Jacob Ziv

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A Biographical Memoir by Neri Merhav, Shlomo Shamai (Shitz), and Andrew Viterbi

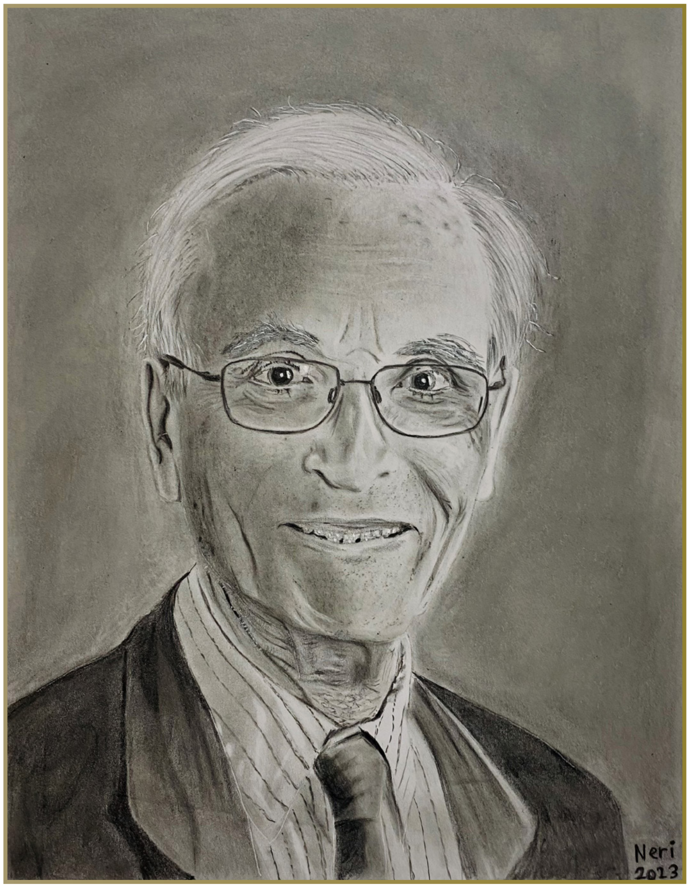

Figure 1 Jacob Ziv. *Credit: Neri Merhav.*

Jacob Ziv was a pioneering electrical engineer in the fields of information theory and data compression technology. He is best known as the codeveloper of the Lempel-Ziv data compression algorithms, which continue to enhance capabilities in devices everyone uses on a daily basis, including cellphones and tablets. The algorithms revolutionized the process of data compression, bypassing the requirement for a prior knowledge of the statistical parameters of the data source. Moreover, Ziv proved that the resulting length of the compressed data sequence approached the lowest number theoretically achievable.

Early Life, Education, and Academic Career

Jacob Ziv was born in Tiberias, Israel, on the shore of the Sea of Galilee. He was the younger of two sons of Ben Tzion and Hannah Ziv. His father was an elementary school principal in Tiberias and later moved to a similar position in Ra'anana in north-central Israel (the school has since been named after him). Jacob and his wife, Shoshana, were parents of four children and grandparents of nine grandchildren and lived to welcome one great-grandchild.

After graduating from high school, Jacob entered the Technion-Israel Institute of Technology, earning a bachelor of science degree in 1954 and a master's degree in 1957 from what is now the Department of Electrical and Computer Engineering. In 1954, he began his career as a research and development engineer in the Scientific Department of the Israeli Ministry of Defense. In 1960, he earned a fellowship to the Massachusetts Institute of Technology (MIT) and took a leave of absence from his job. He earned a Ph.D. from MIT in 1962 with a thesis in communication and information theory. During summers, he also spent time at Bell Laboratories in New Jersey, working with and learning from the pioneers of information theory. Returning to his job in Israel, he remained with the Research Establishment until 1970. That year, Ziv joined the faculty at Technion and over the following half century rose to the Technion's highest academic title of "Distinguished Professor" in the Department of Electrical and Computer Engineering.

He also accepted several administrative roles over this period. At various times, he was dean of the Electrical and Computer Engineering faculty, vice president of Academic Affairs, chair of the Israeli Planning and Grants Committee, and president of the Israel Academy of Sciences and Humanities. During sabbaticals, he also maintained his collaboration with colleagues at Bell Laboratories.

Research Career and the LZ77 and LZ78 Algorithms

During the latter half of the 1970s, Jacob Ziv and colleague Abraham Lempel introduced a groundbreaking shift in information theory.[1,2,3] Departing from the conventional probabilistic paradigm, which characterized sources and channels with known statistical properties, often memoryless in structure, they envisioned a new direction. This was the individual-sequence approach combined with finite-state (FS) encoders and decoders, which offered a fresh perspective on universal data-compression techniques and on coded communication in general. It was within this paradigm that the seeds of the LZ algorithm were sown, culminating in its first two versions in 1977 and 1978: the LZ77 and LZ78 algorithms, respectively.

Countless words have been dedicated in the scientific literature to the illustrious LZ algorithms, lauded for being rare examples of the possibility of the coexistence of an elegant theory and remarkable practicality. Their influence, together with those of later versions of the LZ algorithm, reverberates through the fabric of modern life, touching every individual who possesses a computer, a smartphone, or any device that stores digital information. The impact of the LZ algorithms is profound, representing some of the most widely employed techniques for lossless data compression. Among these, DEFLATE stands out as a variant tailored for optimizing decompression speed and compression ratio. Notably, in the 1980s, spurred by the work of T. Welch, the Lempel-Ziv-Welch (LZW) algorithm emerged as the preferred method for a wide array of compression applications.[4] Its versatility is evident in its adoption across various domains: from GIF images and compression utilities like PKZIP to hardware peripherals such as modems. Moreover, it underpins the compression of file formats such as PDF, TIFF, PNG, and ZIP, as well as popular video formats like MP3, used daily in the multitude of cellphones worldwide. Furthermore, the ubiquity of LZ compression extends to all devices that store or transmit digital content. In each case, it quietly operates in the background, seamlessly managing digital information storage. It is a testament to the algorithm's efficiency that countless individuals interact with LZ compression on a daily basis without necessarily being aware of its presence. The LZ algorithms are a special example of the rare combination of a beautiful theory on the one hand and great practicality on the other hand.

Less commonly recognized are the additional pillars of the individual-sequence approach, alongside the versatility of the LZ algorithms, especially the LZ78 version. Beyond its role in universal data compression, the LZ78 algorithm serves as a potent engine for an array of information processing tasks spanning universal channel decoding,[5] prediction,[6] hypothesis testing,[7] model order estimation,[8] guessing,[9] filtering,[10] and more. Remarkably, the asymptotic optimality of the LZ78 algorithm as a data compressor induces the asymptotic optimality of all these tasks as well. This broad utility suggests that there must be something very deep associated with the ability of the incremental parsing mechanism to gather statistics from data in a profound sense.

Jacob Ziv's contributions to information and communication theory were not limited to universal lossless data compression and its applications. In particular, his contribution to information theory, on which he collaborated with Aaron D. Wyner, is known as the Wyner-Ziv source coding theory;[11] it establishes the path to optimal lossy data compression when side information is available at the decoder only. This is an important extension of the famous Slepian-Wolf coding theorem, which applies to lossless data compression. Wyner-Ziv coding has provided a tremendous benefit in both theoretical and practical aspects of communication and information theory. Most notably, it has been widely applied to video compression.[12]

Ziv contributed to a variety of other results within the field of information theory and communications. One of these relates to the notion of "information combining,"[13] which is central to the theoretical analysis of modern coding schemes. It is especially important in the class of low-density parity-check (LDPC) codes that approach the Shannon channel capacity bound.[14] These results are relevant to information bottleneck problems, which provide theoretical tools for investigating deep learning algorithms.[15] Ziv's paper with Lawrence Ozarow and Aaron D. Wyner was an important contribution to the analysis of communications systems with practical constraints (such as peak-power).[16] Ziv has also contributed to estimation and signal-processing theory through the classical Ziv-Zakai bound on parameter estimation,[17] which is one of the tightest available bounds on accuracy and whose relevance to general frameworks is reflected in recent studies on quantum parameter estimation.[18]

Awards and Honors

As his research gained worldwide recognition, Jacob Ziv received numerous honors and many of the most prestigious awards of his profession, both in his country and worldwide. His most important international awards include the Marconi Prize (1995), the BBVA Foundation Frontiers of

Knowledge Award (2009), and various Institute of Electrical and Electronics Engineers (IEEE) awards, including the IEEE Information Theory Society's Richard W. Hamming Medal (1995) and Claude E. Shannon Award (1997). In 2021, belatedly considering his many contributions to both theory and applications, he was awarded the IEEE Medal of Honor, the most important recognition granted each year to a single recipient. The recipient thereby joins the exclusive club of just over one hundred pioneers of electronics and communication since 1917.

He was elected to international membership in several learned societies in the United States: the National Academy of Engineering (1988), the American Academy of Arts and Sciences (1998), the American Philosophical Society (2003), and the National Academy of Sciences (2004).

Personal Reflections and Reminiscences

The three authors of this memoir, Neri Merhav, Shlomo Shamai (Shitz), and Andrew Viterbi, have each known and collaborated with Jacob Ziv for numerous decades and collectively for over a century. He was a great raconteur with a sense of humor that was enjoyed by all his friends, colleagues, students, and audiences worldwide. He was respected for his groundbreaking research, his teaching, and his wisdom in resolving controversial academic matters with a light touch, generally appreciated by his colleagues. Although disinterested in titles and power, having rejected high-level roles at his own university, he was persuaded to take on the even more demanding assignment of the allocation of scientific research funds among the half-dozen highly competitive scientific research universities in Israel.

Andrew Viterbi met Jacob on his first visit to Technion in 1967, although for a few years previously they had already shared their common interest in coding and information theory through correspondence and exchange of research paper drafts. Over the subsequent half century, they became close friends, meeting at dozens of scientific conferences and venues throughout the world, as well as socializing along with their families. "Jacob Ziv was among the most ethical, kind, and generous persons I have ever known," says Viterbi. "He demonstrated this in the way he shared the credit for research with colleagues. Similarly, he was generous in praise for the work of colleagues and students, both those with whom he was collaborating, and those working on related research. In short, Jacob Ziv, in his work and in his life, was the model of the ideal academic, producing outstanding research discoveries, teaching and training excellent students to follow in his footsteps, and together with them raising the reputation of his institution as one of the leaders in the theory and applications of digital communication, data storage and information processing."

To do justice to the depth and importance of Ziv's contributions, Viterbi sought the help of two of his former students and recent collaborators to properly summarize and comment on its importance. Neri Merhav and Shlomo Shamai (Shitz) are younger Technion colleagues of Jacob Ziv. In the distant past as graduate students, they felt honored and fortunate to have Distinguished Professor Ziv as their Ph.D. advisor; this began with the opportunity to learn from his courses on the basic and advanced topics of information theory, followed by his guidance in their doctoral research, and later in the early phases of their academic careers. Merhav and Shamai (Shitz) feel compelled to express their great pleasure in having continued their scientific collaboration with Jacob Ziv throughout the years, thereby profiting from his influential and original ideas. It is hard for them to accept that they cannot approach him any longer to ask for his excellent guidance and clever advice.

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