1 Information Theory

Tucked into the final chapter of Part One of Louise Varèse's biography of her husband is the intriguing paragraph:

> After spending a day talking with an electrical engineer of the Bell Telephone Laboratory of Pennsylvania he wrote: 'Went to Philadelphia for the whole day yesterday to work. It was wonderful. Sooner or later I'll get what I want. Weyl is extremely knowledgeable and intelligent'. That fall Varèse would meet Harvey Fletcher, director of physical research at Western Electric in New York, and for a while [Varèse's] optimism [for support for electroacoustic music research] seemed justified.[1]

Varèse sought Harvey Fletcher's support in persuading Western Electric to fund research in the development of an electronic instrument of a type conceived by Ferruccio Busoni, based on the Dynamophone of Thaddeus Cahill, with which to explore new realms of harmony. 'My objectives,' Varèse wrote, 'are two-fold: acoustical research in the interest of pure music and the working out and application of certain results for the improvement of the Sound Film – with other ramifications, radio, etc.'[2] The early 1930s was a period of active production of electronic musical instruments, including the Hammond organ and electric piano. In 1928 RCA acquired the rights to the theremin, put into production under the name RCA Thereminvox. Claire Reis, of the League of Composers, recalled that Alfred Norton Goldsmith, vice president and general manager at RCA, was also 'extremely interested in the new field which he felt was being opened up for electronics in music'.[3] Harvey Fletcher was the director of physical research at Western Electric, whose premises were located a short walk away from Varèse's home in New York. Fletcher had oversight of the firm's collaboration with Leopold Stokowski and the Philadelphia Orchestra, culminating in an historic experimental landline transmission, on 27 April 1933, of a concert programme from the Philadelphia Academy of Music to a powerful speaker system mounted on the concert platform at Washington's much larger Constitution Hall.

Fletcher's response to Varèse's overtures had been friendly, no doubt padded out with supportive press releases on the company's research activities, including the vocoder. In 1928, investigatory work on Varèse's project began, only to be discontinued following the Stock Market Crash of 1929. Varèse determined to keep pushing. On 6 March 1933, a month before the Constitution Hall

[1] Louise Varèse, *Varèse: A Looking-Glass Diary, Volume I: 1883–1928* (London, 1973), pp. 260–1, 277–8.
[2] Fernand Ouellette, *Edgard Varèse: A Musical Biography* trans. Derek Coltman (London, 1974), pp. 128–31.
[3] Claire Reis, *Composers, Conductors, and Critics* (New York, 1955), pp. 114–31.

experimental transmission, Nicolas Slonimsky conducted the premiere of Varèse's *Ionisation* for thirteen percussionists and about forty instruments, tuned and untuned, including two sirens, in New York's Carnegie Chapter Hall. *Ionisation* deserves to be recognized as the composer's attempt to make music in the terms of a vocoder, or graduated filter bank, replacing the traditional orchestra by an ensemble largely of percussion instruments comprising a scale of noise bandwidths or resonances of varying degrees of colour or brightness. Such a stratified, low-resolution kind of music appeared designed to be transmitted across the world by telegraph cable, as the vocoder had originally been designed to transmit speech internationally by cable. Listeners were impressed at the composer's resourcefulness in constructing an orchestra of noises instead of the exact pitches of conventional music. But no one could quite figure out Varèse's intention. Hearing *Ionisation* on disc for the first time in 1955 prompted a visceral reaction in fourteen-year-old Frank Zappa. More recently Boulez approached the piece, as he did all of Varèse's music, like a surgeon, operating delicately from behind a mask, while confessing to reporters that the basis of Varèse's aesthetic eluded him. A tribute essay by Milton Babbitt, 'Edgar Varèse: A Few Observations of His Music', included these remarks on *Octandre* (1923):

> It is clear that, for Varèse, the invariant aspect of an instrument, in some important sense, the timbre of the instrument, is to be identified with its formant, that fixed, 'amplificatory' resonance region of an instrument, which operates upon the spectrum of the input sound, resonating, according to the characteristics of the formant region, those partials whose frequencies fall in this region, and – thereby – attenuating those whose frequencies do not.
>
> . . . Crescendi . . . produce . . . a continuation of the number, relations, and densities of the partials of the total spectrum.[4]

Viewed strictly as a compilation of phrases from an acoustics textbook, Babbitt may be correct; but to a lay reader the above description is all but impenetrable, the author clearly not understanding that the process he is describing is a version of what happens acoustically inside the vocal cavity when a person speaks. Concerning *Ionisation*, Odile Vivier observed with amiable perspicacity that in the composer's hands the various percussion instruments functioned effectively as filtered resonances:

> The piano also is only utilized for resonance: crisp, sharp attacks, which are allowed to linger for a certain duration. Here, as later in *Déserts*, we see how Varèse draws inspiration from the 'theory of vowels' of Helmholtz. The large

4 Milton Babbitt, 'Edgard Varèse: A Few Observations of his Music' (1965). In Stephen Peles et al. eds., *Collected Essays* (Princeton, NJ, 2011), p. 218.

> aggregations of notes are not really *tone clusters*, the score gives no indication that they should be played that way at all, with the palm of the hand, fist, or forearm.[5]

Between the wars, young American composers travelled to Paris to study with Nadia Boulanger. Mlle Boulanger's most admired gift as a teacher was her ability to intuit the direction of a composer's thought. 'I am convinced', wrote Aaron Copland,

> that it is Mademoiselle Boulanger's perceptivity as a musician that is at the core of her teaching. She is able to grasp the still-uncertain contours of an incomplete sketch, examine it, and *foretell the probable and possible ways in which it may be developed*. . . . At the period when I was her pupil she had but one all-embracing principle, namely, the desirability of aiming first and foremost at the creation of what she called '*la grande ligne*' – the long line in music.[6]

If Babbitt's remarks on *Octandre* appear to have been drawn piecemeal from a textbook on acoustics, and many of Cage's lectures assembled seemingly at random from a variety of sources, there is reason to suppose that among Nadia Boulanger's most valued skills was her ability to pronounce, on the basis of a few random sketches, what a young pupil was thinking about and how those ideas might be put together and developed towards a larger form. Admitted Copland admiringly, 'she was able to extract from a composer of two-page songs and three-page piano pieces a full-sized ballet lasting thirty-five minutes'. What Mlle Boulanger understood by the long line is conveyed with particular eloquence by the soaring first movement theme of Stravinsky's *Ode* (1943) in memory of Natalie Koussevitsky; however what Copland understood by *la grande ligne* is perhaps more aptly conveyed by his sentence cited earlier, a construction padded out with superfluous material and three times as long as its factual content requires. Taking its author literally, a long line is a sign of culture: longwinded, self-conscious, short of content, and dressed with redundancy. A long line, it implies, is designed to sound impressive, not for coherence, neither to explain, develop, nor to transfer data efficiently.

In the May 1954 issue of *MAD*, an early number of the satirical magazine, editor Harvey Kurtzman experimented with the horror comic genre by reprinting a formulaic three-page strip by artist Jack Davis, 'Murder the Husband!' extracted from the EC publisher's archive in its original form, alongside a parody version, retitled 'Murder the Story!'. The parody version preserved

[5] Odile Vivier, *Varèse* (Paris, 1973), pp. 95–6. *See also* Hermann Helmholtz, *On the Sensations of Tone* (New York, 1954), pp. 103–19.
[6] Aaron Copland, *Copland on Music* (London, 1961), pp. 89–90.

the art work, but its accompanying text and dialogue were rearranged, subverted, and on occasion entirely replaced, to include incongruous lines from Doris Day songs, and cut-outs of alien text in Japanese, German, Greek, Russian, and Hebrew.[7]

The primary purpose of the experiment was to amuse, but the subtext of Kurtzman's exercise was to ask how the reader would be expected to interpret a story in which the visual content remained coherent, but the word content – both 'narrative' and 'speech' – was significantly degraded. This in fact was an approach adopted by US codebreaking specialists during and after World War II. Suppose we treat the actual text as superfluous content, they reasoned, and consider the meaning of an intercepted message from a different perspective, or set of factors: who may have sent the message and to whom; where it originated and was received; at what time; how long was the message; what names, if any, were mentioned; and so on.

Similarly playful tactics were applied by Spike Jones and his City Slickers during and after the war to familiar items of classical music. In these parodies the musical outlines and harmonies of an original composition were largely preserved, but their pretensions punctured and subverted by the substitution of incongruous or disruptive sound effects: a pistol shot, a gargling voice. In the best of Spike Jones, the classical 'long line' is preserved, and the value of the emotional gesture respected, but applied to insinuate a logical connection in an audio montage or *Merzbild* composed in the style of Kurt Schwitters, and consisting in large part of discarded, instantly recognizable sound materials from the world of radio – a genre the humourless French would attempt after the war to elevate into an art form.

In November 1942, Alan Turing arrived in New York on a prearranged mission to discuss the setting up of a secure telephone line between Washington and London. The meeting did not go as planned. Turing, whose expertise lay in text decryption, had expected to meet up with 'Potter' at Bell Laboratories. Ralph K. Potter was the leader of a research team investigating the potential of a speech encryption system, based on the vocoder. Upon arrival in New York, Turing found himself detained on Ellis Island, temporarily prevented from observing anything to do with speech secrecy. Released from detention, instead of meeting with Potter, Turing passed the time in conversation with Claude Shannon in the Bell Labs cafeteria. Shannon was a specialist in statistical analysis, not speech recognition. He knew of Turing's reputation and was almost certainly briefed to find out as much as he could about what Turing

7 Martia Reidelback, *Completely MAD: A History of the Comic Book and Magazine* (Boston, MA, 1991), pp. 25–6.

knew about German text transmissions, while having little knowledge himself to divulge, even inadvertently, of voice encryption.

Both US and British allies were anxious to develop operational memories to store data alongside existing computing devices. It was a matter of interest to the Americans to know if existing British developments in data processing incorporated storage mechanisms that could be adapted to real-time speech processing. There were suspicions and rivalries on both sides. Shannon would later claim that the pair had not discussed cryptography at all, and that he had no knowledge of the Enigma machine. Among topics he admitted the pair did talk about were the possibilities of computer intelligence, chess-playing machines, and how to model human reasoning – topics of relevance to the prospect of realizing Turing's Universal Computing Engine with the aid of Shannon's high-speed electrical relays.[8]

Turing had been despatched to New York to meet Potter to discuss the proposed telephone link. The vocoder team at Bell Labs was rumoured to be working on a Basic English register or memory store of phonemes corresponding to an alphabet of speech sounds from which spoken messages could be reassembled. These speech sounds could be notated graphically in simplified form. Visible speech had developed from Homer Dudley's original vocoder, a voice compression mechanism designed for the transmission of telephone messages by cable, to which a visual display had subsequently been attached allowing an operator to observe the characteristic resonances of the speech signal. To accompany the equipment in its revised form a user's manual was being compiled to assist speech therapists and allow the hearing impaired to interpret speech by sight from continuously updated resonance patterns of filtered speech displayed as slow-moving tongues of fire on a cathode tube screen. Following urgent inquiries into whether the elements of such an index of phonemic units could be freely combined to synthesize speech, it had emerged that for such an application to succeed would require enlarging the database to include an additional and potentially limitless register of transitional sounds in order to reproduce properly liaised phrases and sentences of coherent speech. While not meaningful in isolation, these interpolations were essential for ease of understanding, to maintain a sense of continuity, and assist in conveying an appearance of personality and intentionality.

Adopting a mechanism similar to the tone-controlled multi-channel audio projection system of RCA Fantasound, the vocoder employed a bank of ten narrow-pass filters spaced at one-third octave intervals allowing the fluctuations in intensity of telephone speech to be compressed into a narrow cluster of

[8] Jack Copeland, *The Turing Guide* (Oxford, 2017), pp. 183–7.

amplitude modulated layers for transmission by cable and subsequent expansion and recovery at the destination with the aid of suitable resonance channels. 'The signal produced by each filter was subsequently amplitude-modulated by its corresponding low-frequency signal and the ten channels were combined to reconstitute the speech, in an attempt to mimic the dynamic acoustic resonances of the human mouth, tongue, nose, and throat.'[9] Taking his cue from Dudley's earlier patent, in order to further reduce bandwidth Potter had suggested reserving the high-frequency resonance components – the region of noises representing consonants – for separate processing as off-on channels rather than continuously modulated signals. As a result, unsurprisingly, 'the [reproduced] speech was badly mutilated'. It is possible that this embarrassing outcome and Shannon's hasty recruitment as a noise reduction or 'smoothing filter' consultant may have contributed to the delay in proceeding with Turing's meeting, and the unexpected replacement of Potter by Claude Shannon, as well as explaining Shannon's absence of preparation for substantive discussion.

On being advised of the purpose of Turing's visit, Potter would have had to admit that analogue speech is not reducible to a succession of discrete states – or rather, that it would require the interpolation of transitional states such as artificial diphthongs to reproduce a speech signal to an acceptable standard of intelligibility – an admission explaining why Potter's originally scheduled meeting with Turing was cancelled. The visible speech team subsequently reported:

> It would be convenient for reading if each sound always had only one pattern, but as we combine sounds into syllables and words in connected speech, one sound influences and is changed or influenced by the sound with which it is combined. . . . The patterns indicate that the articulators spend about as much time in the transitional movements as they spend in the characteristic or steady state positions. . . . The basis of how sounds influence each other is in the way the resonating cavities change in shape and size as we say one sound after another in pronouncing words. . . . All sounds are changed to some extent by the sounds that come before and after them.[10]

In Britain, Turing had been tasked with decryption by pattern recognition of German naval telegraph transmissions received in encrypted, but coherent and reversible, text created by a process similar to one in which typewritten messages were repeatedly shuffled from QWERTY keyboard to non-QWERTY keyboard, the pattern of keystrokes remaining the same. As part of a broader

9 David Kahn, 'Cryptology and the origins of spread spectrum'. *IEEE Spectrum* (September 1984), https://spectrum.ieee.org, 24 September 2018.
10 Ralph J. Potter, George A. Kopp, and Harriet Green Kopp, *Visible Speech* (New York, 1966), pp. 38–9.

inquiry into the fundamental units of American English speech, Potter and his team looked briefly into the possibility of applying visible speech protocols to speech synthesis and voice recognition. The necessarily degraded quality of vocoder transmissions did not help matters. The methodological weakness of German text encryption was that underneath all the disguises lay coherent, highly structured operational instructions delivered in a form designed to be decrypted urgently by specialist naval radio officers for immediate execution. The corresponding weakness of the proposed US telephone link between Washington and London was that underneath the noise the original speech would remain connected and correctly ordered. By the time Turing arrived in New York it may already have been decided that the original basis on which the encrypted telephone link had been proposed was theoretically flawed and practically unworkable. The question then would be how to save face, and after that, how to arrive at a system that worked.

As a researcher at MIT, Shannon had assisted in the design of an improved and extremely fast version of a modular control system for the Vannevar Bush differential analyser, employing electrical circuits and switches. This was an analogue computer.

> Shannon's master's thesis 'A Symbolic Analysis of Relay and Switching Circuits' was finished in the fall of 1937. It includes the statement 'any circuit is represented by a set of equations. . . . This calculus is shown to be exactly analogous to the calculus of propositions used in the symbolic study of logic'. . . . That same year, the British mathematician Alan Turing . . . had proven that any solvable mathematical problem could, in principle, be solved by machine.[11]

Subsequently, Shannon had practised on an abandoned eugenics database to refine techniques and applications of data storage and retrieval. The deconstruction of personal data into multiple categories, assigning each a value from which a statistical profile could be generated, and then developing means of evaluating conditions or tendencies in select groups or combinations of attributes at electric speeds, clearly had potential for pattern recognition applications in encrypted telegraph messages of limited size amounting to arrangements of little more than twenty-six letters of the alphabet, ten numerals, and one space. Statistical analysis allowed for filtered searching of a population database by one or more characteristic features or factors.

From a musical perspective, the approach applied by Shannon is clearly serial in implication. The task of defining a population as a register of categories and

[11] Jimmy Soni and Rob Goodman, *A Mind at Play: How Claude Shannon Invented the Information Age* (New York, 2017), pp. 38–41.