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Mathematician Shares a Grammy Award

By James Case

The winner in the Best Historical Album category at the 2008 Grammy Awards Ceremony was *The Live Wire: Woody Guthrie in Performance 1949*. The official citation mentions two "compilation producers" (Nora Lee Guthrie, Woody's daughter and president of the Woody Guthrie Foundation, and Jorge Arévalo Mateus, curator of the Woody Guthrie Archives) and four "mastering engineers" (Jamie Howarth, Steve Rosenthal, Warren Russell-Smith, and Kevin Short); many others contributed to the project as well. Of particular interest to the mathematical sciences community is the presence in the group of Kevin Short, a professor of mathematics at the University of New Hampshire whose interests include nonlinear dynamics, forecasting, signal processing, and climate modeling.

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The story begins in the late winter of 1949, when word reached Paul Braverman—a Rutgers undergraduate with an interest in the social, political, and economic issues of the Great Depression—that Woody Guthrie was scheduled to perform at Fuld Hall, a once-grand concert hall in Newark, New Jersey. Inspired by the work of Benjamin Botkin, a respected scholar of American folklore, Braverman resolved to attend the performance and record Guthrie's edgy songs and banter with his then state-of-the-art wire recorder. It was already clear that Guthrie—often billed as the "Dust Bowl Balladeer"—was an authentic voice of the Depression, well worth recording.

Kevin Short, a professor of mathematics at the University of New Hampshire, received a Grammy award in 2008 for his role in the restoration of a 1949 bootleg wire recording of a performance by folksinger Woody Guthrie. Photo by Douglas Prince, UNH Photo Services.

Born in Okemah, Oklahoma, in July 1912, to musically inclined parents, Woodrow Wilson Guthrie was the author of nearly 3000 song lyrics, two (published) novels, and a host of (published and unpublished) manuscripts, poems, plays, letters, and newspaper articles. Most are now housed at the Woody Guthrie Archives, in New York City. During the early 1940s, Guthrie, Lead Belly, Burl Ives, Pete Seeger, Sis Cunningham, and perhaps half a dozen others formed a loosely knit folk group called the Almanac Singers. A decade later, renamed The Weavers, they became the most commercially successful and artistically influential folk music group of the early 1950s. It was through their recordings and live performances that Guthrie's songs—including the ever-popular "This Land is Your Land"—became known to the general public.

Guthrie died in October 1967, of complications from Huntington's disease, named for George Huntington (1850–1916), the physician who described it in 1872. The most obvious symptoms are abnormal body movements and lack of coordination, but victims tend also to experience impaired cognitive abilities and abrupt mood swings. Huntington's disease was among the first hereditary neurological diseases for which an accurate test was developed. Onset can occur at almost any age; Guthrie was just beginning to show signs of the incurable—but not in itself fatal—affliction in 1949, when Braverman made his recording. Some claim to detect effects of the disease in the recording itself. Guthrie seems to have inherited the disease from his mother; Joe Klein's book *Woody Guthrie: A Life* explores the effects of the disease on mother and son.

The tangible result of Braverman's initiative was two spools of recording wire. After listening to them once or twice, and perhaps playing them for a few friends and family members, he seems to have "archived" them in a cardboard box for about fifty years. After stumbling upon the all-but-forgotten tapes in the spring of 2001 while cleaning out a closet in his Florida home, he donated them to the Woody Guthrie Archives. As curator of those archives, Jorge Arévalo Mateus was determined to find out what was on the tapes—by no means a simple task, given their age and fragility—in the hope that the contents might warrant preservation. The Grammy-winning DVD was the eventual result.

There is no evidence that Guthrie or his then wife Marjorie—who served for several years as a sort of master of ceremonies cum booking agent for Woody's performances—ever heard the tapes or knew of their existence. Before his death in 2004, however, Paul Braverman did have an opportunity to listen to the soundtrack made from his recordings, and he seemed genuinely pleased with the result. So was Nora Guthrie, who exulted that, "For the first time, I was able to hear what my father was like 'live' in front of an audience!" Braverman recalled that about 25 people witnessed the performance.

The late 1940s and early '50s were difficult for Guthrie, in part because his years of pro-union activism and collection of leftist friends exposed him to McCarthy-era innuendo. Unable to find regular work and despondent from the early stages of Huntington's, he divorced Marjorie—amicably by all accounts—to hit the road one last time. After spending several months in Florida, at an enclave of blacklisted writers, he made his way to California, where he married for the third time and fathered his eighth child. Most of his last ten years were spent in a series of institutions in New York and New Jersey.

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The human voice was first recorded in or about 1857 (fueling speculation that a physical record of Abraham Lincoln's voice may still exist). The earliest recording devices were purely mechanical converters of transverse displacements of an elastic diaphragm—responding to incident sound waves—into wavy lines on a rotating drum. But there was then no way to recover the sounds so recorded, and even modern sound engineers have yet to extract an audible signal from any of the (few) surviving records made in this way. Another thirty years were to pass before Thomas Edison developed the first commercially viable records and record players. Not until 1898 did telephone engineer Vladimir Poulsen succeed in recording the human voice on magnetized piano wire. Because the sound quality was never good, wire recorders were sold mainly as dictating machines during the interwar period. Based on surface area considerations, it was clear from the first that tape recordings would eventually offer better sound quality than wire.

Both wire- and tape-recording technology advanced rapidly between the World Wars, especially in Germany, where many developments were kept secret for military reasons. It was there that AEG developed—and quietly began to sell in 1935—the K1 Magnetophon, the first practical tape recorder. Neither wire nor tape recorders became readily available in the U.S. until the end of World War II.

Nora Guthrie and Jorge Mateus first heard the content of the Braverman wires at the home of Art Shiffrin, in Queens, New York, in 2002. Shiffrin had modified an ordinary tape recorder to transfer wire recordings to tape. It wasn't an easy machine to use—the wires tended to break and tangle, tensioning proved difficult, and so on. Yet in time the transfer was complete. Shiffrin's guests, delighted to learn that Braverman had preserved an entire live performance, quickly resolved to invest the time, money, and effort required to clean up and edit the recording for public release. It was not until 2006, however, that the job of restoration was turned over to Jamie Howarth at Plangent Processes and Steve Rosenthal at The Magic Shop. The award-winning album is the result of their collaboration.

Audio restoration projects are often plagued by the failure of the original recording equipment to operate at constant speed. The result is untrue pitch. Anyone with a good musical ear can detect a change in pitch of about 1%, although an error of up to 3% is likely to go unnoticed by most listeners. Movies shown on UK television are sped up by 4.167%, having been shot at 24 frames per second but played at 25 frames per second in deference to local broadcasting standards. One result is an unmistakable increase in the pitch of voices, often to the surprise (and occasionally to the dismay) of actors witnessing their own TV performances for the first time. Recently, digital pitch correction has been applied to some films, in an attempt to correct pitch without destroying lip-sync. This practice has to be considered sound distortion, as there is no way to change the pitch of a signal without also slowing it down, and thereby changing its waveform.

No two tape (or wire) recorders, even of the same make and model, are exactly alike. Each will typically have one or two stronger-than-usual mechanical components, such as a stickier-than-usual source reel or stiffer-than-usual tensioning spring, that serve to impart a signature sound. Experienced recording studio technicians can often identify the source of such distortions by ear. Pseudorandom interactions, such as those between two components, one rotating at 60 cycles and the other at 47.1 cycles, are common and particularly difficult to correct. Because the frequencies in question are not harmonically related, they can interact in ways that seem to vary every time the "play" button is pressed. Still, if it could be determined how the original recording device was operating during a particular recording session, it might be possible to reconstruct the original signal from the one on the record.

The most common effects of variable recording speed are known in the industry as "wow" and "flutter." Wow refers to the effects of a low-frequency (less than 4 Hz) sound distortion; flutter describes higher-frequency distortions. Listeners find flutter most objectionable when its frequency is close to 4 Hz. Yet even a quiet (–50 db) flutter at 200 Hz is deemed unacceptable in sensitive components, such as amplifiers and preamps. Correction is desirable, in short, for a broad range of distortion frequencies. Wow and flutter are particularly audible—and therefore well studied—in oboe and piano music. Whereas the former is heard as pitch variation, the latter tends to make the music sound "cracked," especially in resonant surroundings, where each successive tone beats unavoidably against its own echo. Even a wooden ear recoils at that. A "wowed" signal sounds as if someone had been repeating wow–wow–wow . . . soto voce in the back of the recording studio.

Especially with older recording devices, the end products tend to be corrupted by motor rumbles, spindle eccentricities, and bearing noises that—however unwelcome they may once have been—today constitute periodic signal components from which it is increasingly possible to determine the rate at which the recording medium (be it wire, magnetic tape, or 19th-century wax) was in fact passing the recording head at any specific instant during the long-ago recording session. In 2004, Patrick Wolfe of Cambridge University and Jamie Howarth of Plangent Processes wrote a paper* on the subject, explaining how a lone sinusoidal signal (pure tone) laid down electronically on a wire or magnetic tape could be used to determine the rate at which a given recording was actually made, and reporting on a series of preliminary experiments testing the feasibility of such recovery.

As luck would have it, people in the industry had long been aware that just such a tone is present on most vintage recordings, in the form of a faint almost-constant-pitch hum. There was even speculation that it softened the sound of older recordings in a manner pleasing to the ear. The source was understood to be the oscillating magnetic field surrounding the 60-Hz AC power cord connecting the tape (or wire) recorder to the nearest wall socket. Though weak, that easily measured field was clearly strong enough to register at the (magnetic) recording head. The resulting hum is present on the digitized versions of analog recordings, which ordinarily circulate on CDs in what is called pulse-code-modulated (PCM) format. Plangent uses a patented process to recover the original signal from the speed-distorted version actually recorded.

Being exceedingly faint, the critical hum is by no means easy to extract from the complex signal generated by a voice or instrumental recording. Amplification of the 60-Hz tone is not an option because, faint as it is, all manner of extraneous background noises would surely be amplified with it. In the event, Howarth says, FIR filters with a bandpass of roughly 60 ± 2 Hz were combined with a battery of noise-reduction techniques to extract the desired tone. The result was then interpreted as a mildly distorted sine wave of the form $\sin(f(t))$, with $f(t) \approx \omega t + \theta$. The

P.J. Wolfe and J. Howarth, "Correction of Wow and Flutter in Analog Tape Tranfers," presented at the 117th Convention of the Audio Engineering Society, 2004.

difference between $f(t)$ and $\omega t + \theta$ then represents the amount by which the measured signal lags or leads the pure 60-Hz tone, and permits highly accurate reconstruction of the original signal.

Sampling $\sin(f(t))$ at regular intervals, as in the conversion to PCM format, is equivalent to sampling $\sin(\omega t + \theta)$ at irregular intervals. Once the appropriate intervals are known, it is a simple matter to identify the instants $t_1, t_2, \ldots$ at which $\sin(f(t))$ should have been sampled in order to duplicate the sequence obtained by sampling $\{\sin(\omega t + \theta)\}$ at regular intervals. And by sampling the entire recorded signal at those same instants, one recovers a PCM record of the original performance.

In fact, because Plangent operates entirely on the PCM version of the original recording, it can't be done quite that way. Rather, the engineers have to interpolate between the regular intervals at which the recorded signal was sampled in the conversion to PCM format in order to reconstruct the values that would have been obtained had the recorded signal been sampled at the irregularly spaced instants $\{t_i\}$. Wolfe and Howarth, already at work on this problem in 2004, reported that cubic Hermite, spline, or other polynomial interpolation techniques appeared to surpass the currently more fashionable windowed-sinc methods for the task in question. "The net result," Short writes, "was that unintelligible segments became clear; pitch was correct; and the entire concert seemed brought back to life." It is a valuable addition to the Woody Guthrie archives, and to the record of indigenous art in the Depression era.

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