science and in art and entrepreneurship; they are preparing a generation for a model state. Yes, that was the psyche at the time.

Brock: I wanted to-- another question about your household. Oftentimes there are like very strong themes in a household, like education, or religion, or politics. And I just wondered what mix of themes were in your household. I saw, for example, a reference to the fact that I believe that you went to an explicitly socialist kindergarten.

Pearl: Yeah, yeah.

Brock: So, was-- what was that mix in your household?

Pearl: Okay, in terms of the political ideology, amazingly, despite the fact that my grandfather and the twenty-six other families who founded the town had an image of a religious town -- that was the purpose of their coming, okay -- I grew up in a totally mixed community. I marched in May 1st International Workers Day with a big band and I sang the International anthem. <sings in Hebrew>. Yes, and I went to a kindergarten which was a socialistic kindergarten, used to be called Kindergarten of the Working Family, okay. However, come Grade One, I switched to a religious school, okay. My neighbors were totally mixed. All my friends were, I would say on the socialistic part, or -- I'll call them secular, yes, secular. Part of the town was religious; part of the town was secular. They closed the gate on Saturday -- Friday night, so cars would not be able to come in. They honk the horn at 5 p.m. on Friday night, but people knew how to sneak in and it was a comfortable co-existence between these two factions. I don't remember any skirmishes or any, I would say, hostility between the two. Perhaps sometimes when a car would sneak through on Saturday afternoon, they would chase it with stones or something. But that's all. Otherwise, it was a beautiful harmonious coexistence. Yeah. And it has changed. It has changed recently. I could not go into my hometown without a visa. I'm just kidding! <laughter> But I would put on my yarmulke just to feel accepted.

Brock: Mm hm, as a young person, how did reading factor into your life?

Pearl: Reading?

Brock: Yeah.

Pearl: Yeah, okay, the atmosphere at home was of course reverent for learning. Encouragement for learning. But since my parents were not academics, right, they could not give me any help in studies but they encouraged me in any way possible. When I sat down to do homework, it was clear that my brother and sister should be quiet because “he doing homework;” It's like holy time. <laughs> Oh, my mother went to see the teacher in I think my fourth grade and I was worried that he called her because I was rowdy in school. So, I said, "What have I done again?" And it turns out he wanted to tell her that I'm doing fine and that she should give me all possible encouragement. He told her, "Sell all your possessions but give him education." She was <laughs> very happy. And I was surprised! "You mean, this teacher knows me?" Because I didn't excel or stood out in class. So, on one hand -- from my side it was a surprise that he paid attention to me. On her side it was happiness that I had potential. And she gave me all the encouragement possible. Yeah. In what way? Books. We had books from the library, and she was gracious enough to register me to the library to which I went twice a week and borrowed a book, okay? And literature-wise, we grew on Russian literature, world literature, Dickens and Maupassant. And these were all translations that we grew up with. And they were translated very early, all the classics, okay? So, I grew up on the classics. I read a lot. I remember-- I feel like I grew up in Russia. <laughter> Because <laughs> I read Tolstoy and I read Gogol and I knew this stuff well. So, whenever I meet a Russian today, I say, "Hello!" <laughter>

Brock: Was there anything in your early life that you see connected to your later professional pursuits in mathematics and technical subjects?

Pearl: I can't recall, because, as I said, I did not excel in school. I was about the third or fourth in class in ranking, but I wasn't as good as the geniuses. The geniuses always stood there and said, "It's boring. We're bored." They knew this stuff ahead of time. And for me it wasn't boring! It was interesting, okay? <laughs> So, that is the standing. And one thing I remember and maybe reflects on my temperament even today. And this was in -- I think it must have been in grade five, I was ten years old, and there was a big discussion of how many square meters you have in a square kilometer, right? And I said, "A million." And kids laughed at me, and said, "You have a thousand. It's a thousand-by-thousand meters, so you have a thousand meters." And they went to the math teacher and ask him, "What do you think?" and he said, "It's a thousand!" "Ha!" they all laughed at me, and they mocked me, “See!” And I went home, and I said <laughs> -- I couldn't believe that the math teacher will side with them and not listen to me, okay, and I didn't have the vocabulary to prove it to them four by four or something like that. But I remember being in class and I said, "I'm going to go back to him. I'm not going to give up!" And I went back to him and eventually he apologized to the class. Okay.

Brock: Wow.

Pearl: But I felt terrible, I felt sort of that I have to stand for the truth despite what everybody says. Okay? And now this is what I still retain! <laughter>

Brock: I can see that it's quite some foreshadowing of what happens later, yeah.

Pearl: But it stuck in my mind, you know?

Brock: Yeah, yeah.

Pearl: That a community, the whole community, every kid in class laughed at me, okay? So, it was a community consensus that I'm wrong and I'm stupid, okay? And the teacher, the guru, gives a stamp on the community consensus and I'm at home, I remember it like this, "I'm not going to give up!" Why did this stick with me? I don't know, apparently it left an impression.

Brock: Could you tell us about the decision to-- your high school was in Tel Aviv, is that correct?

Pearl: Yeah.

Brock: Yeah, so was that a big decision for you to go to high school in Tel Aviv? Or was that kind of where everyone in the town was going?

Pearl: No, it was a privilege to go to a municipal school run by the city with a religious orientation and they chose-- they had a quota. The city of Tel Aviv had a quota for the suburbs. We were considered suburb and four people from my town were chosen to enter the high school in Tel Aviv, yes. And I remember being happy upon getting the information. There were four of us and going for an interview with our future principal. And he interviewed me and interviewed my mother, and I was younger than the rest, I was 17-- oh, sorry, <laughs> I was talking high school -- I was 13 whereas the others were 14. So, he tried to convince my mother to send me one year to a Yeshiva so that I will mature and come with the right spiritual strength and then I will go to high school. I said, "No way!" I resisted it. My mother was -- she called me in and said, "What do you think?" I had the answer right there. "No way!"

Anyway, I was accepted and was given the chance to be part of this very good high school. Yes, we had other choices, because we had a local high school. I'm not sure it was already in action -- perhaps. But it wasn't as reputable as the one that I went to in Tel Aviv. So, I was really lucky. Yeah, they had a lot of extra curriculum activities. I remember our math teacher teaching extra hours in the afternoon for children who wanted to study advanced topics. It gave us a feeling that we were just about to make new mathematics, that each one of us had the potential of being an Einstein. Okay? We just had to work at it and play with it and it's possible. We also had a good music teacher. Every Tuesday afternoon, he used to come to our class and play classical music. He played the music that we were about to hear that evening, the music that the Israel Philharmonic was going to play in a concert eight o'clock in that evening. So, he gave the introduction to the pieces that would be played at night. He'd spend with us three, four hours and we listened enchanted. A guy can play a Mozart symphony on the piano and explain it so nice. So, I had a good education, very well-rounded. Okay, I didn't like chemistry, and I still don't know chemistry. <laughter>

Brock: But you did, your connection to mathematics and science certainly deepened in this period, is that true?

Pearl: It was created in high school because it was playful. Mathematics was playful, constantly. And human oriented. I mean, we knew the names of all the Greek mathematicians. Only then we got the theorem. We had the name of the inventor of the theorem on the wall and the name was talking to us, and his life story, if it was available was given to us. We learned from person to person, so, mathematics became a human endeavor, you know? Not a textbook to follow. And we also learned, chronologically, how things were invented. How one theorem's got on top of another as opposed to a logical sequence. And that's also what I told Bill Gates when he asked me what is the secret of your education? I told him, "Teach it chronologically and teach it from the point of view of the inventor." Yes.

Brock: Well, for somebody who loves the history of science and technology, that is a very wonderful message! <laughter> For you to give.

Pearl: Yeah, I don't think we’ve accomplished it. Even in the Kahn Academy, they go by the textbook. They don't go to the history. I think it's a mistake.

Brock: Was that historical approach evident in your science classes in addition to mathematics?

Pearl: Yeah, of course. In the science class, too, yeah. Especially in college. In college I had more of that because each of the professors were really part of the invention.

Brock: Right.

Pearl: Each gave us the feeling that he or she was part of the Cavendish Laboratory where the electron was discovered, or part of the Rutherford laboratory in Manchester, I believe it was. Right? So, we were part of that discovery, as opposed to just a textbook with a recipe to follow. Yes. And our teachers were great enough and confident enough to make us feel that way. We are inventing -- reinventing science together. Yeah.

Brock: Well, could you talk about your decisions about what to do when you were graduating from high school. You know, what you were thinking about and your options.

Pearl: Graduating from high school was the period of my rebellion. Well, my life was rebellion, but this was rebellion on ideological grounds. I moved from religious-oriented environment into secular environment and I went to a secular kibbutz, which was part of the Worker Party kibbutz movement. And I had to hide my conversion from my teachers. Because <laughs> one teacher caught me without the yarmulke one time on the bus, and told me, "Look, I can make you miss your graduation exams, okay? So, don't make me see you without a yarmulke again." And okay, I got the message! I had to hide my conversion, and my joining a secular movement. It was in the last year of high school. And my ideal was to quit all this bourgeois life in which I grew up, and to become a Pioneer -- Half Bolshevik. I wouldn't call it Bolshevik because it's sounds bad. But at that time, it was considered being a Pioneer. Okay? Like the people I read about in books, yeah. They were worshipping physical work, agricultural work, and I wanted to become a member of the kibbutz all my life. And that was my orientation when I went-- when I finished high school and went to the *Hachshara* which means "preparation" for the army. I remember my mother visiting me in that little camp and she started crying because she saw four boys and four girls in the same tent. <laughter> Oh! She flipped and said, "And how do you get dressed?" I said, "I ask them to turn around." She said, "Oy!" <laughter>

Brock: So, was that experience on the kibbutz, was that part of your government service or was it--

Pearl: Yes. It was a special unit which served the army in two modes. Agricultural work on one side and the army duties on the other side. They divided the two-and-a-half years that I had to serve into four periods. Partly working on the kibbutz and partly protecting it at night.

Brock: I see.

Pearl: Yeah, as in the old ideal of rifle in one hand and a plow in the other hand. <laughter> It was the ideal on which we all grew up. You know?

Brock: And so, how did that experience match your -- did the reality of it match your hopes for it?

Pearl: No, no, I was bored. When I worked in the apple groves and with the chickens, I was really bored. So, I didn't, I saw it right away in the last year of my army service that I'm not going to stay the kibbutz. And I prepared myself already to go into engineering. Why engineering? People told me if you are good in math, you go to engineering. Okay? That would serve both to satisfy your mathematical interests, and make it possible to get a job in the post office. Okay? That was the kind of jobs that we could get at that time in Israel. Because it was a period of austerity. There weren’t really fancy jobs in research or industry. I grew up in the time of austerity. Because Israel grew three-fold from 600,000 to a million-point-eight at the end of '60, which means food was scarce, yet no one went hungry because they had a ration system. And a good way to understand what “ration” meant is to follow my brother-in-law. He was bachelor, when he wanted an omelet, he would go to a restaurant and have an egg in his pocket. Once you gave them the egg, they would make an omelet for you! Okay? But with <laughs> but you had to bring the eggs that you were rationed with. And the piece of bread that you were rationed with. Everything was rationed, including clothing -- you had to have “points” for every commodity, see? And no one went hungry because of that strict system that prevented the creation of a black market.

Brock: And when you say that “become an engineer and you could get a position with the post office,” that's because was the post office also providing all of the communications?

Pearl: No. Of course, it was a time when the communication industry developed, yeah. The army needed communications, and civil service needed it. But these sorts of jobs were not available at that time. I don't believe, private companies were in existence at that time in the field of engineering. Right.

Brock: So, could you describe for us your path to the Technion? How you got there and what it was like.

Pearl: The path to the Technion, yeah. In the summer between my army service and the beginning of the school year, I applied to the Technion, and I sat down and read books to be prepared for the entrance exam. And it wasn't easy. I didn’t know any engineering and I knew some theory of physics from high school. But I really wanted to get in, so I read a twelve-volume book on electricity. <laughs> And I prepared well for the exam. I even remember the question that they asked me. Well, I'll give you the question, okay? It's very important. <laughter> Very interesting question. <laughter> No, the point is that I remember the question, and the unique way in which I solved it. And that's why it stuck in my mind. I give it to my grandchildren now and they can't solve it. I have to lead them. So, you have a straw. A drinking straw with two sides and you have a soap bubble on one side, soap bubble on the other side, okay? One is big and one is small. And you let it go. What will happen? Will they equalize in size? Will the big one swallow the small one? Or nothing will happen? Okay? That’s the question, I had to use my intuition and whatever I learned in high school, and I reasoned about at that time, in a way that still makes me proud today. I said to myself, "When I blow a bubble, what do I feel? I feel that when the bubble is large, it's easy for me to blow. When the bubble is small, it's hard for me." Which means the big one will swallow the small one. Right? That's what I did. I passed in flying colors. Okay? I even got a stipend because of my success.

Brock: And what was the institution like when you were there? You were there from '56 to '60. Is that correct?

Pearl: No. Yes, yes, yes. From '57 to '60, yeah.

Brock: Oh, okay, 1957.

Pearl: I started in '57, '58, '59 and the institute, how can I explain it? One thing was different between the learning environment in the Technion and what I found here is that students were rowdy. Not rowdy in the negative sense, but in the positive sense. We must understand, and if we don't, it's the teacher's fault, not us. Which means we used to make noise with our chairs. We used to shout, " I don’t understand. Hey, what?" We wouldn’t let the teacher go forward unless we all understood in real time what he was talking about. So it was a revelation to me when I came here and I saw everybody polite and not understanding. Students told me, "We didn’t understand what he's talking about." And I said, "Why didn’t you ask?" "Oh, it's impolite." So that's the American system. That was one difference which I can tell you. What else was different? I told you about the mode of learning, being part of science. We had a strike. A student strike in the middle of my studies because the tuition was too high. So I remember going on strike. And I forgot how they settled it. And what else I remember that might be of interest here? But basically, it was hard. It was heavy work, and it was pointy. I remember a teacher coming to class and saying, "Why are you looking at me? Start drawing lines." We asked, "Draw what?" “It doesn’t matter what. Start drawing lines. You do first and understand later.” All kind of jokes like that, okay? And there was one teacher who said, "Hey, you behave like an Asiatic." At that time, it was okay to say that, because he came from Bulgaria, from the high echelon of scientific achievement. And we did behaved like Asiatic. Okay.

Brock: And I believe I read somewhere that your future wife was also a student.

Pearl: Right, yes. She was also a student. And it's also interesting, we were 120 males and four girls at that time. I believe the ratio now is 55:45 in female’s favor. Yeah. But that was interesting, especially in electrical engineering. There were more females in architecture and in fundamental studies, physics. But in engineering, four girls and 120 boys. Sharks, I should say. And I was lucky enough to meet one of the four and marry her. She passed away last year, about exactly a year from now.

Brock: I'm very sorry for that. Could you tell us a little about her background?

Pearl: Yes.

Brock: And was she also interested in electrical engineering?

Pearl: She was -- she came from Iraq. So she was not spoon-fed, okay? She was the opposite. She suffered from the Farhud which is the name of the pogrom that they had in 1941 in Baghdad. And she was just a go-getter. She was the one in her family who knew the Muslim dialect, so she could pass for a Muslim in the street. And she was doing all the wheeling and dealing with the Muslims, when things got to be rough. So she came in 1950 or '51 in the big wave of immigration from Iraq. They had a few months of free immigration. The Jews of Iraq were allowed to leave, leave their possessions behind and be taken to Cypress, then from Cypress to Israel. And she has many stories about how they treated her in the airport. How they asked her to give few gifts to the clerks in charge, or else. So they came with almost nothing in their hand, and they lived in a tent city for about a year. But lucky enough, her father was a tailor who had connection with a London bank, from which he imported textiles. Okay? And he arranged for -- he had some reserve money in his account in London, which allowed them to buy an apartment in Tel Aviv in 1952. Okay? She then went to the Army in 1955 and managed to do her technical studies in the Technion in the evening. They had an arrangement whereby soldiers and students who need to work were able to take evening classes and make two years for one year of ordinary studies. So she took this program and served in the navy. She taught mathematics in the navy, high school math to future captains. Why? They needed to know trigonometry. That was the idea, right? No captain without trigonometry. That was her job.

Brock: And she was doing that while you were finishing your studies?

Pearl: She was doing two years in the evening program while she was in the navy teaching mathematics. I did one year of morning college. And we met in the second year of college, yeah. And here, in America, she became a super software analyst, in the sense that she advised on the diagnosis and debugging of highly sophisticated software system to banks and to other companies here in Los Angeles. That was her specialty.

Brock: Did she do that on a consulting basis?

Pearl: First, she worked in NCR, National Cash Register, if you're old enough to remember them.

Brock: Yes.

Pearl: They were one the first in the computer area. They had a facility in El Segundo there. And that's where she started. She worked in TRW, too. And eventually, she went into consulting, private consulting. She stopped working in 2000 when we had the tragedy with our son, and then she took over managing the foundation.

Brock: Right, right. Well, could you-- to go back into those Technion years, was it during that time that you had your first exposure to computers?

Pearl: There wasn't a computer. The first computer class was introduced in my last year of college. I didn't take it. It was a choice. Some of my friends took it. We knew the computer is something ongoing -- the future, but I wasn't interested. What I was interested in was logic, Boolean logic. And that was taught by Professor Yoelli. So it was a good class, minimizing relay networks. And I'm saying relay network, not switching devices, because we didn't have transistors. So the problem was minimizing the number of relays to get a certain Boolean function implemented. Yeah. That was the essence of the class, and I loved it, because it was a combination of mathematics and real life. You get the result in the mathematics, and it translates into a minimal network of relays.

Brock: Was that also your exposure to Claude Shannon in that class?

Pearl: Yes and no, because I don't think his name came up. I didn't know his name until later.

Brock: Okay. So how did your thinking develop as your time at the Technion was coming to a close about what you were going to do next?

Pearl: Yeah. I remember an interview that I had with the dean. He asked me, "What are you going to do?" And I wanted him to write for me a recommendation. I applied for Chicago and, I believe, MIT and others. And he said, "What do you want to do?" I said, "I want to do network synthesis." He said, "Okay." He said, "It's not the hottest thing in science in 1960, but it's a nice intellectual exercise." I said, "Yes, that's what I want to do." So he wrote for me a recommendation and that was really what I wanted to do, because that was a kind of intellectual exercise which I found to be intriguing. Well, I applied to several universities here, and I believe I was accepted to one or two. But I found out that the tuition would be prohibitive for me. The one where I did get accepted and it had possibilities was Brooklyn Poly. Polytechnic Institute of Brooklyn. It was a top school at that time for microwave and other communication technology. And I was accepted there with a provision that I'll get a job in NYU, because I had a friend of a friend of a relative who worked in NYU dental school. And my relative arranged for me to have a stipend to be an assistant in the school of dentistry at NYU.

And on that basis, I went to America. So here we go. We go to America, waking up in Harlem, not knowing English, no one could understand me because I talk English the way I speak now. And I couldn't understand what the bartender said. It was a Black accent. And we didn't communicate. But eventually, I found out that the tuition will be prohibitive. Namely, my job at NYU will not cover the tuition in Brooklyn Poly. And we rented a flat in Brooklyn, and eventually my relative found out that they have an evening school in Newark College of Engineering. Today it's the New Jersey Institute of Technology. But it was in Newark, so we could move and live in Newark instead of Brooklyn, which was cheaper. And they have an evening school, which means I could work in the daytime. And my wife could work, so that was quite a relief.

Brock: And what were you doing to-- how were you addressing the language issue?

Pearl: The language barrier? I could communicate, not with the bartender, but I could communicate with my boss. That was no problem. The bartender still remained a problem. So I worked at NYU, in the school of dentistry. And the same time, I did my master's in Newark College of Engineering, and I did my thesis on my work. We measured the blood flow in the cat tooth. It was very important to measure it at the time, because the volume in the tooth remains the same, so how do you measure the blood flow, as there's no expansion and contraction that you can measure. I had to figure out tricky ways of measuring the blood flow. You can tell the velocity of the blood inside the cat tooth. And we a wrote paper on that. The first time I heard about writing a paper. My first paper was on the cat tooth.

Brock: And you had developed an electronic system?

Pearl: I did the electronics. And the ideas of how to measure velocity of blood. So that was a successful thing. We published two papers on that. And I learned what it means to write a paper. I didn't understand why my boss is working so hard to publish a paper. What's the big thing about a paper? I said, "I mean, come on. You're already an Associate Professor. What do you need a paper for?" He said, "No, we must publish it." I said, "Why? We got the results, right?" We managed to measure the blood flow oscillations." And I learned for the first-time what academia is all about. Yeah. And after that-- that was at NYU-- I wrote my master thesis. My wife at the same time was also going to..

Brock: Newark?

Pearl: To Newark College of Engineering. She wrote her thesis on microwave antennas, and she -- yeah. That's what she wrote on, and later on, she got her masters degree. And she got a job, also, in microwave antennas. That's another story, but that's also for -- only people who come from Israel can understand it. She was interviewed and asked the interviewer: "What are you doing?" He told her, "We are putting microwave antennas from the west coast to the east coast, so we can have communication. And we direct the beams in the required direction." And she says, "Hm, so why don't you do it the right way?" He asked her, "What is the right way?" She goes, "You arrange antenna and you focus the beam by phase control. You make sure the beam goes in the right direction electronically." So they said, "You're hired. Tell us how to do this." She hardly knew what she's talking about. She just thought that this should be a good way to do it, because that's how we learned how to do it. But she had the guts to tell him, "Why don't you do it the right way?" She wouldn't do it now, later in her life. Or maybe she would.

Brock: So what was your next step after getting that master's degree?

Pearl: The next step was taking a job in RCA Laboratory.

Brock: How did that connection come about?

Pearl: The connection to that came -- let me see -- how did I hear about RCA Laboratory? I forgot how I heard about them. They had a training program, of attracting good engineers and allowing them to do their thesis together with the research in the laboratory. I remember the interview that I had. Yeah. How I heard about them? I don't know. Evidently, I heard about the program, and it was attractive to me because it would allow me to do my PhD at night while working in the daytime. Okay, now I remember the interview. They interviewed me and the guy said, "What do you want to do?" I said, "I want to build new digital devices that will switch fast and will be cheaper," and all this. They said, "Well, do you have any ideas?" I said, "Yes, yes. I heard that you can do it with tunnel diodes." He said, "How do you do it?" "You have a tunnel diode and you have this negative resistance, and you make it switch." And the interviewer said, "You're hired." Because I was excited to do it. Once you're excited in an interview, they sense it. And it was not easy to get in. It was a good environment.

Brock: This is the laboratory in Princeton?

Pearl: It was RCA Laboratories in… David Sarnoff Research Laboratory in Princeton, New Jersey. And we were competing there with IBM and Fairchild Camera and Bell Labs, on what? On finding new devices for computers. It was well understood that computers are the way of the future. However, computers were too cumbersome, too big, too noisy, too expensive, too slow. There ought to be a new physical principle by which computer logic and computer memories, specifically computer memories, should be able to be built and serve on the computer. So we all worked on new devices. I believe some people worked on photochromic memories, some people worked on semiconductors. We brushed them off. "It will never work." And some people worked on superconductivity. Yeah, "cryotron" was the name, as you mentioned. And I worked on superconducting films so as to store circulating currents inside thin films of superconductors. You have a grid of X wires, Y wires, and you select the direction of the spinning whirl. And that's how we get a `one' and `zero'. And that would be cheap and faster than everybody else. Well, it worked very well in theory, and it did actually work in practice, too. We built some nice devices. However, semiconductors took over. They managed to wipe us out -- all its contenders for computer memories. But when did they pass us? Not much later. They took over in 1968 or so. Yeah. And I'm talking about 1965 when I was still in RCA Laboratory. At that time, I wanted to become rich. I'm already a PhD. I got my PhD in Brooklyn Poly. Oh, that's something else, another story. My wife was in the hospital when my son was born, and we were visited by an uncle and his wife who were academicians. And they told me, "Where are you getting your PhD?" I said, "In Rutgers University." They said, "It's not a good engineering school." I said, "Who cares about the school?" They said, "You'll be surprised. The name of the school is everything." I didn't quite believe that this is the case, but I switched the last year of my PhD program, 1963 or '64, I went back to Brooklyn Poly and said, "Would you accept me as a student?" And they said, "Yes, if you want to take the classes and take the exams and all." I said, "No way." I had chutzpah at that time too. "If you want me as a student, you let me take the exam without any class. Okay?" So they said, "What can you offer us?" I said, " I can offer you a lot, because I have facilities in RCA Laboratories that you wouldn’t dream having here in your facilities. That's something you should consider." But they said, "No one can pass the exam without taking the classes." I said, "Give me a chance." So I did pass the exam, both the written and the oral in flying colors, except I didn’t know what flying colors were. I had to ask my neighbor what are flying colors. Okay, so I did pass that. And it was a good move, because they really had a much better reputation, but I didn’t learn anything from them. I learned everything in my job, on the job. And I had to teach my advisor what I'm doing. I saw him only twice, but he was a good learner. I think I took one class. No, I didn’t take a single class. No.

Brock: And so did you have a thought of staying at RCA labs? Or you wanted to change?

Pearl: No, no. the last year I thought that I accomplished the first part of my plan. My idea was to get my PhD, to become a millionaire, and go back to Israel. I accomplished the first part, and I was stuck on the second one. So it's about time for me to accomplish the second one-- I'm still working on it, by the way-- and then go to Israel. So here I am, last year of my PhD program. I came to my boss and said, "I want a raise, because I'm worth more in the market." He said, "Yes, but you have good work. You have good environment. You enjoy it." I said, "Yes, it's true. But I have to accomplish my second phase now." So I left RCA. And I went to a place which I thought would make me rich, and this was Electronic Memories here in El Segundo, in California -- in Hawthorn, California, right here. And they offered me a stock option. Something new for me. “Wee, I'm going to own stocks! Stock options,” and I was also director of advanced memories. And that's why I went to California. I came here in 1966 (I believe) to work for Electronic Memories, Inc. My wife started working at TRW. We had already two kids that were born in Princeton, New Jersey. And I worked on something totally different, not on superconductivity. I worked on plated wire memories. Okay? It was a contender to core memories. Instead of threading wires through donuts, you plate magnetic material on top of the wire. So it's already threaded.

Brock: Oh, I see.

Pearl: Then you crisscross them. Three years I worked on that. Frustrated. Frustrated, because it involved a combination of chemistry, electronic, magnetic, and administration. I was frustrated. My wife said I came home and played on the piano with such anger that she knew I'm unhappy. Eventually, after three years, we were barely putting some product on the market, but it found application only in the military, where they wanted to have sustainability against high radiation. Semiconductors at that time were vulnerable. That was a small market and, essentially, I was told, "Find another job."

Brock: By Electronic Memories?

Pearl: By Electronic Memories, yeah.

Brock: Wow.

Pearl: "We are going to phase out this line of research."

Brock: They also had other..

Pearl: They had semiconductors. At the beginning, semiconductors. And I was told, "Find another job." Okay, I'll find another job, and I wasn't worried so much. Why? Because at that time, academia looked up to industry. Industry was the place where all the innovations were made. The laser and the transistor and all these innovations were made in industry. Nothing was accomplished in universities, and they knew it. So I felt like I'm privileged, and I'm dictating my terms. And I wanted to get to a university. My wife said, "You belong in university, not in industry." She saw how frustrated I was, okay? And we had a friend of a friend who knew somebody at UCLA, and I gave them a call. They said, "Yes, come down. We may have a slot." I wasn't exactly sure what a slot is, but I could imagine. I came and interviewed, and they said, "Yeah, we might have something for you." No, I first went to USC and I wanted to work there. And they asked me, "What do you want to work on?" I said, "I want to do software engineering?" "Why software?" I said, "Software is something that is intellectually exciting, right? You put in the software some of your thoughts. You combine them together and you get an operating system that works better than anybody else." So, the dean asked me, "Are you crazy? Have you ever programmed in your life?" "Oh yes, FORTRAN." "And you want to teach software?" He said, "I have people here that have 20 years experience in software coding, and you're telling me that I should hire you to teach software?" I said, "Yes." He said, "On what basis?" I said, "I am successful wherever I go." Really, this was a real chutzpah. I don't know where I got that arrogance at that time, perhaps because I was successful at RCA. So he threw me out of his office. And I'm very happy that he did, because I didn't go to software. Eventually, I went to UCLA. I got into a laboratory there and I started working on a contract with my friend.

Brock: Who was that?

Pearl: Jerry Estrin. Jerry Estrin, you know, was one of the first pioneers of computer systems. He also was one who built the Golem computer in the Weizmann Institute, the first computer in Israel.

Brock: Of course. He and his wife, right?

Pearl: He and his wife, yeah. His wife, Thelma, right. So, they were both at UCLA. And they were managing laboratories, and the computer science department was just formed at that time. It didn't even exist at the time. Well, I was hired by UCLA, and this is where my college reputation made a difference, see? I was not even interviewed. At that time, they didn't interview candidates. They just brought them in. So I was sort of making acquaintances with members of faculty who sized me, rather than interview me. So they size me up and down and said, "Where from? Brooklyn Poly? Oh yeah, I heard about it." Had I said New Jersey Institute, I wouldn't have gotten in. Kleinrock, Leonard Kleinrock, was one of the people who sized me up and said, "Yeah, he can come in" and so forth. I got into teaching computer memories because I had experience with the hardware. They wanted somebody to teach both memories and languages. APL, I believe, was the language.

Brock: Yep.

Pearl: Yes. And computer memories, so I taught that. And eventually, I was hired by a different department. Not computer science, by a department called system engineering or engineering systems. It was a collection-- a interdisciplinary collection of people who were outcast in other fields. But the dean, Boelter, believed in interdisciplinary departments, so we had this mixture of people. Some taught design, some taught operations research, some taught control theory. So I had to teach all the nitty gritty courses of engineering, from control theory to operations research.

Plus I taught a course in decision theory, and that changed my direction. It was part of my teaching engineering statistics. I chose statistical decision theory. So I read all the classics in statistical decision theory from Savage to Ferguson, Raiffa, all the great people in decision theory. And that gave me acquaintance or familiarity with probability and decision-making. And so at that time, the computer science department was established, and I was hired back to computer science to teach computer science. And I taught courses in pattern recognition and in AI. AI at that time was whatever you put into it. Whatever you decided to teach. And at that time, AI meant game-playing. Chess, checkers, okay? And so I got into that in computer science, and I taught also decision theory as part of my AI class. Because, I thought, making clever decisions was the greatest thing that a machine can do.

Brock: May I ask you one quick question about-- was there a connection between the probability theory that's in decision theory and what you were doing with the pattern recognition? Or were those distinct?

Pearl: No, they were distinct. The pattern recognition that I did was a totally different endeavor. I was interested in image coding. And at that time, sending images parsimoniously with the least code, with the shortest code, was the hottest thing in many applications. So I worked on image compression, sending images with the least amount of information. So we worked on transform theory, Fourier transform, Hadamard transform, Walsh transform. That was my contribution at that time. And pattern recognition, too. These were my areas of interest. Still with the idea that everything I do contributes to AI. Because my dream of dreams was obviously everything is eventually going to be done by computer. So we must be ready to have associate memory-- we have to have associative memory to have a fast understanding of images. That was only a dream. And I worked on the components toward that dream. So that -- yeah, go ahead.

Brock: Oh, sorry.

Pearl: Please ask me more, because I don’t know if I'm going on..

Brock: No, this is wonderful. I hesitate to interrupt, but I..

Pearl: Please interrupt me more.

Brock: Okay. I wanted to know about how you first got acquainted with artificial intelligence, and how that connection deepened for you. Was it at UCLA that you really began this reading?

Pearl: At UCLA, yes. At UCLA, on my own, I would say, because we did not have any group working on artificial intelligence. But to me, it was a driving force. So I got into bits and pieces that I knew should be part of the eventual super robot. It should have perception, it should have reasoning, and it should have search. All these were parts on which I tried to work. Then, in 1976, I went on sabbatical to the Weizmann Institute. And there, I worked still on pattern recognition and on coding. I got interested in something else, a different problem: If you really want to minimize computation, and you are willing to sacrifice quality, what does the tradeoff curve look like? Suppose you allow five percent of your answers to be wrong. Do you get an exponential amount of computational saving? Or just five percent? That problem triggered me because I thought there's a threshold here. The reasons I thought why we get stuck on computation is because we insist on correct yes and no answers. If we are only willing to give up one percent, we'll get an exponential gain in memory size and in computation speed. That was an idea that drove me crazy at that time. So I worked on that problem maybe three or four years. And I published a few papers on that. It turns out, you don't get it. There is no phase transition there. Okay?

Brock: Got it. Right, okay.

Pearl: But that led me into the tradeoff between error and computation. And I got interested in the philosophy of science. This tradeoff is everywhere, right? Do we insist on a correct hypothesis, or we allow certain amount of *shpil* or fudginess. And I got into philosophy of science at that point. And then, when I came back from sabbatical, I started working on games, on game playing. Why? Because that tradeoff also plays a role in game theory. You look at the board position, and you assess, perceptually, how good the board position is. That's called the "static evaluation function." Then you look forward a certain number of steps ahead until you get to a certain horizon. You attribute the evaluation function to the nodes on the horizon and you roll them back, and then you decide which is the best move to take. Here is a tradeoff between search and quality of perception. So that was a wonderful arena. It was a wonderful playground, I would say, for understanding this tradeoff. Today, we can say one is system one of Kahneman and one is system two. System one is what you immediately see, instinctively see, and it's obvious and self-evident to you. The other one requires search, reasoning, contemplation, planning. And that is a "search mode." At that time, we didn't have the theory or the metaphor, but I was intrigued by the tradeoff between the two. And I got a few nice results in game theory. Okay? Because I was mathematically oriented, so I asked the question of how good should the heuristic be in order to gain that much in search, which is a question that has to do with the tradeoff between the two. So I got some results in game theory. At that time it was the hottest thing in AI. Which brings us to the 1979, 1980-- no, no. It was before that. 1978. Yeah, three years I worked on search theory. I wrote a book, *Heuristics*, my first book. Any questions about the…

Brock: Yes, because I'm thinking about the limits, the connection between the sort of probabilities and statistics that you were seeing in decision theory and then when you're doing this work on game playing and the limits of search. Are the limits of search a form of uncertainty?

Pearl: I don't understand the question.

Brock: I'm probably saying it in an incoherent way, but bear with me. When you're in game theory and game playing, when you are dealing with these tradeoffs about how thorough of a search to do. Is that about-- does that relate to dealing with uncertainty?

Pearl: Yes, because we don't know in advance what we are going to find on the horizon, right? So I had a paper, for instance, with Richard Carp about the tradeoff, or how far you have to search if you have a random cost on the edges of the tree. So you don't know the cost of the tree ahead of time. So the question is what is the minimum depth you have to go through on the average, and whether it converges to a certain limit. I also found these nice convergence properties on random games. Here's where your randomness comes in. You don't know ahead of time the cost on the edges, okay? You find them as you go along. So that was one place where randomness came in. The other place was when you search a game tree, you don't know the values of the root nodes or the horizon nodes. You don't know those variables, assuming that they are random. Okay? Let's assume they are random. What can you say about the value of your best move? There's an answer to that. It converges to a value. Bing! Another paper. And it's not just publishing another paper, it is a surprising result. It has a value which I could compute in advance, together with average number of nodes you have to search optimally. Plus, the complexity of practical algorithms, such as the alpha-beta. I could find the branching factor of the alpha-beta algorithm. And you can prove it's optimal, which means there's no algorithm that can do better. And that was a nice result. I was very proud. Even Don Knuth was surprised by that.

Brock: Right as your book on heuristics is coming out, embodying these results that you had had, this is the time when this era of knowledge-based systems and expert systems is really starting on the rise. How did you start to think about or view the development of expert systems?

Pearl: Yeah, expert systems started coming out in the late 1970s, with Dendral and the-- I forget the name of it.

Brock: Mycin?

Pearl: Mycin and Prospector. And they presented to me again the issue of dealing with uncertainty, because it turned out that managing uncertainty was one of the obstacles for those systems. They started with logic rules, and it worked well as long as you had the rules. But every rule has exceptions. And the problem was how you deal with exceptions. At that time, in the beginning of the 1980s, there were a lot of theories about how we should deal with uncertainty. One thing was clear, that probability is off the table because probability had a bad reputation. It needed exponential memory and exponential time. So it ran into a period of ill-repute. But the practicing expert system experts needed to feed the rules with some degree of certainty to account for the exceptions. And it was clear that we AI people must invent a new way of dealing with uncertainty. Probability is off, which means the landscape is ready for us to invent a new calculus of uncertainty. That was the agreed-upon consensus among all workers. Because if probability is off, what remains? So Zadeh had his fuzzy logic, and Dempster and Shafer had their belief-functions calculus. And there were certainty factors, which were put on top of the Mycin rules. But they couldn’t combine well-- none of them met the requirement. What was the requirement? Two requirements. One, computational tractability, and the other was intuition. You couldn’t defy intuition. If I tell you that smoke is evidence for fire, and fire normally creates smoke, you have to say something about the certainty of fire if you see smoke, and not run into a feedback loop that runs away and suddenly you would be calling the fire department on the basis of a hint that you might have seen smoke there. The two rules will interact and amplify each other for no reason. So that was one typical example where the certainty factors will not work. Another was the “explain-away” effect. They couldn’t deal with “explain-away.” What is “explain-away”? If I tell you that the-- okay, if I have smoke, it must be it is fire. But if somebody tells me, "No, I had a cigarette. I lighted a cigarette." You should explain away the smoke or the alarm and take away certainty from the fire. So if you find a reason for the evidence that you have, you take away certainty from another reason. And that could not work well, because it's non-monotonic. It didn’t work well with the certainty factors. These were the patterns of reasoning that you expect to see in expert system, and didn’t work out well. So when I heard about these difficulties, for me the solution was very clear. The explain-away and the feedback loop and all this can be treated very well in Bayesian statistics. We do it all the time. We never get into a runaway between smoke and fire, fire and smoke. We do it well. So if you do it correctly, according to Bayes' rule, you are protected from idiosyncratic violation of our intuition.

So let's go back to Bayes' rule. The problem was computational complexity. If you go and do it by ordinary standards of conservative, traditional probability theory, you have to have a table -- exponentially large table of probabilities for all possible instantiations of the variables. And if you have n variables, you need already an exponentially large number of memory cells. It cannot be done. So what did we do? I looked into how Bayesian people do it, and they do it using the parsimony that comes about by conditional dependencies. Not every variable is relevant to every problem. Some are declared irrelevant if you know other variables. For example, if you know that the sprinkler is on, you don't have to worry about what the weather is to know that your grass will be wet. The sprinkler being `on' shields the past from the future, given the present. That's called the Markov property. And it's captured nicely by conditional independence in probability theory.

So I thought if that was the secret, conditional independence, let's find out the logic of conditional independence and let's find out how we can represent it and how we take advantage of it. And that gave rise to Bayesian networks. Before that, I had a paper five years earlier about belief propagation. Belief propagation was a notion that I saw in a Rumelhart paper. He was a cognitive psychologist in UC-San Diego. He is the father of neural network. And he speculated on how children can read so unbelievably fast. It must be a combination of a variety of processes, he said. Some at the syntactic level, some at the semantic level, some at the perception level. So all of them are working together, passing information to each other, top-down and bottom-up. Something that you see at the semantics of the story allows you to disambiguate uncertainty in the shape of the letter. And sometimes the other way around: If you know a letter, it allows you to disambiguate the story. As they are working, they're shaking hands. They're running top and down, bottom-up, so they must be doing some handshaking, passing belief asynchronously, because there is no supervisor there. They just must be collection of neural entities that are passing information to each other. And you get to identify the right word: "It's a Volkswagen," or "it's a cat." Yeah? Though Rumelhart didn't go as deep as certainty factors or probabilities, he had the idea of handshaking and up and down belief propagation. I said, "that must be doable in traditional probability theory too." "I just believed it to be so." I said, "It's impossible otherwise." I don't know where I got the strong-willed conviction that it must be true, for the way we perceive and process probabilities or uncertainties. So I did what my father would probably do. If you have a hard problem, you simplify it. So I said, "Is there any structure for which the belief propagation will work?" I found that: "Yes, a tree." If you have a tree, which means every node, every concept, every variable has only one parent, then, so I found out, you can perform asynchronous belief propagation, and guarantee that after all the messages pass through, eventually the network relaxes to the true value. What is true value? What you would have gotten had you done it by traditional probability.

Brock: Using tables, yeah.

Pearl: Using tables, exponentially large tables. So, now we had a system that worked in a crazy way. A variable wakes up, sends messages to its neighbor, goes to sleep. Whenever you're waking up, you send a message and go to sleep. If you want to do it by a supervisor, fine, you could go ahead. But it's also going to work asynchronously. Sometime the waking up is determined by external stimulus. "Hey, we are going to make a decision." Or spontaneously, unsupervised.

So that was the idea for belief propagation in trees. In 1980 I published this paper, and I had to call it "Reverend Bayes on Inference Engine," because I had to muster all the respectability that I could for repairing the ill-reputed status of probability theory. And then it eventually developed into polytree, where every node has several parents, but you don’t have any loops. And then, in 1985, I found a way of doing it for general networks. And at that time, I published a paper titled Bayesian Network, so I coined the name, and I proposed this framework or structure as a cognitive structure for belief systems. And everybody was excited and started working on loopy networks. There were many, many schemes competing with each other of how to deal with networks with loops. David Spiegelhalter and Phil Dawid had one scheme, Ross Shachter had one, Adnan Darwiche had one, iterative propagation, but the winner was a totally different scheme. I proposed it in my book as a homework. And I didn’t think it's worth more than homework. It's an approximation method: “Ignore the loops and do things by handshaking as if you had a polytree.” And that took over, because it turns out that not only it gave the correct result-- not only it gave a good approximation, in many times it gave the correct result. It seemed like the propagation around the loop gets tired eventually and dies down, whereas the propagation by polytree roots remained substantive. So that took over, because it allows people to program belief networks easily. All you have to tell each node is how to react -- you don’t have to supervise their awakening. So in terms of programming, it was a breakthrough. All you have to specify is how each node reacts to its neighbors. The rest goes on automatically.

Brock: I wanted to ask you two questions. One was, if you could help me better understand why probabilities and Bayesian probability theory was so much off the table in the artificial intelligence community before you started to bring it back in? I don’t understand. It seems more than just, "Oh, it's computationally very difficult." It seemed that there was a philosophical or some deep opposition to it.

Pearl: No, it wasn't.

Brock: No?

Pearl: If you do it by textbook methods, it really looks undoable. Just imagine, for every possible combination of events in the world, somebody has to give the probability of that combination realized. There's no way to infer one combination from another one. They have to sum to one, okay? That's the only constraint you have. What else? Then you have marginalization. Then if you don't see some of them, fine. So you can go from a full specification to partial specification, but you cannot go the other way around. So you have to have this table. And if you go by the textbook, you have to specify all those exceptions. And you just don’t have the time to interact with an expert and ask for all possible exceptions, and attribute to them probabilities. The elicitation time will be horrendous. And then the computational time. Imagine now that you find a new evidence. Say you smell smoke someplace. To compute the probability of fire given smoke, you have to start summing all these tables. It's undoable, considering computation, memory size and elicitation time.

Brock: Okay. And Bayesian networks, which you could show were equivalent to doing the probability theory in this kind of traditional mode, I guess forgive me, but can you help me understand how the Bayesian network escapes from that trap?

Pearl: Escapes from it. That's a very good question. That's a very important question. It's not that it escapes. It so happens, in our real life communications, we make many assumptions. Okay? We know, for instance, that the color of my uncle's eyes is not relevant if I'm trying to find out whether I will get COVID. Right? It's a variable which is not related to my question. I know some variables which are relevant to my problem, and those are a small number -- we call them Markov blanket. They shield all others -- that's all you need to know if you want to make a decision on a particular question. So if I am worried about fire in my house, all I have to know is whether a neighbor smells smoke, or if some other evidence has been observed which is related to fire in my house. I don’t need to know the color of eyes of my uncle.

Brock: Oh, I see. So this is much in the way that heuristics truncate the search that you need to do. In this case, it's these assumptions about relevancy that curtails the network.

Pearl: Exactly, yeah. We make many assumptions of irrelevancies in our life. Otherwise, we wouldn’t be able to communicate. Because then if I ask you a question about the fire, you start asking me question about my uncle and we're never going to communicate. We communicate only because we share the assumptions about the things which are relevant and things which are irrelevant. Okay? So let's capture the benefit of irrelevance. So many things are irrelevant when we are dealing with a given task. Let's capture it in a certain computational object. What is a computational object? A network. In a graph, you also have neighbors, and far-away neighbors or pseudo-neighbors. And you can tell who is shielding whom from whom. So there must be a relationship between probability and graphs, right? Must be. Because I just talked to you about neighbors, relevance and all this. And you tuned to me. You understood me. So there must be a relationship between graphs and probabilities. What is the relationship? Well, I was lucky to have an academic visitor here, Azaria Paz from the Technion in 1985, I believe. Yeah. And we asked the question. What is the relationship between graph theory and probabilities? They seem to be totally unrelated, right? Well, it turns out that conditional independence in probabilities obeys similar axioms to the axioms of graphs. So we totally redefine what a graph is. Graph, instead of being defined by adjacency, we define it by interception. Who intercepts which path between any two nodes. The set of nodes which intercept all paths between node X and node Y are called “separators.” So let's define the axiomatic system of interception. It turns out that the axioms of interception in graph are identical to the axiom of conditioning independency in probability theory. Wow, this is a philosophical handshaking between two seemingly unrelated topics. Probability and graphs.

Brock: Wow, and that.

Pearl: It was called, by the way, it was called “graphoids.” The theory of graphoid. You can look it up in Wikipedia. I had a student write it up.

Brock: Oh good, then it would be reliable. Well, so as you're coming out with these really fascinating results about Bayesian networks, and you're publishing these papers, what is the reaction of people to this work? That's one question. Another is when do people start to build systems that incorporate your results?

Pearl: The reaction in the uncertainty management circles wasn't ecstatic, because everybody had an ego invested already in a different kind of uncertainty management system. So they looked at it and they said, "Yes, that's one way of doing it. It's another way." And it dies there. But the people who were actually interested in building systems-- and I think the first system was in Denmark, HUGEN expert system built on Bayesian network. They appreciated what's going on, and then Microsoft started a research group with Heckerman and Eric Horvitz. And they started building systems for diagnosing software. And they saw that they get all this mileage from Bayesian network. You get this combination of diagnosis and predictions two different things they could handle in the same system. And the most important feature was reconfigurability. The example is a car engine. You diagnose a car. So you build an expert system for diagnosing car troubles. The model changes. They have a different battery or a different oil pump. The rest of the system stays intact. Only the things which are relevant to the oil pump change. This means that you can take the software that you build for the previous model, and reuse it for the next model. All you need to change are the things that are related to the oil pump. Big deal. A minor, local change, and the system works again. According to Heckerman, that was the feature that made Microsoft go to Bayesian network in their diagnosis system. Reconfigurability. And why? Now you can ask yourself, "Why was Bayesian network so good in reconfigurability, and other system not?" Because, we didn’t know it at the time. All Bayesian network systems were designed with causality in mind, and we didn’t know it. Which means that always the parents of the node were the causes of the node. We never went and put the evidence on top and the hypothesis in the bottom. It came natural, right? We thought it [was] just a matter of convenience. No, it's philosophically very deep. Only when you go from cause to effect, you have this invariance -- you can change one component, and the other ones remains unaltered. Invariant.

Brock: Well, I mean, that's-- before we dive into causality, I just wanted to ask-- well, one thing I wanted to ask was one, about funding. How were you funding your work? And the other is about the communities, professional communities that were important to you in this time. The ACM, the AAAI, if you could speak to those two.

Pearl: Okay, funding. I remember that my funding depended on finding a good Samaritan among the officers of the Army Research Institute or the Navy or NSF. Without finding those – and I would call them “enlightened officers” -- I wouldn’t have been funded. But one or two of them said, "That's the way to go." And they pushed me and they supported me with small grants. Always small grants. I never got to what you see today with the data science, which is a -- I tell you what I call them. It's erecting gothic cathedrals to a handcuffed God. Quote me, please. Don't take it out.

Brock: Yes, I will. No, that is a very-- that is a great quote.

Pearl: Okay, so I was never splurging in money, but I always had a good Samaritan guardian angel among the NSF officers and all the Navy. Navy has been very good to me. NRO. NRO? Naval Research Office? No.

Brock: ONR.

Brock: Well, let's talk about, then, community a bit.

Pearl: The community in 1985. Okay. The practitioners received it very well. And I told you why, reconfiguration. Funding, I was always under good guardian angel. And you asked me about the rest of the AI community.

Brock: Yeah.

Pearl: That's important.

Brock: And computing community, yeah.

Pearl: There was some reception in areas such as default logic, nonmonotonic logic. What we did here in probability had some projection in nonmonotonic logic, which is also the idea of dealing with exception. Birds fly, but penguin is a bird, and it doesn't fly. So we had exceptions. We had some projection over there, and people took it seriously. Also, people took seriously the idea that you cannot combine causal with evidential rule and hope to get a correct result without paying attention. So that also became part of the nonmonotonic logic. And where else I saw resonance-- yeah, well, I guess that was later. Not in Bayesian networks thing. Where else can you find it in computer science? Software systems people didn’t care, unless you do diagnosis or troubleshooting. Yeah.

Brock: Well, let's turn then to-- let me see. I'm just scanning my notes here.

Pearl: Oh, we can have a drink here.

Brock: Yeah. I guess I wanted to talk about your work with graduate students and how that has been in the development in your work. If you could just talk about that aspect of your efforts.

Pearl: We are still in the Bayesian network period, right?

David Brock: Yeah.

Pearl: I had good students, I might say. I had very good students. Some of them pushed me into doing things that I wouldn’t have done myself. For instance, going from trees to polytrees was an idea of Kim, my student Jin Kim, who went back to Korea. And he pushed me. He said, "There's a conference in Germany. Let's present a paper." And he derived all the equations for the polytree. And if it wasn't for him, I just wouldn’t have done it. And who else? Well, I did a lot of work on constraint satisfaction, that I didn’t mention here, and that was done with my former student Rina Dechter. Who, by the way, is the chair of IJCAI, which takes place this week in Vienna. So she was adapting some of the ideas of graph-based reasoning to constraint satisfaction problems. That is satisfiability, graph coloring, that kind of problems. Probability did not get, in the beginning -- did not play a major role in constraint satisfaction, unless you have soft constraints. Two teachers cannot teach in the same subject unless you make an exception, and so forth. But okay, so she took the graph-based reasoning system and software and algorithm and applied them to constraint satisfaction problem. She found things like tree depth, tree width and hyper tree width. And then she went into -- she then went back and brought ideas from constraint satisfaction into Bayesian networks. Yeah, so that is a body of work which I wouldn’t have done myself if it wasn't for her. My student Geffner took seriously the work on default logic, nonmonotonic logic, and developed a system. And also he took seriously work on automatic discovery of heuristic, he applied it to planning. All these got developed because I had good students. They took the initiative. Many of them told me, “You don’t know anything about AI.” And they were right. I didn’t know anything about default logic until Geffner told me; “This is where the hard stuff is. This is where the action is.” So they moved me into different areas, because of their interests in whatever they met in conferences and among their peers.

Brock: Right. Well, I remember reading somewhere about how at one point during the development of your Bayesian network work that there came a point where you explicitly rejected a treatment of causality from it. The issue of causality came up, and you kind of set it aside or something. And you thought that a treatment of causality wasn’t necessary, that you could handle everything with probabilities alone.

Pearl: Yeah, I was so excited with the success of probability. Really, the fact that probability is keeping us coherent—it's a guardian of coherence. It's a protector against paradoxes, okay? I thought that human reasoning is completely describable by probabilistic reasoning. And I then thought that the consideration of causality are just convenience. It's just a shorthand notation for patterns of probabilistic independency. So instead of their saying: "this is dependent on that, given that and that and that -- a pattern -- we just say, "This one causes that." But it doesn't play any essential role. I completely changed my mind. In the preface to my book *Causality*, I apologize for being so stupid. At least I had the honesty to say so.

Brock: Could you share with us how causality started to come back in for you? This is happening in the later 1980s, is that right?

Pearl: When my book on probabilistic reasoning came out in 1988, I already felt that I am an imposter, because I didn't deal with causality. And I knew in my heart that the future is in causality. What I thought was just a matter of convenience, or of convention, turns out to be a totally different dimension, orthogonal to probability, something without which we cannot have any reasoning at all. Probability is a surface phenomena, the convenience stuff. Not causality, causality is the real stuff. It's the real core of reasoning and intelligence. And probability are just surface phenomena. That's what I believe now, see? And I already felt that way in 1988, when I finish my book on probabilistic reasoning and Bayesian networks took off and became a successful subfield. And I already felt that my heart is elsewhere.

Brock: What was leading you to that? Was it your intuition? Or what accounts for this very deep shift.

Pearl: Well, two different things. Two influences. One was the Heckerman analysis of why Microsoft is so successful with their Bayesian network, and the idea of reconfigurability. Reconfigurability made me think that causality is not just a passing pattern, a surface pattern of independencies, but it is basic. It is connected with the idea of invariance. Invariance is everywhere in the world. Things remain the same even when the light changes. You should know that, right? We change the light, but my face doesn't, I am the same person. So the idea of invariance, which is everywhere around us, and which is the assumptions by which we communicate, is in causality. It's not captured by the probabilities. So that was one philosophical shakeup. And then came another shakeup in 1991. I went to a conference in Uppsala, Sweden, and two things happened there. I had a dinner with Granger, Clive Granger from Granger causality. And we talked about causality. And after the second glass of wine, he confessed to me that "Granger Causality" has nothing to do with causality. But since people adopted it, he doesn't have the heart to tell them: "It's not that." And the second one was a lecture by Peter Spirtes from Carnegie-Mellon, a philosopher with whom I worked before. But he showed an idea of how to do interventions in graphs, okay? By cutting off the edges from the parents to the son. This kind of surgery amounts to forcing, externally, the value of a variable to a constant. Similar to randomized experiment. That, he got from economists -- Strotz and Wold, two economists who deleted an equation, but he translated it into a graph. And that gave me the idea that we can borrow everything that we have done in Bayesian network and apply it to a new field, which is totally orthogonal to the previous one. It's causal reasoning. And we can build a new calculus for action and for explanation. And we are on to a new revolution. So that took place in 1993 when I published the paper on-- not Do-calculus yet, but it was on the "backdoor criterion."

Brock: Okay. And that's interesting to me, because I thought that there was some sort of-- that you were adding kind of an interpretation of causality onto Bayesian networks. But I see now that that was incorrect. What you're doing is taking all the kind of structure and methodology.

Pearl: Methodology and the algorithms.

Brock: ... of the graphs and everything, and then using that methodology and applying it to causality.

Pearl: Which is a totally different world. It's a hard thing for people to understand that we are dealing now with a total different world. It's a new school of thought. It's a new paradigm. You cannot go from probability to causality. No causes in, no causes out. This led to the ladder of causation, which consists of three levels. You cannot get any answer to a query at level i unless you have information or assumptions from level i or higher. From probability, you cannot go to causal effect. From causal effect, you cannot go to explanation. Two separate layers. They don't meet. It's like oil and water.

Brock: But what accounts for, do you believe, the fact that you can take this structure, for lack of a better word, that you used for probability, for Bayesian networks, and take-- what accounts for the fact that that same structure is applicable for causality? Why does it work in both places?

Pearl: Well, because conditional independence is still used in causal reasoning. It is a component. We still use conditional independence to figure out when you have a spurious correlation or when you don't have spurious correlation. Yes, but that's only one building block. Only one brick, in a scheme of things which are totally different in the sense that the question is different. What if you take aspirin? Will your headache go-- cure or not? That is not the same question as, "What if you see someone taking aspirin?" Would it-- so doing and seeing are two different worlds. A world apart. Which means you cannot get doing from seeing.

Brock: I get it. Yeah, yeah.

Pearl: So it's mighty hard to understand how far apart the world of causality is from the world of observation which probabilities is the guardian of.

Brock: And one of the cruxes of that is intervention, as you've.

Pearl: Yeah. Intervention is the level two, because we are predicting the effect of interventions.

Brock: Right. And then another big one is the importance of counterfactuals, which is, in a way, imagined interventions, is it not?

Pearl: Correct. That's the imagining part of our brain.

Brock: So you start to have this big realization around 1993. Was it 1994 that you became professor emeritus?

Pearl: In 1994, you're right. Or maybe five. One of the two.

Brock: Well, I was just wondering how that affected what happened. Here you are, you're starting on this huge new thing that is very-- treating causality as a big thing from the history of philosophy and everything. And I wondered if that changed things for you.

Pearl: I didn't think a cause-effect relationship existed between the two, but maybe. Because I had more time. Suddenly, in 1995, I could teach what I want. I still had graduate students, and my office. I had a cut in salary, but who cares? I could do everything that I wanted without worrying and without teaching -- without teaching stuff I don't want to teach. I taught things which I wanted to teach. And no committees. That was a Nirvana. I was even telling our dean that we should hire new faculty on emeritus status and phase them into hard work slowly.

Brock: That's a great idea.

Pearl: It gives them a chance to express themselves.

Brock: To really do something, and then they can get to work.

Pearl: So yeah, it may have had some connection, because it gave me freedom which I didn't have before.

Brock: Well sure, yeah. It was just to ask you-- to challenge you to express for a general audience some of the most important things that you would want them to understand about your work in causality, and also to-- the biggest misconceptions that you would like to disabuse people of about causality.

Pearl: Okay. As you know, causality has been a misunderstood concept, or it is a puzzle to many philosophers, from the time of Aristotle to the time of modern philosophers. And therefore, this kind of disagreement has its traces and marks in many fields, going from economics to statistics to epidemiology. So depending on what school of thoughts people were trained on, they would like to understand causality in that narrow paradigm. So I currently have discussions-- I would say disagreements or perhaps even fights with many disciplines, going from economics to statistics and computer science, because computer science today is dominated by deep learning, data science. And data science is statistics on steroids. Which means that people understand what probability is, they know what prediction is. They go from one type of data to another type of data. And they live and die by the data. There's a limitation to that, which not everybody understands. I already mentioned the limitation that you have a hierarchy going from correlation to causation, and from causation to explanation or to imagination. It's hard for people, especially in machine learning, to grasp that barrier between layers, where one-layer ends and the other one begins. Why? Because of two things. Machine learning school of thought has two paradigms that they love. Everybody loves. Number one, tabula rasa. I don't want to depend on any opinion. I don't want to depend on any preconceived knowledge. I want to derive everything by myself. Let the computer learn it, and you find the word learning overused in that. Learn to learn, and learn to learn to learn, and learn -- everything was learned. Namely, I don't want to deal with it. Let the computer deal with it. So I do some tricks, and I hope the computer will learn it. So that is the tabula rasa handcuff. The other handcuff is let's do it the way that the brain does it. So if it looks like neurons interacting, it's good. If it looks like knowledge coming from rule system, it's bad because it's man-made. Okay? We hear a lot, "Neurons don't act like that." Indeed, you don't have rules in the neuron. You have interconnection, you have spikes. You have interactions, but you don't have rules – In general, so if it looks like the brain could be structured a certain way, it's good. We are at the basic. We are at the basis of intelligence, because we looked at the brain itself. These two paradigms are very seductive. And I understand it. Everybody wants to do brain-like. Brain-like means intelligent-like. And data, we don’t want any opinion. We want to have tabula rasa and learn to learn to learn to learn.

Now, there's a limitation to that. We can prove today that you cannot do certain things by looking at data and data only. It's not a matter of opinion. It's a matter of mathematical proof that you can look all day at people who take aspirin and record whether or not they have a headache, and you cannot prove that the aspirin is what causes the headache to subside. Maybe it’s the other way around. Time sequence plays a role here. But yeah, if you just take data all day long of ice cream sales and drowning accidents and you find a correlation there, and you don’t know what causes what. The drowning causes the ice cream sales, or the ice cream causes drowning? And on and on. You can have a situation where you find that students who smoke get a better grade than students who don’t smoke. But if you take into account their family income, then it's suddenly the other way around. Those who smoke do worse than those who don’t smoke in every income category. And then if you can take into account also, perhaps, age, then it reverses again, and those who smoke do better than those who don’t -- so by introducing new variables, you get a different correlation. That's essentially a proof that data tells you nothing about cause and effect. Even a better one, which I like to use, this is the Simpson paradox, okay? You can find out that a certain drug is good for girls and good for boys, but worse for people. Okay? Good for men, I should say, and for women, and worse for people, namely, people whose gender you don’t know are doing worse. And that doesn’t make sense, okay? It's an intrinsic part of correlation logic. It's part of the data. There's nothing in the data that will prevent you from making this stupid conclusion. What do you do? You have to deal with a new entity. It's called cause-effect relationship. So that's something which is not taught [in] data science courses, nor in the traditional statistical education. Some of it is in economics, but molested. Not done in a proper way. Epidemiology is a field which has made the transition. They understand the importance of reasoning with causality as a separate science. Some social scientists also begin to understand it. But unfortunately, statistics proper and data science as we see them today do not teach this transition from data to the process that generated the data. This is what causal reasoning is all about.

So I don’t know if I answered the question, but I give you a hint of what needs to be done. There are three levels of reasoning. One cannot stay within the lower one and expect to answer a question in a higher one. It's just mathematically undoable by proof, not by opinion. How to convince people that this is the case? You see, it's hard because people in data science are so entrenched in the belief that they can do things by learning, to learn, to learn, to learn and today they tell me, "We can learn how to incorporate causal constraints too by just looking at data and doing certain things, moving from environment to environment, eventually we are going to get it.” Or “We can program it in what they call “inductive bias.” A mysterious thing, “inductive bias,” <laughs> which happens to help them in prediction tasks. For instance, if you have a preference for a polynomial of lower degree over a higher degree, then you can fit data better. You protect yourself from overfitting by what is called “inductive bias.” So they believe they can do the same trick with causality but there’s a proof you cannot. And whatever you do, whatever you succeed in doing, it’s because you made some assumption that we can mathematically explicate and do better once we know what assumptions we are looking for. So what can I tell you? It's an educational tragedy.

Brock: And what do you think are the biggest misconceptions about your causality work?

Pearl: About my work?

Brock: Yeah.

Pearl: From machine learning circles, I don't think there is a misconception about my work as opposed to other people's works. It's only the difficulty of liberating yourself from the handcuffs of these two ingredients which I mentioned, tabula rasa and neuron-like. It sounds hard to accept judgmental opinion, expert opinion, to accept a model, an outside model to guide your inference because it's against the idea of machine learning. You don't want to sit down with an expert and receive a model from an expert. You want the machine learning to learn by itself. But my point is that even if you are learning the model by yourself, by machine learning, namely by what is called "causal discovery," and there are methods of doing causal discovery that are subject to a certain ambivalence, that means you don't have uniqueness. But you can discover a set of causal models that is compatible with the data. Even if you do it purely by starting from scratch, eventually you have to answer a question from a human user and the question that the user asks are causal questions. So you have to know how to manipulate your discovered model and get the right answer. And the answer normally involves explanation, okay. "Why was my loan denied?" <laughs> "Why do I have to go to this bureaucrat?" So you have to explain it. Explanation is a causal process. You have to know how things are organized in the person's mind before you can give adequate explanations. So there is no escape from studying causal reasoning, causal inference, causal networks, okay, and incorporate them into machine learning. There is no escape there. I don't know if I was convincing to you.

Brock: <laughs> Well--

Pearl: So this are the things which are harder for machine learning people to absorb.

Brock: What to you are some of the applications of your work with causal networks and causal reasoning? What are some of the achievements of it--

Pearl: Oh, unbelievable.

Brock: That have really given you, you know, confidence and more courage in the approach?

Pearl: I look at all the obstacles that machine learning people are facing. We can solve them. I'll give you examples. How to deal with confounding, this is one which I already solved two decades ago. Putting heterogeneous data sources together. You have experiment here, experiment there, experiment in Arkansas and you want to combine them together and you want to know how to combine them. Oh, they don't talk about experiments. Sorry, they talk about learning, okay. So assume that you learn something in Arkansas and then you learn something <laughs> in Texas and you want to put them together (two things that you learn). Now they're in the form of two neural networks trained in two different environments and you want to get a conclusion about Hawaii. How can you do that? This is called "transfer learning." It has been in existence as an obstacle, only as an obstacle, not a solution, okay, as an obstacle, as a wishful thinking thing since I think two generations ago. We now have a solution to this problem. If you know the structure of the experiment in Arkansas and the one in Hawaii, you can put them together. We know how to do that, okay. That's called "data fusion." "Missing data," is another solved problem: how do you deal with it, okay? Some sensors fade. People lie on their questionnaire because rich people don't like to be regarded as rich <laughs> and so forth. So how do you correct for missing data? We have a solution for that. We have an algorithm that will fill in the correct data and answer correct question based on a model of what makes people lie or in general, what causes missingness? Another problem is named “selection bias.” People are selected for experiment by the incentives they're getting. They recruit a lot of homeless people. If you measure things on the homeless, how can you generalize to the general population and get the answer for the population on which the drug will be eventually used, okay? Neural nets cannot do that. If you train it on homeless, okay, it's not going to work for the population at large. In summary, list all the obstacles that you can find in the machine learning industry, and we have a solution for them. We haven't left any of them unturned. Plus, much more. We are now talking about “social intelligence” in which robots understand what it means to build trust with another robot and communicate in the level that you and I communicate. “You trust me,” “I really care for you,” “I feel for you.” Or, “have I lied to you before? I haven't, right? Therefore trust me, okay?” This is how people communicate and this is what would make a team of robots play better soccer than non-communicating robots, So I'm talking about implementing social intelligence among robots, okay. This is not doable without having a model of yourself and model of the belief system of your conversant and we have such models. So if you remove models from your training, you're not going to do that. I'm talking even further. I want to algorithmatize free will. Why not? Or consciousness, okay? I don't see any reason why we shouldn't. What is consciousness? That's a big mystery and many philosopher are fighting about. For me, consciousness is one thing. You have a blueprint of your software, you can’t have a total mapping of your software, that will defy the Turing halting problem, right? No. It's just a blueprint. And that is what we mean by consciousness. So you know what the limitation are of your beliefs, you know what you know and don't know, to a certain extent. That is consciousness. Once you have consciousness you can talk about free will which is just a filter that tells you that certain acts were meant to be acted and others were not meant to be acted. They were performed nonchalantly or spontaneously or by an instinct, so you have a filter that tells you which acts were deliberate. That is free will. It comes after the effect, after you enact it. There is no free will, of course. One neuron drives the other. What one neuron does is only a product of what other neurons in the neighborhood tell it to do, okay. So there's no free will but we have a very powerful and vivid sensation that I have the option of either touching my nose or not. Before I even touch it, I'm sure that I have the option, right, which is stupid, which is not true. I don't have the option. Anyway, <laughs> okay. So what -- It is just a filter that tells you which act was done by deliberation and which act was done either by spontaneous motion or by being forced to do it. Now I see a tremendous horizon of applications from having the philosophy of causal networks drive our belief system.

Brock: I wanted to ask you about what you think are the greatest challenges or obstacles for causal networks, causal reasoning to-- in the pursuit of those very ambitious goals that you just mentioned? What are the big challenges in the way?

Pearl: Funding. Research. There are some research problems that we need to work on. Those require research. You have to hire post-docs that we can fund and that would spend a year or two quietly and grind those problems and bring those obstacles to a solution. We are starving by <laughs> the Big Data people. We are not getting the kind of attention both in the educational field and in training and in research. We need a center for causal reasoning and it doesn't exist. Some pop up here and there but they are not funded one-tenth of a percent of what you see in the Big Data business. Not only we – it’s a problem for causal research all around.

Brock: Yeah.

Pearl: If I go today to the chancellor of my university and I say, "I found a millionaire, a billionaire who wants to fund it." He will say, "It's not data science. I want data science. That's where the action is." I'll have a hard time convincing him to change the culture in my university from where it is entrenched right now, which is the hype of data science, okay, and get into some real science. That's what I am doing.

<laughter>

Brock: So it's a cultural challenge at the end of the day.

Pearl: It's a cultural challenge, yeah. I'm facing here a cultural challenge. Believe me, it's a much harder job than St. Paul had going to Rome by himself, <laughs> a nice Jewish boy going to change the entire culture of the empire, of the Roman Empire, okay? And he believed that he can do it because he saw the miracle with his own eye, right? <laughs> He had quite a challenge. Sometimes I feel the way he felt. Even worse. Even worse because, you know, it’s not a big deal to change one religion to another, because we are all after one thing, right? Be good to other people, that's all in common. <laughs> In science, we are facing a much harder challenge because people have invested, especially their leaders, they invested all their professional life in one paradigm.

Brock: Mm-hmm.

Pearl: Thomas Kuhn complains about it, yeah. You can't ask them to change it. They were trained to milk the most from their paradigm, okay. They cannot change it. Don't ask them the impossible. Look at the young people. But if you let these gurus be in control of education, you lost it.

Brock: Well, it's, yeah, it's there's also, I mean, part of the cultural issue I think is some of the rhetorical grounds that people in machine learning and data science have taken, you know, to retreat from these rhetorical grounds where you have the people saying, you know, machine learning is up there with the invention of fire, you know, you've kind of staked out a rhetorical ground that it's hard to retreat from <laughs> or hard to accommodate, you know, other perspectives or possibilities.

Pearl: No, I didn't get that. I understand their rhetorical ground, their rhetorical tools are used very efficiently in preserving the paradigm.

Brock: Right.

Pearl: Yeah, you get, once you get entrenched in one vocabulary, you can't get out of it, okay. That I understand. But I didn't get the relation to the invention of fire.

Brock: Well, that, I was just saying, some of the-- Maybe it's not rhetoric, but it's some of the positions that advocates for, like, a machine learning approach have staked out that will say something like the development of machine learning is up there in historical importance as with, you know, hominids getting control of fire. That's a very strong place to be.

Pearl: That's not true.

Brock: Well, I'm not saying, but it--

Pearl: That's not true because part of the success of fire was that you could learn by imitation.

Brock: I wasn't saying that it was-- I wasn't arguing that that was the case, just to say that if you're-- if you're putting machine learning up there with fire--

Pearl: Yeah.

Brock: It's kind of hard to be, you know, more open-minded about alternate approaches or a challenging approach.

Pearl: If you say that all knowledge comes from the senses, okay--

Brock: Yeah. <laughs>

Pearl: Obviously, the amoeba developed into Einstein, right? You can't beat that. Amoebas did develop into an Einstein, okay. But can we wait for that sequence of evolutionary process to be replicated? That's one question, if it's feasible at all. The other question, we don't have the time to wait for that development and we have so much to learn from our forefathers who have invented fire and they invented the bow and arrow and we can imitate them. So imitation is a very important component. In addition to the imitation comes the reasoning. Why is this bow so much more efficient and this arrow so much more powerful than the others? The reasoning. Once I found the reason, I'll duplicate it in a different way. So reasoning is part of our development. If you take away the reasoning from machine learning, all you have is machine learning.

Brock: Right.

Pearl: Predictive devices. I call it data fitting or function fitting.

Brock: I wanted to shift gears to ask just a few other questions in kind of some different directions, but I first wanted to make sure that there isn't something additional that you wanted to say about, you know, your work in causal networks.

Pearl: I want to say something.

Brock: Yes.

Pearl: I've learned that the ability of a subfield, a field or a discipline, to liberate itself from orthodoxy depends on one or two leaders. All you need is one or two enlightened leaders in a field to make the whole field enlightened. And if you don't have this seed of enlightened leaders, the discipline will remain in orthodoxy for generation after generation. I noticed it through my good luck of befriending <laughs> two epidemiologists in 1995. Eventually we published a paper in 1999 which turned epidemiology around, and liberated epidemiology from the tyranny of statistics. It turned it into an enlightened discipline. Today causal graphs are a second language to every epidemiologist, okay. And look at the field that should have been the main beneficiary of causal graph, namely econometrics. Zero, zero and zero. Why? Because there weren't two enlightened gurus. There's another reason. Economists are extremely proud of their profession, so proud that they have an allegiance to the profession and everything that comes from outside economics must be either invented by some economist earlier <laughs> or its no good.

<laughter>

Brock: Okay.

Pearl: So that's the difference in style of different fields. And I found that this is the crux of the matter. This is what makes science move forward or go-- or move backward, okay. It was a nice <laughs> I would say revelation for me as an academician which I only learned in the last two decades of my life: Find one enlightened guru, and you move the whole discipline.

Brock: Yeah. Well, I guess it goes back to, you know, that-- what you were learning in high school about the, you know, about science and mathematics being the story of people reacting to other people--

Pearl: Yeah. Yeah, yeah, right.

Brock: Building and reacting. You know, it's, it goes right back to that.

Pearl: It's a melting pot of a social jungle.

Brock: Yeah. <laughs> Well, thank you. Thank you for sharing that. I did want to ask because this interview is, you know, related to your winning of the Turing Award. I just wanted to touch on that and ask you about what winning that award meant for you, if that was a validation of all your struggles or, <laughs> yeah.

Pearl: Let me just think about it. I have to--

Brock: Sure.

Pearl: Well, in computer science, it gave prominence to my work -- respectability. People didn't brush it off as they used to. But it took some time before they took the time to seriously consider my ideas, even when they were speculations. Outside computer science I don't think it played a role because people have -- Well, in areas where I thought it's important, like among economics, computer science has a very low reputation, saying: “This is good for computer scientists but not for us.” Even in statistics I occasionally find “There's another method developed in computer science, but that's for computer scientists, okay, not for us. Real scientists.” In short -- it didn't play an important role in penetrating other sciences, but in computer science it did. What else can I say about it? I had to explain myself to other fields within computer science, which was a good pressure for me. And I think I did a good job in my Turing Lecture. What else in the award affected me? It was a steppingstone to other awards, perhaps the National Academy and other awards. Like the latest one, the Frontier of Knowledge Award in Spain. Where they really turned me into a rock star for four days.

<laughter>

Pearl: So.

Brock: Okay.

Pearl: Otherwise-- Well, it does, I mean, I'm sure for many people the fact that I got this award made them more curious about the work that I've done and that's terrific. That means that young people will have the courage to defy their professors, rebel and learn something new.

<laughter>

Brock: Well, I wanted to again shift a little bit entirely to talk about something outside of your professional life that I know has been very important to you. If it's okay, I'd like to ask you about your work with the Daniel Pearl Foundation and your-- what it does and your aspirations for it.

Pearl: I should say that right now we are on a low burner. My wife has passed away and she was the moving personality behind it and I'm busy with fighting for science. <laughs> So it's on a low burner. At the time we felt that we have an opportunity to change the world. We have here a name of a person who is a role model in several circles. Among journalists, he's a role model of decent and honest reporting. Among musicians, he was a journalist who always carried his violin with him to create connection, friendships with people in the various countries whom he visited. And for Jews, he became a role model of a proud Jew, proud of his heritage, primarily due to the last words that he said in front of a camera, "I'm Jewish," which I believe he meant, "And if you have problem with that, it's your problem, not mine." So he became a role model of Jewish pride. And so we have three communities. Then, among Muslims, I should say, many Muslims felt that he represents their own fight against their extremists. So we have here an opportunity of inspiring people in four communities to fight the hate that took Daniel's life. And we did quite well, I believe. I had a series of open dialogues with Muslims, city to city. We had "music days," which was a beautiful project, with 10,000 concerts in dozens of countries. They're still calling me to organize a concert now in Taiwan because China is making threats and they feel that their press freedom is in danger, so they want to put together a music day event in the name of Daniel Pearl there. In short, when people want to continue, we open the door and help them, but we do not now solicit new participation due to the lack of strength, I would say.

Brock: Right.

Pearl: Yeah. So that's where we are. And I do lots of work now defending Israel. Yes. Defending partly in the name of Daniel Pearl since he gives a reason for Jews to be proud, yeah, and partly because of the growth of antisemitism under the guise of Anti-Zionism. So I work a lot in that area. I spend at least 40 percent of my time.

Brock: And how-- is that through speaking out or using your--?

Pearl: I speak out in high schools. I speak out in communities. I do Twitter. I have 61,000 followers in my Twitter account, where we elaborate on issues when they turn into news. And I write a lot. I write op-eds. I have maybe 100 op-eds on various issues of the Middle East conflict. I became an expert on the Middle East conflict, I simply needed to, because I have to debate people who don't see things my way and I have to know the facts and figures.

Brock: What does the-- what are your thoughts about what's happening in this country today--

Pearl: Yeah.

Brock: Around these issues?

Pearl: I don't know. It's bad. The polarization is getting worse. I think this country is going to split if it could, but it's hard for half of the country to secede.

<laughter>

Pearl: I don't know how a person, a pro-choice person can agree with a right to life person. It's one issue that each side sees as basic, basic of all basics.

Brock: Yeah.

Pearl: How can you live with that?

Brock: Well, let me ask a different question then. About your hopes, you know, both from the sorts of issues that we've been talking about with, you know, through your work with the Daniel Pearl Foundation, your hopes for the world and also your hopes for the world of computing.

Pearl: AI will solve the problem.

Brock: <laughs> I should have-- I should have--

Pearl: I'm kidding, but I'm not kidding.

Brock: Well, yeah. So again, it was your hopes for the world and your hopes for the world of computing.

Pearl: Yeah, I think AI could contribute. Not now, but eventually when you do have an understanding of the social fabric, the inner belief of one agent and another, there will be a solution, or a proposed solution coming from AI about conflict resolution. Perhaps a pro-choice guy could sit with a pro-life guy and come to an agreement with the help of AI system who would focus on their commonalities and would enable the two of them to communicate and work together. I can see it's possible in the way that we handle conflicts in our families, in society. There are tricks and methods of conflict resolution. Unfortunately, those who learn the textbook of conflict resolution are the worst in handling real conflicts because they cannot transfer knowledge from one area to another. Some people tell me, "If it works in Ireland it must work in the Middle East, right?" And I say, "Come on, guys. You don't understand the differences, okay." But AI could do it because we have a method now of transfer learning. You understand the key differences and the commonalities. You renovate the former and you build on the latter and you create a new prediction or a new causal effect answer. So we have the basics, just the basics. We are far away from doing it in a huge conflict such as the Middle East or such as the pro-choice and pro-life, okay, but the basics are there -- we can hope. I hope that with the algorithms that will be developed eventually in social intelligence, that AI systems will enable us to come together.

Brock: That's great. I guess I have-- I have one last question that I had to ask. But before I do that, I just wanted to make sure to ask you if there's anything that, you know, we've missed out on or that we should-- that you feel we should talk about that we haven't yet talked about?

Pearl: I think we really covered everything.

Brock: <laughs> Okay.

Pearl: Oh, I was born in a hospital. <laughs>

Brock: Yeah. <laughs> We got it.

Pearl: <laughs>

Brock: The last question I wanted to ask is something that we ask everyone who we interview and that is for one word of advice for someone who is starting out on their career or their educational journey or just as a young person, if you could give those people one word of advice, you know, what would that be and why that word?

Pearl: Well, insist on understanding things your way. Don't take `No’ for an answer. Rebel against your professors, in order to understand things your way. Yeah.

Brock: Well, that's great. Well, I think that's all the questions that I had. Thank you so much. Thank you so very much for doing this interview with us.

Pearl: Thank you very much.

Brock: Yeah.

END OF THE INTERVIEW

