Routledge
Taylor & Francis Group

History and Technology

An International Journal

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/ghat20

The oleaginous voice: Auto-Tune, linear predictive coding, and the security-petroleum complex

Owen Marshall

To cite this article: Owen Marshall (2024) The oleaginous voice: Auto-Tune, linear predictive coding, and the security-petroleum complex, History and Technology, 40:3, 276-296, DOI: 10.1080/07341512.2024.2402580

To link to this article: https://doi.org/10.1080/07341512.2024.2402580

HISTORY AND TECHNOLOGY
2024, VOL. 40, NO. 3, 276–296
https://doi.org/10.1080/07341512.2024.2402580

The oleaginous voice: Auto-Tune, linear predictive coding, and the security-petroleum complex

Owen Marshall

Department of Information Science and Science & Technology Studies, Cornell University, Ithaca, NY, USA

ABSTRACT

In the twentieth century, exploration geophysics and digital vocal processing each underwent key technical transformations based on formally similar signal processing techniques derived from prior work in statistics and information theory. Engineers at Texas Instruments (TI) and the Massachusetts Institute of Technology (MIT) developed deconvolution filtering as a way to model geological strata from seismograph recordings in order to facilitate oil exploration. Meanwhile, engineers at Bell Laboratories and Nippon Telegraph and Telephone (NTT) used similar techniques to digitally encode and transmit speech signals more efficiently – a method known as linear predictive coding (LPC). These cognate approaches to modeling geophysical and vocal signals provided a practical basis for subsequent forays by oil industry figures into the world of digital audio. Tracing the histories of four technologies – LPC secure voice transmission terminals, the TI Speak & Spell educational toy, automatic speech recognition, and the vocal pitch correction software Auto-Tune – I analyze the role of security interests in facilitating spillovers between technologies of oil and the voice. I argue that, by approaching both geophysical and vocal signals as matters of national security, the United States' defense and intelligence services furnished the bulk of socio-economic connective tissue between petroleum geophysics and vocal processing research.

ARTICLE HISTORY
Received 7 March 2022
Accepted 5 September 2024

KEYWORDS
Oil; voice; computing; geophysics; signal processing; military

Introduction

The musical pitch correction software Antares Auto-Tune is likely the best-known case of the influence of oil industry research on the world of digital vocal processing. Since its debut in the late 1990s, Auto-Tune and the several competing vocal tuning technologies it heralded have made it possible to correct sour notes in post-production, thereby decreasing the average amount of singing ability and studio time necessary to produce a professional-sounding vocal take. Somewhat unexpectedly, it also made possible new types of deliberately artificial-sounding vocal effects, most famously associated with Cher's 1998 hit 'Believe' and T-Pain's 2005 album 'Rappa Ternt Sanga'. Antares' founder and Auto-Tune's inventor Harold Anson Hildebrand – better known as 'Dr. Andy' – has spoken publicly about how the same signal processing techniques he honed at Exxon's production research department in the 1970s

CONTACT Owen Marshall omarshall@cornell.edu

translated to his later work in vocal processing. Mathematical techniques such as autocorrelation and linear predictive coding, he has explained, are all applicable to the seemingly disparate tasks of finding oil and tuning a singer's voice.[1]

This connection has in turn been echoed by numerous popular articles with headlines like 'How the Oil Industry Accidentally Created Auto-Tune'[2] and 'How an Oil Engineer Created Auto-Tune and Changed Music Forever'.[3] Coverage of this sort expresses an enduring public fascination with the idea that a field as infrastructural and literally subterranean as oil exploration could have such a close relation to the rarefied voices of Top 40 pop music. It seems fitting that the much maligned 'plastic' pop music of the post-war period should eventually adopt production techniques pioneered in petroleum geophysics. Hildebrand's invention has been presented as an ingenious exploitation of a previously untapped natural commensurability between seismic and vocal signals.

By casting Auto-Tune's oily origins as particularly novel or exceptional, however, this narrative obscures a profound web of historical entanglements between oil and the voice. The petroleum and telecommunications industries, both born of the nineteenth century, developed in intimate relation with one another. From the turn of the twentieth century, as Standard Oil and the Bell System pursued their respective monopolies on oil and the technologically mediated voice, each organization funded massive and frequently overlapping networks of technical research. As increasingly important forms of infrastructure, both industries blurred the boundary between two burgeoning political-economic organizational forms: the modern nation state and corporate firm. By the onset of the Cold War,[4] the global circulation of oil and the voice had become both extremely profitable and strategically important. As scholars such as Paul Edwards and Timothy Mitchell have shown, the exercise of political power since at least the beginning of World War Two has been profoundly conditioned by sociotechnical practices conveniently denoted by two key military-industrial acronyms: Information and Communication Technology (ICT) and Petroleum, Oil, and Lubricants (POL).[5]

With this broader context in mind, we can refocus on the specific question of how technological developments in the oil industry related to technologies of the digital voice following the first world war. Along with Auto-Tune, this article traces three earlier but lesser-known paths of technological spillover from oil to digital vocal processing technology, showing how they interweave both with each other and with the US security state. It argues that US military, intelligence, and national security interests served as decisive points of mediation between technologies of oil and the voice in this period, insofar as they provided both material support and a shared strategic-technological framing. Political and economic historians have noted how the intertwining of oil and security interests produced a new form of 'oleaginous diplomacy' over the course of the twentieth century.[6] In a similar vein, this article outlines the construction of what we might call the 'oleaginous voice': a socio-technical interpretation of the vocal tract and its movements as a speculative, extractable, and refineable asset.

I begin with the founding of Geophysical Service Incorporated (GSI, the predecessor to TI), the Geophysical Analysis Group (GAG) at the Massachusetts Institute of Technology (MIT), and the career of John Parker Burg, who began his career at GSI and eventually transitioned to the design of secure telephone systems for the US Government. I then discuss TI's parallel yet largely separate development of the Speak & Spell educational toy, which pioneered single chip digital signal processing with its implementation of digital voice coding methods beginning in 1976. Third, I examine TI and Exxon's respective forays into the world of automatic digital speech recognition in response to the success of the Speak & Spell and the windfall oil profits following 1973. I then return to Auto-Tune and Andy Hildebrand, whose post-graduate career led from submarine navigation research for the United States Navy, through the world of petroleum geophysics, and into the music technology industry. I close with a reflection on the broader relational patterns produced by these interacting narratives and the figurative-technical and political-economic isomorphisms they construct between oil and the voice.

From geophysical service to entropic speech

The early career of Cecil H. Green, co-founder of the company that would become Texas Instruments, offers an object lesson in how thoroughly entangled voice communications, oil exploration, and military research had already become by the interwar period. After graduating MIT with a Master's in electrical engineering in 1924, Green worked first at Raytheon in Cambridge and then at a subsidiary of the International Telephone and Telegraph Company (ITT) in Palo Alto. His friend from Raytheon, Roland F. Beers, had gotten a job at Geophysical Research Corp (GRC), a subsidiary of Amerada Petroleum, following a stint in the Submarine Signal Corps. Another GRC employee with a background in anti-submersible warfare, John Clarence Karcher, had adapted submarine-detection methods used during the war to the task of detecting oil deposits. In 1930, Karcher and his colleague Eugene McDermott left GRC and founded GSI, taking many GRC associates with them as 'party chiefs' on geophysical expeditions, among them Beers, H.B. Peacock, and a young electrical engineer named Kenneth E. Burg. That year GSI poached Green from the telecommunications industry. Green drove from California to Oklahoma, where he learned geophysical surveying under Beers.[7] During World War Two, GSI branched out of oil services via a number of military contracts, the first of which was to build an airplane-mounted magnetic submarine detector using geophysical techniques (which, via Karcher, were themselves rooted in earlier work on submarine detection.) By 1951, GSI's electronics-oriented contracts with the Army, Signal Corps, and Navy had so outgrown its oil-specific work that the company undertook a broader remit under the name Texas Instruments, with GSI as a subsidiary.

The following year, TI sent two geophysicists to a meeting at MIT on 'Generalized Harmonic Analysis of Seismograms' where Enders A. Robinson, a graduate student and director of the institute's fledgling Geophysical Analysis Group (GAG), presented to a group of oil industry experts his successful use of MIT mathematician Norbert Wiener's filtering methods to identify underground reflections in seismic records. Robinson had received the records from Dallas-based Magnolia Petroleum Company, a Standard Oil of New York (Socony) affiliate which would later be absorbed into Socony under its new name: Mobil Oil. This was one of the first successful practical applications of what is now called 'deconvolution' – the statistical separation of signals from noisy and reverberant backgrounds in time-series data. The results were promising enough for the attendees' companies to form a consortium which would fund future GAG research into applying similar methods using computers at MIT and Raytheon. The flood of oil money meant that GAG attracted many graduate students who would have otherwise not been particularly interested in geophysics.[8]

After graduating in 1950 from ordnance school at the Aberdeen Proving Ground (home of the ENIAC computer), Robinson began a research assistantship at MIT, working with Wiener and George Wadsworth on a project applying time-series methods to seismic data. Wadsworth had developed weather prediction techniques for the Air Force during the war and became interested in applying similar methods to seismic records as a result of conversations he had while carpooling with MIT geologist Patrick Hurley. Wiener's classified wartime research on anti-aircraft targeting systems, the mathematics of which had been recently published under the title 'Extrapolation, Interpolation, and Smoothing of Stationary Time Series' (1949), provided much of the practical inspiration for the influential and wide-reaching 'cybernetic' philosophy first articulated in his 1948 book *Cybernetics: or Control and Communication of the Animal and the Machine*. Wiener's cybernetics had one foot in the concept of feedback-based servomechanical control systems, the paradigm examples of which were the human pilot and anti-aircraft targeting system, and the other in concepts of communication Wiener had drawn from his work with the 'father of information theory' Claude Shannon. An engineer at Bell Telephone Labs, Shannon's work was largely focused on problems of electronic speech transmission, particularly the first digital speech encryption and transmission system, known as SIGSALY or simply 'Project X' – a predecessor to the secure speech technologies later taken up by engineers like John Parker Burg and Tom Tremain.[9]

In addition to his work with Wiener, Robinson drew inspiration from studying with economists Paul Samuelson and Robert Solow. Part of his early tinkering with what would become his predictive deconvolution method involved developing a mathematical representation of the impact of technological innovations on economic time series (industrial growth over time, for example). Robinson was especially interested in Joseph Schumpeter's cyclical theory of innovation, which casts new technologies, and the 'creative destruction' they wreak on existing economic orders, as the main driver of the periodic booms and busts of the business cycle. As economic historian Philip Mirowski has shown, Schumpeter's theory was derived in large part as a metaphorical extension of physics.[10] For Robinson, however, this was a new and untapped analogy between disruptive technological change in an economic system and reverberant physical systems, one that shaped the way he thought about the geological horizons of a seismic recording.[11] Just as the location of an oil reserve can be predicted through the reverberations elicited during a geophysical survey, so might economic innovations be identified within the perturbations of the stock market.

At the time of the GAG meetings, Kenneth Burg was serving as director of GSI's digital research effort, a role that brought him into close interaction with MIT. His son, John Parker Burg, who had grown up accompanying his father on geological surveys and working in TI's machine shop, subsequently enrolled as a graduate student in physics at MIT after completing his undergraduate work at the University of Texas in Austin in 1953. During this time, the younger Burg met Robinson and briefly studied under Wiener. Though he saw the value of Wiener's mathematical contributions, Burg was unimpressed by his teaching style, describing his course as 'pathetically bad'.[12] After getting his Master's degree in 1960, Burg returned to GSI to undertake a classified project in which he used a 'seismic array observatory to detect underground nuclear explosions and derived an algorithm for rejecting surface waves and enhancing P-waves using

Wiener multichannel filters'.[13] This was but a small part of the massive Vela-Uniform program on seismic detection of underground nuclear tests, conducted by the Atomic Energy Commission and the Department of Defense's Advanced Research Projects Agency (ARPA). Spurred by the desire of the Eisenhower administration to monitor Soviet compliance with the new nuclear arms testing agreements, Vela-Uniform supported the work of virtually every US seismologist during the 1960s, multiplying the funding of seismological research by a factor of 30 and transforming a previously obscure field into a massive military-industrial discipline.[14] The GAG windfall of the 1950s was modest by comparison.

This influx of federal funding helped facilitate the shift in the 1960s from analog to digital recording and analysis techniques. At TI, the elder Burg drove this effort, which included building a digital computer for processing seismic traces. In a 2003 interview with the information theorist and LPC historian Robert M. Gray, the younger Burg recounts using the computer to produce charts of the correlation of the seismic signal with itself at various time lags – what is known as the signal's 'autocorrelation':

> I could take the digital data and one of the things I did was calculate autocorrelations. Very long ones. And I'd just hang it up, put it on the wall, in a big hall, and just go up and down and look at it, and so forth. And I could see where, you know you might see something that wiggles here and then at twice the distance you'd see another wiggle. You know I could just sort of see things that I could say 'hey there's predictability here'.[15]

Through this extended work with seismic records, by 1963 Burg began to develop a new spectral estimation method based around a selection criterion of 'maximum entropy' – employing the information-theoretical conception of entropy developed by Shannon at Bell. When trying to predict which of a set of possible spectra correspond to a given set of autocorrelation values, Burg posited that the best bet is the spectrum with the greatest possible entropy. In 1967, Burg presented his Maximum Entropy (ME) method to the October meeting of the Society of Exploration Geophysicists. Though some reacted negatively, calling ME 'voodoo' or 'ad hoc',[16] Burg's talk was ultimately well received, even garnering the meeting's 'best paper' award.

That same year, Bell Labs researcher Bishnu Atal presented a voice signal processing method called adaptive predictive coding (APC) at a speech conference in Cambridge, Massachusetts. With his Bell Labs colleague Manfred Schroeder, Atal would later develop this method further into a 'linear predictive coder' for speech, first presented at the Acoustical Society of America in 1969. Atal was trying to solve two problems. The first was reducing the amount of data required to transmit intelligible speech. Second was the problem of encryption. He solved the first problem by transforming speech signals into a model based around a small set of parameters, essentially dividing the voice up into a series of repeating pulses, corresponding to fluctuations of the glottis (i.e. the opening between the vibrating vocal cords), and a series of ladder filters, corresponding to the constriction points of the vocal tract.

Having rendered the voice as a simplified mathematical model, which could be reconstructed via a corresponding model upon reception, Atal found that he could further reduce the information required by using each transmitter and receiver's respective and matching models to statistically predict what the next sample would be. Instead of sending the full parameters, you could then just send the error signal – i.e., the discrepancy between what waveform was guessed and what was actually produced by the speaker's body. The relative predictability of a speech signal from one moment to the next meant that the prediction error information was far less than that of the signal itself. With that done, addressing the security problem was relatively simple, as secret keys for decoding could be provided at each end of the transmission line.

In a 1984 paper, Schroeder reflected on the fact that Burg's ME and Atal's LP method were essentially two different ways of deriving the same result. 'There is room for proper astonishment here', he wrote that 'a rather specific *technical* formulation of spectral estimation (LP combined with a mean-square error criterion) leads to the same result as ME, a very broadly – one is tempted to say philosophically – based approach'.[17] Schroeder ventured an explanation related to biological evolution that species adapt more plausibly by detecting 'peaky' signals rather than 'holes' in signals. A complementary socio-historical explanation would note that though ME and LP arose from seemingly disparate fields of practice – speech and geophysics – neither was far removed from Wiener's wartime work on time-series analysis, from which both approaches drew heavily.[18] The problem of anti-aircraft targeting, as mathematized by Wiener, provided a methodological common denominator for vocal and seismic signal processing pursued by Atal and Burg, respectively.

Though predictive voice coding methods were developed into the mid-1960s, they would not find commercially viable technological implementations until the 1970s. At Bell, Atal was spurred to further refine his speech coding method in 1977, when the Pentagon began raising concerns that the Soviet embassy in Washington DC was intercepting US telecommunications signals transmitted via microwave. In particular, there was suspicion that the Soviets were using 'word picking' technologies to sift through telephone communications between farmers and the USDA in the late 1960s and early 1970s to get tips on wheat prices. Atal recounts:

> [I]n 1977 . . . the lab director [Arno Penzias] came to me and said 'you know we have found that the Soviet Union is building an embassy in Virginia which is in direct line of sight between Washington and New York. We know why they're doing that, they want to monitor all of our communications which were taking place on microwave links . . . do you have something' – because he had heard that I was working on speech coding – 'that I can put a speech coder, encrypt it so Soviet Union people can't hear our conversations'.[19]

By that point, however, Bell already had a new competitor in the field of secure speech coding: John Parker Burg. Interestingly, Atal also appears to be the first person to inform Burg of ME's relevance to vocal processing. In a conversation in the early to mid 1970s (possibly, the Audio and Electroacoustics group DSP committee's Arden House Workshops in upstate New York, January 1974), Atal told Burg that speech researchers were using a method similar to his ME criterion to digitally process speech. Having recently left TI to start his own signal processing company, Time and Space Processing (TSP) Incorporated, following a project with the USGS, Burg began to develop a speech coding product based on his ME method. In 1977, TSP debuted the Model 100 secure vocal communication terminal at an Armed Forces Communications and Electronics trade show. Since 1971, Tom Tremain at the NSA had been producing LPC boxes based on the Atal coding method (the STU-I and II) but Burg's device apparently had better sound quality. According to Burg, this did not sit well with Tremain.

> When we got it working, Sid Maitre said we've gotta call NSA and tell them about this. And I said 'no no no'. One day I finally said 'okay'. He called them. Two days later Tom Tremain and somebody else were there at our door. They came in and we played it and showed them how it worked. Tom Tremain kept saying 'well this isn't as good as what we're doing in the lab, but how do you do it?' . . . [laughs] I said 'well I'm not gonna tell you'. He says 'well if you don't tell me we're gonna shut you down as a national security problem. Furthermore you will never sell anything to the US government because this is *our* job to make the LPC vocoder' . . . which was bad news, but I said 'we're not gonna tell you'. Nothing ever happened, and in fact we sold a thousand of these to the government over the years . . . So I was never friends with NSA or Tom Tremain because we embarrassed him pretty badly.[20]

At $12,000 apiece, TSP was able to sell several Model 100 units to the military, NSA, and White house before the NSA's new model, the STU-III, finally beat it out in 1987.[21] In 1982, Burg sold TSP and founded another company, Entropic Processing, which he later split into Entropic Geophysics and Entropic Speech, selling the latter to Microsoft upon his retirement in 1999.[22] Thus ended our first case of spillover, wherein the son of an oil exploration pioneer was able, through the well-funded networks of the US security-petroleum complex, to also make his name in the world of speech encryption.

The Speak & Spell

Following its successful development of handheld calculators beginning in 1967, TI branched into other areas of consumer electronics. These included electronic teaching aids such as the 'Little Professor', which displayed math problems and asked the user to solve them. Paul Breedlove, who had worked on the Little Professor project, came up with the idea to make a spelling version, tentatively named the 'spelling bee'. In 1976, Breedlove secured $25,000 of seed money and assembled a team of collaborators. The resulting product, called the Speak & Spell, debuted in 1978 as the first successful commercial implementation of single-chip digital signal processing. Giving the Speak & Spell its voice had been the project's most significant technical challenge. The device had to be able to recite the alphabet and the contents of a 200-item word bank. The amount of digital memory required to store all of this would have been prohibitively expensive and bulky, however. Linear predictive coding provided a solution to this problem by greatly reducing the amount of storage required for the Speak & Spell's speech data. Instead of entire audio files, the device stored information on how to resynthesize each word according to its built-in model of the vocal tract. The resulting robotically inflected speech was not just intelligible but ultimately became iconic, particularly in the experimental electronic music and 'circuit bending' communities.[23]

The Speak & Spell's relation to oil is somewhat less direct than the one between Burg and LPC. Here, the path of spillover between oil and speech research takes the form of an organization rather than a single person. Though the Speak & Spell did come out of TI, a firm with deep roots in petroleum geophysics, it did so in the mid 1970s, decades after the company had pivoted to a broader electronics-oriented business model and compartmentalized its geophysical operations into its GSI subsidiary. None of the project's main team members – George Doddington, Paul Breedlove, Gene Frantz, Larry

Brantingham, or Richard Wiggins – had any specific petroleum or geophysical background, specializing instead in fields like computing, chip design, and applied mathematics.

While the linear prediction techniques they used to make their invention speak had found early applied use in the 1950s seismic analysis work of Robinson and others, these early applications can be traced further back via Wiener's wartime work to Shannon's digital speech coding research at Bell Labs. The specific techniques used in the Speak & Spell derived mostly from more contemporary speech-specific work at places like Bell Labs, Nippon Telephone and Telegraph (NTT), the National Security Agency (NSA), and ARPA's Network Secure Communication (NSC) program – organizations whose linear prediction research is better understood as proceeding in parallel with, rather than following entirely from, cognate work in geophysics. The Speak & Spell emerged from a massive corporate ecosystem which, although founded by oil money in the first instance, had for decades been equally involved in technologies pertaining to the voice, a fact due largely to its imbrication into government projects of control and communication.

Richard Wiggins was the Speak & Spell team member specializing in voice processing algorithms. He was born in 1942 in Louisiana and studied mathematics at Louisiana State University, after which he worked for the NSA and got his MS in math at American University on a DoD fellowship. In 1966, he joined the MITRE Corporation, a non-profit Federal Contract Research Center in Bedford, Massachusetts, where he worked on radar and encrypted voice data compression software for the Air Force. Through the MITRE 'Staff Scholar' program, he earned a PhD in applied mathematics from Harvard, after which he worked on narrow band and LPC speech research at MITRE, MIT's Lincoln Lab, and Hanscom Air Force base.

In November 1976 Wiggins joined the Speech Research group at Texas Instruments' Corporate Research Lab in Dallas, working on a government-funded effort to implement channel 'vocoding' (short for 'voice encoding', a technique initially developed for encryption purposes by Bell Labs scientist Homer Dudley in 1938) on CCD semiconductors. It was his decision to use linear predictive coding to give the Speak & Spell its voice, and he worked closely with Larry Brantingham on designing the necessary processing architecture. Wiggins worked on other voice projects as well during his time at TI, including portable military voice coders – 'basically a cell phone done in the '70s' – and a talking doll equipped with speech recognition.[24] Wiggins had also been an occasional guest at the meetings of ARPA's Network Secure Communication (NSC, later renamed 'Network Speech Compression'), a program led partly by John Markel of UC Santa Barbara's Speech Communication Research Laboratory (SCRL), which was focused on using LPC methods to compress and transmit speech via the fledgling ARPANET.[25] According to Robert Gray, the Speak & Spell's specific LPC method 'was a mishmash of everything they knew about, including some Atal, some Markel, some bits and pieces from here and there'.[26]

Somewhat surprisingly, given his TI affiliation and interest in LPC, John Parker Burg was never involved in the Speak & Spell project. His closest interaction with Richard Wiggins, for example, apparently involved being coincidentally seated next to each other on an airplane.

> I happened to be on an airplane and my seatmate was Richard Wiggins. That's the only time I ever met him ... we just started talking and suddenly, I guess he told me who he was and I said, 'you're the Speak & Spell guy' and 'oh you're the LPC, the other guy' ... but I had nothing to do with Speak & Spell directly.[27]

To really get at the oil industry's more specific contributions to the technical success of the Speak & Spell as a consumer-grade implementation of LPC – beyond such general conditions as TI's existence, willingness to support potentially risky projects and access to the various petroleum byproducts employed in building the device itself – it is useful to consider the oil industry's relation to the political interests driving the allocation of material resources to LPC research during this period. The 1960s work on predictive speech coding, including that of Atal at Bell Labs and the somewhat earlier work of Itakura and Saito at Japan's NTT, had not been the result of a deliberate organizational effort, but was instead seen as relatively esoteric and peripheral. Bell had tasked Atal primarily with work in room acoustics, and his colleagues in speech research 'showed no interest' in the concept of predictive coding.[28] It was not until the release of Speak & Spell that NTT saw Itakura's invention as more than a mathematical curiosity.[29]

Along with the previously mentioned problem of thwarting Soviet surveillance, a major cause of the full development and implementation of linear predictive speech coding research was a spur in NSA and DoD support for secure speech communication research following operations security studies prompted by the escalation of the Vietnam War post-1965. A 1971 DoD study found that voice communications were 'the most significant exploitable weakness in present-day military communications' and assigned 'highest national COMSEC priority ... to research, develop, production [sic] and operational deployment of techniques and equipment to reach an acceptable level of voice security'.[30] LPC became the solution of choice for retaining voice quality on narrow-band voice encryption systems, pre-LPC versions of which had been plagued by a Donald Duck-style vocal effect that limited their usability.

The specific relation of the oil industry to the prosecution of the Vietnam War, particularly its intensification under the Johnson administration circa 1965, is a more delicate question. Clearly, the US war effort required vast quantities of oil. The Shell corporation's chief officer in Saigon memorably compared the war's increase in global oil consumption to 'the sudden appearance of a new medium-sized industrialized nation on the map, like a massive island arising out of the ocean by geological accident'.[31] The billions of dollars' worth of infrastructural work in Vietnam during this period was carried out not by the military itself but rather by a small consortium of private contractors. This consortium, called RMK-BRJ,[32] included America's largest construction company, Brown & Root, which since 1962 had been a subsidiary of the oil services firm Halliburton.[33] More controversial still is the suggestion made by some scholars that oil industry figures and interests did not simply benefit from the war but helped instigate or exacerbate it for their own purposes.[34] Either way, government funding for secure voice research on linear predictive coding continued well past the fall of Saigon. From 1974 to 1977, in the end stages and aftermath of the conflict, NSA's voice security efforts counted Vice President and oil scion Nelson Rockefeller among its 'strong supporters'.[35] It was in this period that Wiggins' DoD and NSA work provided him with a wealth of speech coding resources which he would eventually be able to bring to the Speak & Spell.

TI and Exxon's forays into voice automation technology

Our third case of oil influence on vocal processing technologies concerns inter and intra-industrial relations, specifically those involving TI and Exxon's respective ventures into the world of automatic speech recognition. As Xiaochang Li and Mara Mills have shown, this field of research took an important turn in the 1960s, away from the problem of individualized speaker identification or voice 'fingerprinting' towards automatic speech transcription systems based on a putatively more 'scientific' search for universally valid speech characteristics.[36] This change in focus was partially signaled by a 1969 letter titled 'Whither Speech Recognition?', sent to the editor of the Journal of the Acoustical Society of America by renowned Bell Labs engineer and executive John R. Pierce. In the letter, Pierce suggested that the glamorous reputation and ample funding of speech recognition research over previous decades had produced little of value.[37] As the head of the government-commissioned Automatic Language Processing Advisory (ALPAC) report of 1966, Pierce had expressed similarly withering skepticism about the progress of machine translation efforts thus far, ultimately leading to sharp cuts in research budgets.[38] The result was similarly dire for automatic speech recognition (ASR) research at Bell, which was defunded until Pierce left Bell for Caltech in 1971.

George Doddington was a visiting graduate student doing speech research at Bell when Pierce brought the hammer down on the lab's ASR work. Rather than continue at Bell following his 1970 dissertation on speaker identification, he instead took a job as the head of TI's fledgling speech processing unit. There, Doddington and his growing team of speech researchers took on various government contracts, including the design of a voice-based security system for the Air Force. TI also commissioned a speech-to-text 'Talkwriter' system, a difficult project that produced a great deal of conflict between Doddington and TI executives. In light of Doddington's role in the unexpected success of the Speak & Spell, however, TI invested heavily in speech research after 1977. Things became messy in 1983, however, when an exodus of Doddington's speech researchers to a competing speech recognition start-up called Voice Control Systems (VCS) triggered an acrimonious trial over intellectual property theft. TI's suspicion that their former employees might have taken proprietary research to VCS was based on a tip from a disgruntled VCS employee named Sam Kuzbary. A former engineer on a top-secret project for the Syrian military, Kuzbary had also worked for a few months at TI until he was fired for being a security risk, and was widely suspected to have been brought over to the US as a CIA asset.[39] TI won the case, but it was a decided setback to its speech research efforts.

At Exxon, meanwhile, increased oil revenues of the 1970s did not just fund new production research. Exxon Enterprises, the company's venture capital arm, invested hundreds of millions of dollars in over a dozen business automation companies, which it later consolidated under the name Exxon Information Systems. Among these was an 'automated voice response' firm called Periphonics and an automatic speech recognition firm called Dialog Systems Incorporated (renamed Verbex in 1980). Periphonics was founded in 1969 by Sydney Thomas Emerson, who had previously worked under former Manhattan Project scientist Max Palevsky at the Brookhaven National Laboratory. In 1970, the company released the Voicepac 2000, an interface which made it possible to operate a computer via a touch-tone telephone or acoustic coupler and was able to respond with pre-recorded speech from a 2000-word vocabulary.[40] Exxon bought a controlling share in Periphonics in 1971 and the company's devices went on to find some success in automated banking systems.

Dialog Systems was founded in 1971 by Jim Cook and Stephen L. Moshier. Cook had developed computer operating systems for US Navy submarines while he was a mathematics grad student at MIT and was drafted into a top-secret military computing project from 1968 to 1970. Moshier, while studying physics at Harvard and earning an undergraduate degree in mathematics from Boston University, worked on acoustic devices for a small company called Listening Incorporated beginning in 1965. These included designing a human-dolphin speech translation device – the 'Man-to-Porpoise Translator MDT-5' – under a contract with the US Naval Ordnance Station in 1967. 'A word spoken into the microphone of the MDT', he wrote in the project's final report, 'is translated into a frequency-modulated whistle which is coupled into the dolphin's aquatic environment via a hydrophone. The modulated whistles thus produced are potentially comprehensible to a dolphin, inasmuch as dolphins use similar whistles as a mode of communication among themselves'.[41] Strange as it sounds, the dolphin translation circuit did include a 'complex voice recognition circuit'[42] activated 'as soon as the logic circuitry recognizes speech'[43] which provided some preparation for the human-computer speech recognition devices Moshier and Cook would go on to develop at Dialog.

When Exxon began investing in Dialog in the early 1970s, however, Moshier found he was less prepared for the corporation's management style. By 1980 he was complaining in *Business Week* about all the paperwork he had to fill out and the frequent trips he was required to take to New York for long-range planning meetings.[44] A major part of the long-range plan involved conducting research and development for the military. By the mid 1970s, Dialog was under multiple contracts with the Rome Air Development Center (RADC), a major Air Force command, control, and communication (C3) laboratory. One aim of this work involved developing automatic 'keyword spotting' in continuous speech recordings – practically identical with the aforementioned 'word picking' technologies allegedly being used by the Soviets during the same period. In 1977, he reported on this and other Dialog projects to the Naval Air Development Center's symposium on voice technology for interactive real-time command and control systems. In 1978, the company released a limited-vocabulary recognition system suitable for 'operational use'.[45]

James and Janet Baker, who had worked as graduate students on a DARPA speech-understanding project at Carnegie Mellon, were hired to conduct speech research at IBM's Watson Research Center in 1975. By 1979, however, they had grown frustrated with IBM's hesitancy to bring their work to market and were recruited as Dialog's new vice presidents of research and advanced development.[46] Dialog was renamed Verbex Voice Systems under their tenure, but when Exxon began withdrawing from its business automation subsidiaries in 1983 the Bakers left to start their own speech technology company, Dragon. Verbex continued without Exxon and in 1984 licensed its Verbex 3000 continuous speech recognition technology to the arms manufacturer Lear Siegler's instrument division to supplement their 'voice recognition products for military and commercial aircraft instrument/avionics systems as well as military land and amphibious vehicle controls'.[47] Dragon, in 2009, reported having sold approximately 100,000 licenses of its medical transcription software, about one-fifth of which were sold to the US military.[48]

Andy Hildebrand: inertial navigation, Exxon, and auto-tune

This brings us back to the case of digital pitch correction software Auto-Tune, which provides perhaps the clearest connection between oil and voice research. In 1966, a decade before he began his career in the oil industry, Hildebrand studied systems science and signal processing as an electrical engineering undergraduate at Michigan State University. Upon graduating, he took a job at the Naval Ships Engineering Center in Washington, DC, where he worked mainly on inertial navigation systems for attack-class submarines using Kalman filtering. 'If you're in a submarine and launch a ballistic missile', he explains, 'if you don't know where you are when you launch it, you're not gonna hit the target'.[49] He also worked on a joint project with the Air Force, Army, and Navy launching navigation satellites into orbit.[50] In 1970, he started as an EE grad student at the University of Illinois Urbana-Champaign, studying under control systems theorists Abraham Haddad and William Perkins. Haddad, Hildebrand recalls, 'was in a building called the Coordinated Science Lab and they did a lot of DARPA work as well as other military [research]'.[51]

In 1972, following his Master's thesis on state estimation with unknown noise inputs, he began looking for a PhD thesis topic. A couple of hours' drive north of Urbana-Champaign, the Chicago Board of Options Exchange (CBOE) was about to open the first public market for listed options. Like Enders Robinson before him, Hildebrand saw the economic time-series data as a problem amenable to statistical prediction methods like those employed in navigation and targeting systems. At the time, he was working at the University's office of Long-Range Planning (a managerial construct which, as Cyrus Mody points out in this issue's introduction, was itself shaped by oil industry practices) and so was able to use the largest mainframe computers on campus to predict options prices. Hildebrand claims to have made around $25,000 using this method before the release of the Black-Scholes options pricing model – and, crucially, a TI calculator with the model as a built-in feature – gave up the game. 'They used a model that was a diffusion model, because they had to be a little fancier than something straightforward', he explained in a 2020 interview conducted by the author, 'but essentially they did the exact same arithmetic and the final formulas they developed are the exact same formulas I developed'.[52] Though he had come out ahead, Hildebrand felt that he had clearly been scooped and thus needed to find another dissertation topic. At the time, his neighbor, an entomologist, was having difficulty estimating the size of weevil populations in alfalfa fields – an important factor in deciding when to spray pesticides. With a heat diffusion model, the same used by Black and Scholes, Hildebrand developed a weevil population model which became the basis of his doctoral work.[53]

When he joined Exxon's Production Research team (EPR) in Houston in 1976 the oil industry was booming. The 1973 'oil shock' meant that US oil companies had a strong incentive to seek new reserves outside of OPEC control and, with oil prices spiking, plenty of money with which to do so. Hildebrand benefited greatly from the extensive proprietary research Exxon had undertaken in addition to the publicly available research begun in the 1950s. 'I learned as much after one year at Exxon as I did in all my PhD work', he recalls.[54] In addition to work on seismic analysis problems like optimal linear estimation, he used estimation theory to detect failures in Exxon's Alaska pipeline.[55] In 1980, as oil prices were reaching unprecedented heights, he left Exxon and founded a consulting company called Cyberan Geophysical. In 1982, at a time when even the riskiest oil ventures could expect seemingly limitless access to capital, Hildebrand started another company, Landmark Graphics, which developed new computer workstation-based geophysical analysis software. Then came the bust.

Concerned that they were losing market share, OPEC decided in 1983 to cut its prices for the first time.[56] In the resulting price war, over 6,000 US firms went out of business and around 600,000 oil and gas-related jobs disappeared.[57] Corporate raiders, a relatively recent phenomenon, descended upon older firms seen as having undervalued assets, which they then 'dismembered and sold piecemeal'.[58] The exploration geophysicists were not spared, with SEG membership dropping over 20 percent between 1985 and 1986. Undergraduate enrollments in geophysics dropped even more sharply.[59] Following a broader outsourcing trend, oil companies began closing in-house laboratories and farming out their research and development work to other firms. Landmark could hardly have been better positioned. Their workstation-based products, which allowed an individual geophysical interpreter to do the work of an entire crew, became the industry standard. When Halliburton acquired Landmark in 1996, then-CEO Dick Cheney was quoted in the *New York Times* as saying 'the most exciting developments are occurring in the information technology field, and that's what Landmark specializes in'.[60]

Hildebrand, a former professional flautist, left Landmark in 1989 to study composition at Rice University's Shepherd School of Music. Dissatisfied with the existing software tools for creating looped audio samples, he made his own. In 1991, he started a music technology company called Jupiter Systems – for copyright reasons, later renamed Antares (a pseudo-portmanteau of Andy and Terry – referring to Hildebrand's business partner and former Exxon coworker Terry Smith) – in order to sell his Infinity looping software. Infinity became particularly popular in film scoring, and Hildebrand claims to have nearly bankrupted the LA Philharmonic by reducing the demand for live orchestration.[61] In 1997, Antares released Auto-Tune as a software 'plug-in' effect for the Pro-Tools digital audio workstation (DAW) which was in the process of overtaking magnetic tape as the music industry-standard audio recording format.

The idea behind Auto-Tune was simple: an out-of-tune voice goes in, an in-tune voice comes out. One of the software's earliest adopters was Howard Benson, an LA-based record producer who happened to have worked as an engineer for oil industry-affiliated military aircraft manufacturer Garret AiResearch prior to entering the music business full time. Around the time that he was working with the ska-punk band Less Than Jake, Benson recalls getting a call from the makers of Pro-Tools,

> and they said we're gonna send you this program from this company that makes stuff for the military, called Antares, and they do Fourier transforms – and I knew what that was from going to engineering school – and we can change the pitch on things … they sent me a floppy drive and it's Auto-Tune 1.0.[62]

Benson was mistaken about Antares being a military contractor, though given Hildebrand's background in Naval research, he was not too far off. He also mistook Auto-Tune's pitch-detection method. In fact, the decision to use autocorrelation instead of the more commonplace discrete Fourier transform (DFT) was Hildebrand's major innovation, as it allowed for faster and more accurate pitch tracking without the windowing effects of DFT.

What was really important about Auto-Tune was its economization of the recording process, however, something that Benson understood perfectly. Even from the perspective of its inventor, Auto-Tune was not about achieving pitch-perfection for its own sake, but was rather a tool for reducing labor time and optimizing vocal productivity. Just as Landmark workstations had made it possible to survey and exploit untapped oil reserves which would have previously been seen as a risky investment, Auto-Tune allowed engineers to make use of emotionally energetic but inexperienced vocalists. The next album Benson produced, San Diego rap-metal band P.O.D's, was,

> really done in post. A lot of tuning and editing. That was a band with a huge amount of energy but not really any recording chops, and that was a record that would've taken a year or two to make. It took me two months to make, because we were in the computer.[63]

When Auto-Tune was introduced in the late 1990s, the recording industry was posting record profits. The CD boom of the previous decade, further leavened by industry price-fixing practices,[64] meant that major label artists would enter the studio with seemingly limitless recording budgets. Like the oil industry three decades earlier, the music industry was investing its profits in transitioning from analog to digital recording formats. Nearly every recording studio was investing in a digital Pro-Tools rig, complete with the latest version of Auto-Tune.

Since the 1980s, record labels had become increasingly entangled with Wall Street, so when the dotcom bubble burst in 2000 the music industry was hit hard. The simultaneous rise of Napster, the first major peer-to-peer file sharing service, allowed fans to get music in the form of free pirated MP3s instead of $20 CDs. Inflation-adjusted music revenues fell by more than two-thirds, from over $21 billion in 1999 to under $7 billion by 2014.[65] Unlike their 1990s predecessors, recording engineers coming up in the 2000s faced fierce competition and shrinking recording budgets.

The 2008 financial crisis, largely the consequence of the derivatives trading revolution heralded by Black-Scholes, contributed to the decimation of recording studios. According to one widely circulated report, recording industry employment fell nearly 43 percent between 2007 and 2016.[66] Once again, Hildebrand's company was well positioned to take advantage of the downturn. Under conditions of increasing austerity, Auto-Tune went from being an amusing new gadget to being a virtually obligatory cost-cutting tool. Perhaps uncoincidentally, anti-Auto-Tune sentiment peaked around 2009, with Grammy attendees wearing baby blue ribbons as a protest against Auto-Tune abuse and Jay-Z releasing his hit single 'Death of Auto-Tune' – the video for which featured footage of Auto-Tune product boxes exploding in slow motion.[67]

Conclusion

Reflecting on our final case in terms of the oil-to-voice pipeline, we can see not just the migration of signal processing methods and capital from petroleum geophysics to pop music production, but also the translation of an oilfield-tested business strategy of disruptive Schumpeterian innovation. The boom-bust cycle of the oil industry, and

Hildebrand's exploitation of it, was echoed in many ways by the recording industry crisis two decades later. Here, again, it is tempting to draw yet another parallel with how the anti-trust restructuring of the Standard Oil monopoly in 1911 provided a template for the 1984 breakup of the Bell telephone system. What is it about petroleum and the electronically processed voice that explains these seeming sociotechnical echoes? While I want to take care to avoid the suggestion of any particular natural identity in form and/or substance between oil and voice – each of these being thoroughly historically conditioned and endlessly mutable materials – I want to argue that these two very different phenomena have been shaped by a shared confluence of social forces – i.e. industrial capitalism and the securitized nation-state – and that this confluence goes a long way towards explaining their surprisingly persistent techno-political entanglements and isomorphisms.

In his mathematical interpretation of Schumpeter's concept of economic creative destruction, Enders Robinson saw technological innovations as impulses which could be deconvolved from their consequent economic reverberations. In such a view, technologies appear as explanations for social relations, not the things to be *explained* in terms of social relations. A non-deterministic approach to the history of technology entails something like the inverse of this operation, a demonstration of how the retrospectively discrete artifact-impulses of technological change did not simply appear out of nowhere but were in fact produced by complex interactions between ongoing social processes. These include processes of retrospective accounting conducted by the historical actors themselves, the results of which offer their own kind of spectral decomposition of the technological event.

Arguably the most important DSP method ever developed, the Fast Fourier Transform (FFT), offers a good example of this sort of decomposition. FFT is an elaboration of a method that mathematician Jean-Baptiste Joseph Fourier developed to analyze complex waveforms into a set of component sine waves. One popular (and possibly apocryphal) account claims that Fourier's discovery was informed by his work as a scientific advisor for Napoleon's Egyptian campaign, during which he became interested in modeling the diffusion of heat in cannon barrels.[68] The invention of the 'fast' form of Fourier's transform is conventionally attributed to a 1965 paper by IBM's James Cooley and John W. Tukey of Princeton and Bell Labs, the research for which was in turn motivated by the problem of nuclear test ban monitoring (almost certainly funded by VELA UNIFORM).[69] According to Rice University DSP pioneer Tom Parks, however, FFT was invented by the geophysical community prior to Cooley and Tukey's work.[70] Others have traced the method to one of Gauss' notebooks circa 1804, long neglected largely because of its archaic notation, in which case FFT would predate both the first commercial oil well (1859) and the Fourier Transform itself![71]

At work here is a sociological phenomenon akin to what signal processing researchers call the time-frequency uncertainty relation. Because the Fourier Transform's capacity to describe the frequency spectrum of a signal is limited by the assumption that the waveform 'extends unaltered in time from the remote past to the remote future … *sub specie aeternitatis*',[72] the temporal accuracy with which we can say *when* an event takes place entails a necessary ambiguity regarding its spectral content, and vice versa. Similarly, the lived practical and material content of a technological innovation – its relative rooting in concrete problems of oil exploration or vocal processing, say – becomes unclear to the extent that it is specified in the abstract technical terms endemic to scientific publication. Assigning a date of birth to an equation or algorithm, paradoxically, entails a certain loss of historical context. This process of practical decontextualization, a kind of 'real abstraction',[73] is not a bug but a feature, in that it makes things objectively appear to exist outside of time, rendering them seemingly natural and unquestionable. Oil and voice have been integrated via signal processing practices into a common *habitus*: 'history turned into nature, i.e. denied as such'.[74] The prime movers of this integration process, the securitized state and industrial capital, are implicitly invested in this de-historicizing work insofar as it underwrites their respective monopolies on violence and value. The technical commensurability of vocal tracts and oil tracts, their mutual *tractability*, is just another useful byproduct.

The state security apparatus, embodied in organizations such as the army, navy, ARPA, and the NSA, takes on many functions in the foregoing account. Among the most important of these functions are the provision of funding and convening of interdisciplinary collaboration and cross-pollination. Because they provide money and context, but not necessarily the technical 'content' itself, security interests can all too easily get lost in the background of a historical account of technology. By tracing the sometimes strange ways in which these interests mediate and shape technologies of oil and voice, I have tried to pull them back into the foreground. This re-sensitization to the role of military-security actors may offer us new perspectives on classic works in the field of interdisciplinary sound studies. For example, readers of *Analog Days*, Trevor Pinch and Frank Trocco's classic study of Bob Moog's invention of the synthesizer, might not have heard about Bob's cousin and fellow engineer Bill, whose company Moog Incorporated (as opposed to Moog *Music* Inc.) is a major supplier of turreted weapons systems and missile steering solutions for the military.[75] Similarly, some ambiguities remain regarding the relation between defense funding and the history of Stanford's Center for Computer Research in Music and Acoustics (CCRMA).[76] That these military-industrial connections might facilitate a broader oleaginous account of electronic music should come as no surprise.

Notes

1. Hildebrand, "Auto-Tune."
2. Dunn, "How the Oil Industry Accidentally Created Autotune."
3. Eckard, "How an Oil Engineer Created Auto-Tune and Changed Music Forever."
4. On Cold War technoscience see Oreskes and Krige (eds.), *Science and Technology in the Global Cold War*; on the marine sciences, see Hamblin *Oceanographers and the Cold War;* on geoscience see Turchetti and Roberts, *The Surveillance Imperative.*
5. Edwards, *The Closed World*; and Mitchell, *Carbon Democracy.*
6. Earle, "The Turkish Petroleum Company – A Study in Oleaginous Diplomacy"; Adams, Brock and Blair, "Retarding the Development of Iraq's Oil Resources"; and Venn, "Oleaginous Diplomacy."
7. Lawyer, Bates, and Rice, *Geophysics in the Affairs of Mankind.*
8. Goldstein, *Oral History.*
9. Edwards, *The Closed World.*
10. On the influence of physics on Schumpeter's theory, as well as his spurious denial of that influence, see Mirowski, *More Heat than Light*, 12.
11. Robinson, "The MIT Geophysical Analysis Group (GAG) from Inception to 1954."

12. Robert M. Gray, Interview with John Parker Burg (unpublished). I am deeply indebted to Robert Gray, not only for his writing on the history of LPC but for giving me access to an unpublished cassette recording of an oral historical interview he conducted with J.P. Burg in 2003.
13. Bell, "John Parker Burg."
14. Barth, "The Politics of Seismology", 744; and Volmar, "Listening to the Cold War."
15. Robert M. Gray, Interview with John Parker Burg (unpublished).
16. Gray, *Linear Predictive Coding and the Internet Protocol A Survey of LPC and a History of Realtime Digital Speech on Packet Networks*, 57.
17. Schroeder, "Linear Prediction, Entropy and Signal Analysis," 3.
18. This account is somewhat complicated, however, by the fact that in 1965 Nippon Telegraph and Telephone (NTT) had independently produced a confidential report on linear predictive speech methods as early as 1965, realized in 1966 by Nagoya University PhD student Fumitada Itakura, but not published in English until 1968. In addition to the language barrier, it was apparently NTT management's failure to recognize the practical implications of Itakura's work that kept them from capitalizing on their earlier discovery. The lack of a clear oil connection in the Japanese case puts it beyond the scope of the present paper. The same goes for important LPC work carried out largely in California as part of ARPAnet, all of which is treated more fully in: Gray, *Linear Predictive Coding and the Internet Protocol A Survey of LPC and a History of of Realtime Digital Speech on Packet Networks*.
19. Atal, "ISCA Medal Talk by Bishnu S. Atal – Part 2."
20. Robert M. Gray, Interview with John Parker Burg (unpublished).
21. Gray, *Linear Predictive Coding and the Internet Protocol A Survey of LPC and a History of Realtime Digital Speech on Packet Networks*. Johnson Cryptography vol III, 150.
22. Ibid.
23. Pinch, "'Bring on Sector Two!' The Sounds of Bent and Broken Circuits."
24. Edwards, "30 Years Later, Richard Wiggins Talks Speak & Spell Development."
25. Gray, *Linear Predictive Coding and the Internet Protocol A Survey of LPC and a History of Realtime Digital Speech on Packet Networks*, 85.
26. Robert M. Gray interviewing JP Burg, side B 22:25 (unpublished).
27. Robert M. Gray interviewing JP Burg, side B 22:35 (unpublished).
28. Atal, "The History of Linear Prediction," 155.
29. Gray, *Linear Predictive Coding and the Internet Protocol A Survey of LPC and a History of Realtime Digital Speech on Packet Networks*.
30. Johnson, *American Cryptology During the Cold War, 1945–1989. Book III*, 142.
31. Wesseling, *Fuelling the War*, 6.
32. An abbreviation of "Raymond International, Morrison-Knudsen, Brown & Root, and J.A. Jones."
33. Miller, *Blood Money*, 98.
34. Kinzer, *The Brothers*, 193; and Colby and Dennett, *Thy Will Be Done*, 560.
35. Johnson, *American Cryptology During the Cold War, 1945–1989. Book III*.
36. Li and Mills, "Vocal Features."
37. Pierce, "Whither Speech Recognition?"
38. Hutchins, "ALPAC."
39. Hollandsworth, "The Case of the Terminal Secrets."
40. http://bitsavers.trailing-edge.com/magazines/Modern_Data/Modern_Data_1973_11.pdf.
41. Moshier, *Man/Dolphin Communication Final Report Appendix A Technical Manual MDT-5*, 2.
42. Moshier, "FET Oscillator Helps Dolphins Understand People," 85.
43. Moshier, *Man/Dolphin Communication Final Report Appendix A Technical Manual MDT-5*, 3.
44. "Exxon's Next Prey," 98.
45. Moshier, *Statistical Assessment of Speech System Performance*, 278.
46. Garfinkel, "Enter the Dragon."
47. "Computer Industry," 89.
48. Felipe-Barkin, "Nuance and Uncle Sam Unleash the Dragon on U.S. Military Bases."

49. Interview with author, 10 January 2020.
50. Ibid.
51. Ibid.
52. Ibid. Interestingly, the heat diffusion model, first developed by Jean Baptiste Fourier, was supposedly inspired by a study of overheating cannons Fourier conducted during Napoleon's Egyptian campaign, see: Coleman, *An Introduction to Partial Differential Equations with MATLAB*, 41.
53. Hildebrand, "Nonlinear Filters For Estimating an Insect Population Density."
54. Interview with author, 10 January 2020.
55. Smith, "Harold Hildebrand."
56. Feder, "OPEC States Agree to Cut Oil Prices for the First Time."
57. Nussbaum and Wethe, "Oil Companies Feeling Effects of '80s Layoffs".; and Bertrand, "Thirty Years Later, the Industry Is Losing Its Best and Brightest, Again."
58. See note 7 above.
59. Ibid.
60. Myerson, "Halliburton Will Acquire Landmark Graphics in Stock Swap."
61. Crockett, "The Inventor of Auto-Tune."
62. Pensado, "Producer Howard Benson – Pensado's Place #172."
63. Ibid.
64. London, "Record Companies Settle FTC Charges of Restraining Competition in CD Music Market."
65. Friedlander, *Year-End 2019 RIAA Music Revenues Report*.
66. Stebbins and Comen, "America's 24 Dying Industries."
67. Dovey, "Death Cab for Cutie Takes a Stand against Auto-Tune."
68. "A Novel Formulation to Explain Heat Propagation."
69. ETHW, "James W. Cooley."
70. Nebeker, "Oral-History".
71. Heideman, Johnson, and Burrus, "Gauss and the History of the Fast Fourier Transform."
72. Wiener, *A Life in Cybernetics*.
73. Sohn-Rethel, *Intellectual and Manual Labour*.
74. Bourdieu, "Outline of a Theory of Practice."
75. Pinch and Trocco, *Analog Days*; https://www.moog.com/markets/defense.html.
76. Nelson, *The Sound of Innovation*; and Marshall, "Andrew Nelson, The Sound of Innovation."

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The work was supported by the National Science Foundation [1455647].

ORCID

Owen Marshall http://orcid.org/0000-0003-3477-2618

Bibliography

Adams, W., J. W. Brock, and J. M. Blair. "Retarding the Development of Iraq's Oil Resources: An Episode in Oleaginous Diplomacy, 1927-1939." *Journal of Economic Issues* 27, no. 1 (1993): 69–93. doi:10.1080/00213624.1993.11505393.

Atal, B. S. "The History of Linear Prediction." *IEEE Signal Processing Magazine*, March, 2006.

Atal, B. S. "ISCA Medal Talk by Bishnu S. Atal - Part 2." *Interspeech* (2018).

"A Novel Formulation to Explain Heat Propagation." EPFL News. 2020. https://actu.epfl.ch/news/a-novel-formulation-to-explain-heat-propagation/.

Barth, K.-H. "The Politics of Seismology." *Social Studies of Science* 33, no. 5 (2003): 743–781. doi:10.1177/0306312703335005.

Bell, M. L. "Honors and Awards." *The Leading Edge* 37, no. 11 (2018): 842–854.

Bertrand, P. "Thirty Years Later, the Industry is Losing Its Best and Brightest, Again." *Control Engineering* (2015).

Bourdieu, P. "Outline of a Theory of Practice." In *Cambridge Studies in Social Anthropology*, edited by J. Goody, 16 vols, Cambridge University Press, 1977. doi:10.1590/S0103-20702013000100001.

Colby, G., and C. Dennett. *Thy Will Be Done: The Conquest of the Amazon, Nelson Rockefeller, and Evangelism in the Age of Oil*. New York: HarperCollins, 1996.

Coleman, M. P. *An Introduction to Partial Differential Equations with MATLAB*. 2nd ed. Boca Raton: CRC Press, 2013.

"Computer Industry." *Computerworld*, Framingham, MA November, 1984. https://ia600805.us.archive.org/32/items/computerworld1847unse/computerworld1847unse.pdf.

Crockett, Z. "The Inventor of Auto-Tune." *Priceonomics*, December, 2015. http://priceonomics.com/the-inventor-of-auto-tune/.

Dovey, R. "Death Cab for Cutie Takes a Stand Against Auto-Tune." *Paste*, February, 2009. http://www.pastemagazine.com/articles/2009/02/death-cab-takes-stand-against-auto-tune.html .

Dunn, T. "How the Oil Industry Accidentally Created Autotune." *Boingboing* (2021).

Earle, E. M. "The Turkish Petroleum Company–A Study in Oleaginous Diplomacy." *Political Science Quarterly* 39, no. 2 (1924): 265–279. doi:10.2307/2142190.

Eckard, G. "How an Oil Engineer Created Auto-Tune and Changed Music Forever." *Vice* (2016). https://www.vice.com/en/article/how-an-oil-engineer-created-auto-tune-and-changed-music-forever-interview-creator/#:~:text=What%20made%20Auto%2DTune%20unique,Exxon%20between%201976%20and%201989 .

Edwards, B. "30 Years Later, Richard Wiggins Talks Speak & Spell Development." *Vintage Computing and Gaming* (2008).

Edwards, P. N. *The Closed World: Computers and the Politics of Discourse in Cold War America*. Cambridge: MIT Press, 1996.

ETHW. "James W. Cooley." *ETHW*, 2016.

"Exxon's Next Prey: IBM and Xerox." *Business Week*. 1980.

Feder, B. J. "OPEC States Agree to Cut Oil Prices for the First Time." *The New York Times*, March, 1983.

Felipe-Barkin, E. "Nuance and Uncle Sam Unleash the Dragon on U.S. Military Bases." *Speech Technology*, February, 2009. https://www.speechtechmag.com/Articles/ReadArticle.aspx?ArticleID=52682 .

Friedlander, J. P. *Year-End 2019 RIAA Music Revenues Report*. 2019.

Garfinkel, S. "Enter the Dragon." *MIT Technology Review*, Cambridge September, 1998.

Goldstein, A. *Oral History: Enders Robinson*. New York, NY: Center for History of Electrical Engineering, 1997.

Gray, R. M. "Interview with John Parker Burg." Un-published audio cassette recording provided to the author by Robert M. Gray (personal correspondence, October 12, 2021). Interview conducted November 13 2003).

Gray, R. M. "A History of Realtime Digital Speech on Packet Networks: Part II of Linear Predictive Coding and the Internet Protocol." *Foundations and Trends in Signal Processing* 3, no. 4 (2010): 203–303.

Hamblin, J. D. *Oceanographers and the Cold War: Disciples of Marine Science*. Seattle: University of Washington Press, 2005.
Heideman, M. T., D. H. Johnson, and S. C. Burrus. "Gauss and the History of the Fast Fourier Transform." *IEEE ASSP Magazine*, October, 1984.
Hildebrand, H. A. *Nonlinear Filters for Estimating an Insect Population Density*. Urbana-Champaign, IL: University of Illinois at Urbana-Champaign, 1976.
Hildebrand, H. A. "Auto-Tune: Expert Q&A." *Nova*, 2009. http://www.pbs.org/wgbh/nova/tech/hildebrand-auto-tune.html .
Hollandsworth, S. "The Case of the Terminal Secrets." *D Magazine*, November, 1986.
Hutchins, J. "ALPAC: The (In)famous Report." In *Readings in Machine Translation*, edited by S. Nirenburg, H. L. Somers, and Y. A. Wilks, 131–135. Cambridge, MA: MIT Press, 2003.
Johnson, T. R. *American Cryptology During the Cold War, 1945-1989. Book III: Retrenchment and Reform, 1972-1980*. Fort Meade, MD: The Center for Cryptologic History, National Security Agency, 1998.
Kinzer, S. *The Brothers: John Foster Dulles, Allen Dulles, and Their Secret World War*. New York: Henry Holt, 2013.
Lawyer, L. C., C. Carpenter Bates, and R. B. Rice. *Geophysics in the Affairs of Mankind: A Personalized History of Exploration Geophysics*. Tulsa, OK: Society for Exploration Geophysics, 2001.
Li, X., and M. Mills "Vocal Features: From Voice Identification to Speech Recognition by Machine." *Technology and Culture* 60, no. 2 (2019): S129–S160. doi:10.1353/tech.2019.0066.
London, E. "Record Companies Settle FTC Charges of Restraining Competition in CD Music Market." Washington DC. 2000. https://www.ftc.gov/news-events/press-releases/2000/05/record-companies-settle-ftc-charges-restraining-competition-cd.
Marshall, O. "Andrew Nelson, the Sound of Innovation: Stanford and the Computer Music Revolution (Book Review)." *Annals of the History of Computing* (January-March 2018): 89–91.
Miller, T. C. *Blood Money: Wasted Billions, Lost Lives, and Corporate Greed in Iraq*. New York: Little, Brown and Company Hachette Book Group, 2006.
Mirowski, P. *More Heat Than Light: Economics as Social Physics, Physics as nature's Economics*. Cambridge: Cambridge University Press, 1989.
Mitchell, T. *Carbon Democracy: Political Power in the Age of Oil*. London and New York: Verso, 2011.
Moshier, S. L. *Man/Dolphin Communication Final Report Appendix a Technical Manual MDT-5*. Arlington, MA: 1967.
Moshier, S. L. *FET Oscillator Helps Dolphins Understand People*. *Electronics*. Albany, NY: 1968.
Moshier, S. L. "Voice Technology for Interactive Real-Time Command (Control Systems Application)." *Statistical Assessment of Speech System Performance*. Warminster, PA: Naval Air Development Center, 1977.
Myerson, A. R. "Halliburton Will Acquire Landmark Graphics in Stock Swap." *The New York Times*, July 2, 1996. http://www.nytimes.com/1996/07/02/business/halliburton-will-acquire-landmark-graphics-in-stock-swap.html?_r=0.
Nebeker, F. "Oral-History: Tom Parks." IEEE History Center, Seattle, WA, 1998.
Nelson, A. J. *The Sound of Innovation: Stanford and the Computer Music Revolution*. Cambridge: MIT Press, 2015.
Nussbaum, A., and D. Wethe "Oil Companies Feeling Effects of '80s Layoffs." *Arkansas Democrat Gazette* (July 2016).
Oreskes, N., and J. Krige, eds. *Science and Technology in the Global Cold War*. Cambridge: MIT Press, 2014.
Pensado, D. *Producer Howard Benson – Pensado's Place #172*. Los Angeles, CA: 2014. https://www.youtube.com/watch?v=ZXUIQzU8M6o.
Pierce, J. R. "Whither Speech Recognition?" *The Journal of the Acoustical Society of America* 46, no. 4 (1969): 1049–1051. doi:10.1121/1.1911801.
Pinch, T. J. "'Bring on Sector Two!' the Sounds of Bent and Broken Circuits." *Sound Studies* 2, no. 1 (2016): 36–51. doi:10.1080/20551940.2016.1215595.

Pinch, T., and F. Trocco *Analog Days: The Invention and Impact of the Moog Synthesizer*. Cambridge: Harvard University Press, 2004.

Robinson, E. A. "The MIT Geophysical Analysis Group (GAG) from Inception to 1954." *Geophysics* 70, no. 4 (2005): 7JA–30JA. doi:10.1190/1.2000287.

Schroeder, M. R. "Linear Prediction, Entropy and Signal Analysis." IEEE ASSP Magazine, Murray Hill, NJ, July 1984.

Smith, T. "Harold Hildebrand." *SEG Wiki*, 2016.

Sohn-Rethel, A. *Intellectual and Manual Labour: A Critique of Epistemology*. Atlantic Highlands, NJ: Humanities Press, 1978.

Stebbins, S., and E. Comen "America's 24 Dying Industries." *24/7 Wall St.* (2017).

Turchetti, S., and R. Peder. *The Surveillance Imperative: Geosciences During the Cold War and Beyond*. edited by Simone Turchetti and Peder Roberts. New York: Palgrave Macmillan, 2014.

Venn, F. "Oleaginous Diplomacy: Oil, Anglo–American Relations and the Lausanne Conference, 1922–23." *Diplomacy and Statecraft* 20, no. 3 (2009): 414–433. doi:10.1080/09592290903293753.

Volmar, A. "Listening to the Cold War: The Nuclear Test Ban Negotiations, Seismology, and Psychoacoustics, 1958–1963." *Technology and Culture* 28, no. 1 (2013): 80–102. doi:10.1086/671364.

Wesseling, L. *Fuelling the War: Revealing an Oil Company's Role in Vietnam*. London, NY: I.B. Tauris, 2000.

Wiener, N. *A Life in Cybernetics: Ex-Prodigy: My Childhood and Youth and I Am a Mathematician: The Later Life of a Prodigy*. edited by Ronald Kline. Cambridge: MIT Press, 2018.