A conversation with Robert Fano

Sergio Verdú

I met with Robert Fano on June 14, 2013 in his residence in Concord, Massachusetts. What follows is an edited and condensed transcript of our conversation.

SV: Bob, at 95 you seem to be in great shape.

RF: I lost the vision in one eye a few years ago and I have some dizziness in the morning but, otherwise, I cannot complain.

SV: You were born a year after Claude Shannon.

RF: Yes, in Torino. Italy. I grew up in an academic environment. My father, Gino, was a Professor of Mathematics at the University of Torino. He had worked with Felix Klein. He died in 1952. My older brother, Ugo, became a theoretical physicist and worked with Fermi and Heisenberg. He became a professor at the University of Chicago and died in 2001; My cousin Giulio Racah, was also a theoretical physicist. He eventually became rector of the Hebrew University of Jerusalem.

SV: What are your memories of Torino?

RF: I have very happy memories of my life in Torino. I did mountain climbing on skis in winter and early spring and, rock climbing with ropes and pitons in the Dolomites during the summer. My happy life ended abruptly in 1938 when I turned 21 and Mussolini decided to join Hitler in a campaign against Jews, in spite of the fact that there was no sentiment against Jews in the country. Suddenly, a committee of "experts" decided that there was an identifiable Italian race of which Jews were not part. That was the beginning of the racial laws. These laws had become serious enough by fall that my family decided that we should leave Italy. My parents went to Switzerland; my father would not go to any country that might be at war with Italy. My brother decided to come the US. He was already in Paris and arrived in the US in the Summer of 1939 after picking up his wife in Argentina where she had gone earlier with her family. I decided to complete my fourth year of engineering in Torino, but not the fifth one, before emigrating.

SV: So you decided to come to the US because your brother was here...

RF: No, I too wanted to come to the US. I had visited the US with my parents in the summer 1932 and I had a great memory of it. I took the exams of the 4th year of Engineering and joined my parents in July 1939 with the intent of getting the visa to the US in Switzerland.

SV: Was that electrical engineering?

RF: In Italy, Engineering was a very broad program with the specialization occurring in the last year. For reasons I don't remember I was always interested in electrical engineering.

RF: Back to the visa to the US. I had to make several trips to the US consulate in Zurich. On August 31 I was told that my visa was just waiting for the quota number from Washington. Upon leaving the consulate, I saw in the newspaper that Germany and Russia had signed a non-aggression treaty, which meant that the war was going to start the next day. And in fact it did. Now my problem was to get to the US. I could not leave from Italy because Mussolini did not approve emigration to the US. I had to leave through France, which was already at war and required that all visas be approved in Paris. Fortunately, I was traveling with a cousin from Rome who had family diplomatic connections leading to the French ambassador. I got though him the visa to get aboard the Manhattan in Bordeaux. I arrived in New York in late October 1939. My brother Ugo was there to greet me.

SV: How was your English?

RF: I had learned English in Italy but I had trouble with local accents, particularly in Washington where I spent my first two months. My first task was to complete my undergraduate engineering degree. Initially, I did not apply to MIT because I thought I had no chance of being admitted to such a famous school. But my sister-in-law, who had a sharp tongue, insisted that not applying was a sure way of not being admitted! So I did apply, and MIT was not only the first school to admit me but also the one that gave me the most credits for my studies in Italy, including for the humanities that I had taken in high school. It turned out that MIT was very friendly to foreign students. I started at MIT in February 1940 and, by attending the summer term, I completed the requirements for the SB degree by February 1941. I received top grades in all subjects except for the first laboratory. I mention this because I was well aware that my personal standing would not cross the Atlantic with me and I would have to rebuild it in the US.

SV: You worked extra hard.

RF: I did. My thesis was on the feedback control of the speed of an electric motor. The executive officer of the EE department asked me if I would be interest in a teaching assistantship. I said no, because at that time I wanted to go to work in industry. Unfortunately, the electrical industry was already on a war footing and the jobs that I was offered turned out to require a military clearance that I could not get because I was not a US citizen. The only job that did not require a clearance was in a General Motors stamping and welding plant in Grand Rapids, Michigan. Unfortunately, the job turned out to be very different from what I had expected and rather unpleasant. I informed MIT that I had changed my mind. The offer of a teaching assistantship arrived at the beginning of the fall term and two days later I was on my way back to MIT.

Teaching assistants were expected to devote half of their time to the tasks assigned to them and the other half to their graduate studies so that they could qualify for an SM degree by the end of the second year. My first year went according to this plan, but by the beginning of the second year, September 1942, the US was at war and several members of the faculty had left for war duties and teaching assistants had to take over their classes. I had the opportunity to attend the classes of a subject that I had to teach

the next term. Otherwise I had to learn the material just ahead of my students. That kind of teaching became a major part of my graduate education. Apparently my performance was good enough to merit my promotion to the rank of instructor. In addition I was put in charge of a pair of graduate subjects on microwaves and antennas that, of course, I had never taken. This time I was really two weeks ahead of my students and they were aware of it. We learned together. I was encouraged to accept that tasks by my mentor, Ernst Guillemin, the "guru" of network theory who told me that he had started out by being asked to teach a subject on filters about which he knew nothing. Did you know about Guillemin?

SV: Sure I did. As an undergraduate in Barcelona we had a full course on network synthesis. We learned all about Guillemin, Cauer, and Hurwitz polynomials.

RF: By the way, what does Verdú mean?

SV: Nothing. It is the name of a town in Catalonia.

RF: Fano is the name of a town on the Adriatic coast. Some Pope had decreed that Jews had to adopt the name of their town of origin.

SV: Yes, also in Spain.

RF: Back to MIT. By the summer of 1944, Italy was out of the war and I was cleared to join the Radiation Lab since I was no longer a citizen of an enemy nation. I became a "microwave plumber" and designed a variety of components for radar systems. I also became a coauthor of two chapters on microwave filters in volume 9 of the Radiation Laboratory series. I completed the manuscript of those chapters in April 1946 just when the leftover of the Radiation Laboratory became the beginning of the Research Laboratory of Electronics. I became a Research Associate in the Electrical Engineering Department, resumed my teaching, and turned my attention to completing my doctorate.

The doctoral thesis was the major task confronting me. Most of my time at the Radiation Laboratory was spent "broadbanding" some microwave component and I often wondered whether there was a fundamental limit to how broad a band could be achieved. I decided to tackle that problem in the simpler case of a two-terminal network of LCR components, with antennas being special cases. The problem had been solved by Hendrik Bode for simple RL and RC impedances. I didn't get anywhere until Christmas. I was walking to the train station to go to Washington when I saw the light. The rest was just a lot of mathematics in the complex plane. The thesis titled "Theoretical Limitations on the Broadband Matching of Arbitrary Impedances" was completed in time for my receiving my ScD in June 1947.The graduation ceremony that took place (for the last time) in Boston's Symphony Hall was attended by my parents. My appointment to Assistant Professor started shortly thereafter on July 1, 1947.

My interest turned at that point to the field of communication in which there was considerable activity in RLE, mostly centered on the book by Norbert Wiener entitled "Extrapolation, Interpolation, and Smoothing of Stationary Time Series".

SV: Had you already met Claude Shannon?

RF: I had heard of him from Jerry Wiesner who was an undergraduate with him at the University of Michigan and because Shannon's Masters thesis was famous at MIT. Jerry had told me that Shannon was developing some sort of theory of communications. I had no idea what it was. Norbert Wiener had the habit of wandering into friends' MIT offices, making some statement and then leaving without waiting for an answer. One morning he came into my office with his cigar and said "You know: Information is Entropy" and walked out without any further comment. I never found out where he had gotten that idea but it excited my curiosity and I kept thinking about it. Again, while walking to the train station to attend the IRE meeting in New York, it occurred to me that that relation might have to do with the representation of messages with binary digits. By the time I arrived to New York I had defined the entropy of a set of messages and proved the coding theorem for noiseless channels.

SV: In fact, Shannon describes your idea in his paper.

RF: Wait a minute. At the IRE meeting the next day I buttonholed Shannon after the presentation of his paper, and asked him permission to visit him in his office the next day. Obviously, he didn't like the idea but he was nice to me and he agreed to see me. The next morning, I went to Murray Hill and he received me in his office with the same bored face. But when I started telling him what I had done on the train his face lit up: I had duplicated the initial part of his work. Shannon was kind enough to make reference to my work in his famous BSTJ paper that appeared in the fall 1948. I was very embarrassed when Shannon asked me for a reference to my work. I had not yet put it on paper. I gave him the first unused number in the series of reports of the Research Laboratory of Electronics and got busy writing the report.

SV: When you first saw Shannon's paper, were you already familiar with the language of probability, random processes? It was not yet common in the toolbox of engineers.

RF: I was generally familiar with it, but there was still a lot to learn. The basic and most important notion in Shannon's work is that information is transmitted in the form of selections from finite sets of messages. This was very different from the previous goal of accurate transmission of waveforms. I accepted Shannon's statement that it was possible to transmit information at any rate smaller than channel capacity with a vanishing small probability of error. However I was not satisfied with Shannon's original proof. I challenged a physics student looking for a thesis topic to provide a solid proof. He did it in a very short time but I had a very hard time getting him to write a thesis acceptable by the physics department. He had the mind of a mathematician and not that of a physicist.

SV: Was this Feinstein?

RF: Yes. He was a very bright fellow but there was something strange about him. I don't know what happened to him.

SV: He wrote a book and translated Pinsker's book into English. He is one of the people in information theory I always felt was most underrated. Wolfowitz, Ahlswede, that mathematical branch of information theory, was very much influenced by Feinstein's work.

RF: He disappeared. The last time I saw him was at an information theory meeting at Lake Como.

SV: Did you keep in touch with Claude Shannon? What was he like?

RF: Oh Yes! He was a wonderful and interesting person. He had the strangest ideas. He built an aerial tramway in his backyard to the lake. He bought a school bus and transformed it into a travel home. He learned how to ride a monocycle…etc. He came to MIT as a visiting professor and then accepted a permanent chair. However he never acted as a regular professor. He lectured for a while; he was a wonderful speaker. Then slowly faded away. When I became director of Project MAC I put a time-sharing terminal in his home hoping that he would do something interesting, but only Betty used it. Claude was very photogenic; I was given a portrait of Claude around 1965, and it is still adorning my office.

SV: So true. Also Shannon had the fortune to be photographed by some of the giants of XXth century photography: Henri Cartier-Bresson, Alfred Eisenstaedt.

SV: Your course on information theory must have been the first course on the subject anywhere.

RF: Yes, I believe so. The first time I offered the subject in 1950 I presented in class all I knew about the subject, just a little more than the content of Shannon's paper. I could not think of problems for the students to solve so I asked them to write term papers on some pertinent subjects. Dave Huffman, who was in my class, invented the procedure for constructing the most efficient codes.

SV: He was your PhD student?

RF: No, I believe his thesis was on switching networks.

SV: Going back to Wiener, did you ever talk with him?

RF: Yes, but always about what interested him.

SV: Did he know you were teaching "Information Theory"?

RF: Possibly. However I doubt he knew what I meant by information theory. Wiener was a bit professionally self-centered; also he was getting old and had vision problems. I doubt that he ever read Shannon's 1948 paper.

SV: Peter Elias. He also became interested in Information Theory.

RF: I gave a talk at Harvard and he came to speak with me. I thought he was very smart and I invited him to come to MIT as an assistant professor. He did some very good work in information theory and eventually became Department Head. He died very suddenly in 2001.

SV: You came up with the name "mutual information".

RF: Yeah. It's not generally known that I did. I am surprised you know that.

SV: How did Fano's inequality came about? Did you notice there was a gap in the converse in Shannon's paper?

RF: No. I felt that entropy measures did not provide a physical understanding of the process of communication in the presence of noise. Noise causes errors and the probability of error is what counts. So I thought it would be nice to relate the entropy loss caused by noise to the probability of error.

SV: You never published it.

RF: By that time I didn't worry about publishing. My information theory output was primarily in my class notes and my textbook.

SV: Let's talk about your next phase: computers. At some point you decided you had enough of information theory.

RF: My textbook "Transmission of Information" evolved in the form of class notes over a decade and appeared in print in 1961. I was developing at the same time class notes for an undergraduate subject on electromagnetism which led to the textbook "Electromagnetic Fields, Energy, and Forces" that appeared in print at about the same time. I decided to take a vacation from teaching in the form of a sabbatical leave at the MIT Lincoln Laboratory over the academic year 1961–62. My intention was to look around for something else to do but my mind kept going back to information theory and I ended up inventing the sequential decoding algorithm that I described at the end of my invited paper "A Heuristic Discussion of Probabilistic Decoding". It was a good idea, but it could not be used in practice at that time. A few years later, however, Irwin Jacobs mentioned my algorithm while introducing me at an IEEE meeting, pulled a chip out of his pocket and said "here it is"! Indeed, chip technology made a big impact on the evolution of information theory.

SV: By the way, you gave one of the first Shannon lectures.

RF: Yes, the third: Shannon, Slepian and me. By that time I had been away from information theory for several years and I must have talked about on-line computation and time-sharing systems. I got involved with computers and became the founding director of Project MAC, a laboratory that has evolved into the present "Computer Science and Artificial Intelligence Laboratory".

Project MAC originated from work done at the MIT Computation Center toward the two goals that eventually led to the present Internet: providing personal access to computers and providing it to the population at large in the form of a computer utility. In the fall 1962, a branch of the Advanced Research Projects Agency of the Department of Defense directed by J.C.R. Licklider was offering large financial support for work toward these goals. MIT was in an excellent position to obtain it because of the work already in progress at the Computation Center. What was missing was an individual willing to pull together the MIT resources, write a proposal and, if accepted, lead the research effort. I felt very strongly that MIT should not miss this opportunity particularly because I believed that Computer Science was going to become an important new discipline. Unfortunately the right person was not available. I had no management experience, and I was not, by nature, a multitasker. In the end, I closed my eyes and jumped in. Fortunately I had the full support of the MIT administration and the wholehearted participation of the Computation Center. Project MAC started on July 1, 1963 and I was its Director until the Fall of 1968.

SV: That must have been quite a job managing the logistics of such a large scale project. A lot of headaches.

RF: Yes. I had a lot of those.

SV: How long did the project last?

RF: Still exists. Just changed its name. At the beginning I didn't want to call it a Laboratory because I needed the participation of people from the whole of MIT. Later on it became the Laboratory for Computer Science.

SV: Tell me a bit about your family.

RF: I met my wife at a dance on Valentine's Day 1948. We got married in the Spring break in 1949. Our first girl was born in 1950, the second girl in 1955. Our boy was born in 1960. He recently decided to change sex so now I have three daughters. I have five grand children. They are all doing fine. I lost my wife in August 1998 to ovarian cancer.

SV: Well, Bob it has been a pleasure meeting with you and listening to so many fascinating stories.

Photo courtesy of Sergio Verdú

RF: Let me just add that I formally retired in 1984, but I still have an office in CSAIL, which I share with my colleague J.F. Corbató. I still drive to MIT periodically.

SV: Bob, you are so fortunate that your mind is so sharp. Stay healthy! One more thing: Would you mind if I take your picture?

RF: Oh sure.

IEEE Information Theory Society Board of Governors Meeting Minutes

Catamaran Resort, San Diego, CA, 02.10.2013, 1–6 pm

Edmund Yeh

Present

Jeff Andrews, Matthieu Bloch, Giuseppe Caire, Michelle Effros, Abbas El Gamal, Elza Erkip, Michael Honig, Tara Javidi, Negar Kiyavash, Joerg Kliewer, P. Vijay Kumar, Urbashi Mitra, Alon Orlitsky, Petar Popovski, Paul Siegel, Emina Soljanin, David Tse, Rudiger Urbanke, Sergio Verdu, Alex Vardy, Emanuele Viterbo, Edmund Yeh, Aylin Yener.

The meeting was called to order at 1:10 pm by the Information Theory Society (ITSoc) President, Gerhard Kramer, who welcomed the Board of Governors (BoG).

1. Motion: The minutes of the BoG Meeting at ITW 2012 held at Lausanne, Switzerland, were approved.

2. Motion: The agenda was approved.

3. Gerhard Presented the President's Report: Gerhard welcomed the new members of the BoG: Jeff Andrews, Michael Honig, P. Vijay Kumar, Emina Soljanin, Rudiger Urbanke, and Ram Zamir.

Major honors for IT Society members were celebrated: Sol Golomb (recipient of U.S. National Medal of Science), Abbas El Gamal (elected Member of the U.S. National Academy of Engineering), Shlomo Shamai (Shitz) (elected Foreign Associate of the U.S. National Academy of Engineering), Irwin Jacobs (recipient of the IEEE Medal of Honor), Robert Calderbank (recipient of the Hamming Medal), Erdal Arikan (recipient of the W.R.G. Baker Prize Paper Award), Vahid Tarokh, Hamid Jafarkhani, Siavash Alamouti (recipients of the Eric E. Sumner Award).

Congratulations to the new IEEE Fellows from IT Society: Jeff Andrews, Andrew Barron, Gerard Cohen, Max Costa, Suhas Diggavi, Anders Host–Madsen, Kenneth Kreutz-Delgado, Tamas Linder, Daniel Palomar, Erchin Serpedin, Antonia Tulino, Pramod Viswanath, Tsachy Weissman, Feng Wu.

Gerhard noted that the IEEE Technical Activities Board (TAB) meeting will take place February 15–16. The IT Society Review will take place on Thursday, Feb. 14. He expressed thanks to Muriel for organizing the society review, and to the following contributors for providing text: Bruce, Helmut, Abbas, Sriram, Elza, Joerg, Negar, Prakash, Frank, Tara, Matthieu, Aylin.

4. Aylin Presented the Treasurer's Report: Aylin first summarized some recent conference closings. The 2011 North American IT School held in Austin, Texas, ended with no surplus (and with $25,008 society support). The 2011 ISIT ended with a surplus of $118,074. The 2012 North American IT School, Cornell, ended with a surplus of $6,939. Conferences which have not started the closing process include the 2012 European IT School, Turkey, April 2012, and the 2012 ISIT, MIT, July 2012.

With regards to conference closings, Aylin held up ITW 2012 as a great example. The conference generated a surplus of $8,453. It was held September 2012 in Lausanne. As of February 7, 2013, it was ready to close within a week. The overall process took only five months from the conclusion of the conference (inclusive of the audit).

Aylin continued onto the 2013 budget. The budget was prepared in May 2012, approved in July 2012, and finalized in November 2012. The initial projected surplus for 2013 was $131k (approved by Aylin). The surplus was then decreased to $2k due to an increase in the page budget of IT Transactions pages to 8000. Then, in September, the budget was updated to have a surplus of $179.4k. The explanation given by the IEEE is that this was due