Reflections of Some Shannon Lecturers (continued)

The following brief commentaries by four recipients of the Shannon Award provide enlightening personal insight into the minds and attitudes of those who reached the pinnacle of achievement in our field. All but the last of these these reflections were not available in time for their inclusion with those that appeared in the Summer 1998 Special Golden Jubilee Issue of this Newsletter. The final piece, by Jacob Ziv, is reprinted here due to an error in its original printing.
The Eds.

Mark Semenovich Pinsker

(1979 Shannon Award Recipient)

[Editors' Note: Mark S. Pinsker was invited to be the Shannon Lecturer at the 1979 IEEE International Symposium on Information Theory, but could not obtain permission at that time to travel to the symposium. At the 1995 symposium, he was officially recognized by the IEEE Information Theory Society as the 1979 Shannon Award recipient.]

It does not often happen that the name of the founder of a theory and the theory itself are as closely linked as the name of Claude Elwood Shannon and information theory. Many others have contributed to the development of this theory, but Claude Shannon towers over every one of us.

The great Kolmogorov was the first to appreciate the importance of Shannon's ideas for mathematics as a whole. His remarkable words about Shannon made an indelible impression on me. This is what he wrote:
"In our age, when human knowledge is becoming more and more specialized, Claude Shannon is an exceptional example of a scientist who combines deep abstract mathematical thought with a broad and at the same time very concrete understanding of vital problems of technology. He can be considered equally well as one of the greatest mathematicians and as one of the greatest engineers of the last few decades. ... It is true that Shannon left to his followers the strict mathematical validation of his ideas in cases of real complexity. However, his mathematical intuition is amazingly correct. I know of only one case where his intuition seems to have deceived him: the correctness of the formula for λ at the end of Appendix 7 to his paper 'The mathematical theory of communication' is open to doubt."

The mentioned formula is about "the dimension rate per time unit", based on the calculation of the (ϵ, δ) entropy of a random process per time unit. The most striking thing was that even in this case Shannon's "amazingly accurate" mathematical intuition did not fail him. Years later it was proved that Shannon's formula in Appendix 7 was correct–it was he who was right and not Kolmogorov!

In 1965 Shannon visited Russia at the invitation of the Alexander Popov Scientific and Technical Society of Radio Engineering and Electrical Communications. He met Kolmogorov, Kotelnikov, Siforov and the world chess champion, Mikhail Botvinnik. He even played a game of chess with the latter. He lost, but accepted the defeat with dignity. Boris Tsybakov, who was present at Shannon's meeting with Kolmogorov, told me that Shannon tried to arouse Kolmogorov's interest in a problem of multi-user channels. Many people who chanced to

meet Shannon then recall him as a very attractive man with delicate features, a somewhat swarthy complexion, and a graceful stature and style of dress.

In the USSR, information theory, influenced by Kolmogorov, was developing with a visible mathematical "bias", although Kolmogorov himself had a keen interest in the applications of information theory and used to question me closely about various models of communication channels, sources, etc. He admired Shannon's engineering intuition no less than his mathematical insight.

The ideas of Shannon's information theory spread rapidly to a variety of scientific domains and this has been reflected in the activities of our institute in Moscow, the Institute for Information Transmission Problems of the Russian Academy of Sciences. Conceived as a community of engineers and mathematicians, the institute soon incorporated biologists and then linguists. It is now a broad community of scientists whose contributions are known the world over. However, in the beginning was the word of Claude Elwood Shannon.

William L. Root

(1986 Shannon Lecturer)

I was regrettably slow in coming to a real appreciation of Claude Shannon's magnificent theory of information, and unfortunately, was not very much directly motivated and instructed by his work. In 1952 when I joined the staff of the MIT Lincoln Laboratory in Bill Davenport's communication group, I was made aware of Shannon and his 1948 paper. But I was then trying to learn some stochastic process and statistical inference theory and did not pay much attention – not even when a little later Tom Pitcher and I checked through Amiel Feinstein's proof (handwritten by Feinstein on a couple of sheets of paper) of a channel coding theorem.

In 1968 Pravin Varaiya and I published a long paper on the capacity of a continuous-time Gaussian channel for which the signal is transformed by a linear integral operator known only to belong to a certain class of operators. Our treatment was based on a 1959 paper of Blackwell, Breiman and Thomasian "The capacity of a class of channels," with no reference to Shannon. We were certainly motivated and influenced by Shannon's development of information theory, but only through intermediaries. This was my only research venture into what might be called classical, probabilistic Shannon information theory.

In one instance though I felt Shannon's influence directly in a sort of backhanded way. This was in the late 1970's. I had become interested in coding for channels that are not characterized probabilistically, with the constraint that any admissible code possess a decoding scheme yielding zero error. I was not motivated by any particular thing I had read and was totally unaware of Shannon's classic paper "The zero-error capacity of a noisy channel." In my approach to this problem, I defined a channel as a set of mappings from input (transmitter) to output (receiver), this set to be known to both communicators, but the particular mapping in effect over a given time interval unknown to both of them. Included are certain channels with finite, but not necessarily zero, memory. I presented some preliminary results on attainable rates and channel capacity for such channels at a NATO Institute in 1977. At this presentation Jim Massey pointed out that one of my theorems on zero-error capacity was false in the generality stated – a counterexample being provided by a channel whose adjacency graph is a pentagon and discussed in the Shannon paper just mentioned.

The zero-error capacity of such a channel had been left as an open problem by Shannon and was not determined until later by L. Lovasz, but Shannon had done enough to give the counterexample. I need hardly add I then read the 1956 Shannon paper.

Eventually I accumulated enough special results in this area to warrant a paper in the IT Transactions–at least so I thought, and also, grudgingly, did the editor. The paper appeared in 1982; it incorporates a few of Shannon's results, but I was not able to use his elegant approach to extend what I had done.

David Slepian

(1974 Shannon Lecturer)

Shannon's monumental paper "A Mathematical Theory of Communication" was first published in two parts in the July and October 1948 editions of the *Bell System Technical Journal*. At that time I was a graduate student in physics at Harvard starting my doctoral thesis. I was granted my degree in the summer of 1949 and in the fall of that year, as a Parker Fellow in physics from Harvard, I went off to Europe to spend my last year as a student.

In September 1950 my real professional career began when I accepted an offer to work in the Mathematics Research Center of Bell Laboratories. I had interviewed at the Laboratories in several departments searching for a physicist and was quite surprised and pleased that the offer came from the Mathematics Research Center, for the truth of the matter was that the part of physics that I enjoyed most was the mathematical one. However, as I had never taken any graduate pure mathematics course, I felt somewhat uncertain that I could handle the job before me. On my first day of the new job, my boss, Brockway McMillan, gave me Shannon's paper to read and study. I had never before heard of Shannon or of Information Theory. Was this paper of importance to me? For the next 32 years, the duration of my entire professional career, at least 3/4 of my waking hours were devoted to pondering this theory and its many consequences. As I worked on and became more familiar with the earlier work on communications, I came to see what a truly remarkable contribution had been made by Shannon. This paper was a gem.

Was this paper of importance to others? At first mainly to the theorists. Many of the remarkable ideas for improving communications that were suggested there were soon seen to be too complicated to be realized practically with the existing technology. But then in the sixties and seventies along came integrated circuits and practical computers and new levels of manipulating signals were attainable. The ideas contained in Shannon's paper could be implemented. The present "explosion of the digital world" is the result. As to the theoretical importance of this paper, as more and more scientists have come to appreciate its generality, its profundity, and its originality, it has come to be regarded by many as the greatest contribution to science and technology by a single scientist in the last half century. I thoroughly agree, as will surely most readers of this *Newsletter*.

The readers of this reminiscence would of course like to hear some words about Shannon himself. My office was two doors down from his for the six years 1951-1956. We were friends who chatted together, sometimes talked shop a bit, but never were co-workers. Claude was way out of my class for me to suggest that, and he by nature was a lone worker, one of the few on the corridor who worked with his door closed. He was much interested in the

theory of computers at that time and I believe that the only workers at Bell with whom he collaborated during that period were Edward Moore and David Hagelbarger whose interests were close to his. I consulted with him occasionally on difficulties in my work. He was always ready to hear me out and almost always had an immediate understanding of the problems and useful suggestions to make. But my more usual sources of aid and sympathy were Brock McMillan and Ed Gilbert with whom I consulted much too often, I'm sure.

A good feeling for Shannon's personality can be had from the two interviews with professional reporters that are reproduced in the introduction to *Claude Elwood Shannon, Collected Papers* by Wyner and Sloane, IEEE Press, 1993. I believe two caveats are appropriate with regard to these interviews. They may give the impression that Shannon was shy. I do not think he was; he just did not care to become instant buddies with everyone. They also fail to show how lightly he took life. Many things about our society amused him and he did enjoy to laugh at them privately. In making his many machines I always thought Claude was having great personal fun. That he might be demonstrating something of importance seemed quite incidental to him. In fact, in those early days he seemed to take an enormous hidden amusement at all things going on around him in the external world – in his notoriety, in the silly pompous questions his interviewers sometimes asked him, in the fact that he didn't answer his mail, that he made scads of money without really working for it. Everything seemed to secretly amuse him. I can best describe the nature of his cleverness by noting that with a tiny shift in his mores he could have been the world's greatest, most ingenious con-man and its most charming scoundrel. As he was, he was one of its greatest scientist and a remarkable modest original man.

For the last several years, Claude has been a victim of Alzheimer's disease. With Ophelia as she laments in "Hamlet", "O, what a noble mind is here o'erthrown", we all cry out at this most unjust irony of Fate.

Jacob Ziv

(1997 Shannon Lecturer)

I well remember my first visit to Shannon's own study.

I came to MIT to study for my D.Sc. degree in the fall of 1959. Being an R&D engineer, I already knew that it was Information Theory that I would like to learn and investigate. I had first encountered Claude Shannon's monumental contributions after reading and trying to understand Goldman's book on the subject. I was therefore excited when my wife, Shoshana, and I were invited one weekend in the fall of 1959 to an open-house party for all the new foreign students to take place at the Shannon's residence, a beautiful house on top of a hill.

If I remember well, Claude was out-of-town that weekend, but many of the EE faculty were there to host us and warmly greet us. The party took place on the Shannons' huge hillside lawn. We were all impressed by one of the many self-made gadgets: a cable car that took you all the way up to the house. But one could operate it only at dinner time! (A clear message to the Shannon kids to be home for dinner on time!)

After a warm welcome by the faculty, I decided to dare to have a look at Claude's own study. I was impressed by the sight of a huge blackboard behind his desk. The blackboard was covered by a green shade. I was suddenly facing a real dilemma: Should I dare to have a peek at some of Claude's most recent, yet unpublished great results? Finally, after a period

of tense hesitation, I moved the shade slightly, only to find out that there was indeed a formula spelled on the blackboard, neatly written in big letters;

$$H = -\sum_i p_i \log p_i.$$

Claude was apparently ready for us, counting on the fact that at least some of us could not withstand the temptation ... Since then, I never actually stopped searching for many of the erased results on Shannon's own blackboard.