This Week's Citation Classic

Makhoul J. Linear prediction: a tutorial review. *Proc. IEEE* **63**:561-80, 1975.
[Bolt Beranek and Newman Inc., Cambridge, MA]

Modeling a signal as the output of an all-pole filter with a white spectral input is important in many applications. This paper is a tutorial review of methods using linear prediction for the extraction of the model filter parameters. [The *SCI®* indicates that this paper has been cited over 185 times since 1975.]

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"In 1971, one year after graduating from the Massachusetts Institute of Technology and joining Bolt Beranek and Newman Inc., I started work on a speech recognition project and had to choose a method for spectral modeling of speech signals. After reading papers by Atal[1] and Markel[2] on applications of linear prediction to speech analysis, I was excited by the results but was struck by the differences in the two methods. So I decided to study linear prediction, and shortly afterward prepared some of my immediate results for presentation at a conference. My department manager, whose background was in artificial intelligence, asked me to write a report that would make my four-page paper understandable to him. As I wrote, I kept finding more aspects of linear prediction that I did not understand. The result was

uninterrupted research for five full months, and what was to be a short report became a comprehensive report of 236 pages. The MIT Press declined to publish the report as a monograph, calling it too 'controversial.' However, on the basis of the report, I was invited by IEEE to write a tutorial review on the topic.

"Although the topic of linear prediction was not new, its application to different areas such as speech, geophysics, and sonar rose sharply in the early-1970s because of the general increase in the use of digital signal processing and the simplicity of the method. My paper, therefore, was very timely. I attempted to present the topic in an organized and clear manner and to provide information for the novice as well as the expert in the area. Beyond the straightforward mathematics, the paper elaborated on some of the less obvious but important properties of linear prediction, many of which were novel. The paper became a popular reference and was cited often, here and abroad. For example, in 1978, during a National Science Foundation-sponsored exchange trip to the Soviet Union, I was surprised to find that scientists I met knew who I was, mainly because of this paper.

"One important area not covered in the tutorial review is that of lattice analysis, originally developed by Itakura.[3] A more recent review of spectral analysis, including linear prediction, is that of Kay and Marple.[4]

"I believe this paper played a major role in my election to the grade of Fellow in the IEEE and the Acoustical Society of America, and in my receiving the 1978 Senior Award of the IEEE ASSP Society."

1. Atal B S & Hanauer S L. Speech analysis and synthesis by linear prediction of the speech wave.
   J. Acoust. Soc. Amer. **50**:637-55, 1971.
2. Markel J D. *Formant trajectory estimation from a linear least-squares inverse filter formulation.*
   Santa Barbara, CA: Speech Communications Research Laboratory, 1971. 180 p.
3. Itakura F & Saito S. Digital filtering techniques for speech analysis and synthesis. *Proceedings of the 7th International Congress on Acoustics.* Budapest: Akadémiai Kiadó, 1971. Vol. 3. p. 261-4.
4. Kay S M & Marple S L. Spectrum analysis—a modern perspective. *Proc. IEEE* **69**:1380-419, 1981.

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