time as US engineer Arthur Kennelly — that radio waves propagated around the world because they bounced off a layer of charged gas particles in the ionosphere. Experimentally confirmed in the 1920s, this reflective portion is now known as the Kennelly–Heaviside layer.

The importance of Heaviside's work was recognized, but he received no compensation from practical applications. A case in point was the long-distance telephone network built by the American Telephone and Telegraphy Company (AT&T). AT&T asked engineers George Campbell and Michael Pupin to study Heaviside's papers on transmission lines. Using his mathematics, they designed inductive loading coils, enabling calls to be made from New York to San Francisco, California, by 1915. They became wealthy from their patents. AT&T offered to pay Heaviside for his early contribution, but he insisted that he be given full credit for using induction coils on transmission lines. When AT&T proved unwilling to do this, Heaviside refused to take the money.

Heaviside's scientific peers, however, eventually recognized his contributions, making him a fellow of the Royal Society; the Institution of Electrical Engineers bestowed its Faraday Medal on him. Still embittered by his experience with the Society of Telegraph Engineers, Heaviside turned his back on it all. He spent his final years living modestly in Devonshire and died in 1925.

Drawing on his previous works, such as the Maxwell biography *The Man Who Changed Everything* (Wiley, 2003), Mahon superbly explains Heaviside's ideas and how they came to define electrical engineering. He deftly pieces together, from letters and notebooks, the scant details we have about Heaviside's personal life. In Mahon's hands, the story resembles a play by Henrik Ibsen, with an angry, complex central character whose life plays out in difficult family relationships. Yet ultimately, Mahon struggles to illuminate the inner Heaviside, and I was left wondering what motivated this extraordinary engineer to pursue the mathematical rendering of electricity with such intensity. What prompted the young telegrapher to dig so deeply into esoteric theory and mathematics, and to isolate himself from people?

Today's electronic technology — and all it implies in terms of global communication and corporate wealth — owes much to Heaviside's brilliant work. Mahon reminds us that such brilliance is often the result of isolation, sacrifice and sheer dogged persistence. ■

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LAURA SPINNEY

Luc Steels presents an extract of *Fausto* at the Gaîté Lyrique theatre in Paris.

Q&A Luc Steels

The AI composer

Computer scientist Luc Steels uses artificial intelligence to explore the origins and evolution of language. He is best known for his 1999–2001 Talking Heads Experiment, in which robots had to construct a language from scratch to communicate with each other. Now Steels, who works at the Free University of Brussels (VUB), has composed an opera based on the legend of Faust, with a twenty-first-century twist. He talks about Mozart as a nascent computer programmer, how music maps onto language, and the blurred boundaries of a digitized world.

Is there a relationship between computer science and music?

A lot of computer scientists are interested in music. I think it has to do with the ability to think abstractly. Musical composition is a lot like parallel programming. You have to organize complex material in time, and convey meaning — if, like me, you believe that is what music should do. You have to build a multidimensional abstract object, and that requires an understanding of the physical properties of instruments or voices. Both music and computer science demand the ability to combine high-level imagination with very practical, technical skills. Wolfgang Amadeus Mozart, I think, had the brain of a computer programmer — albeit an exceptional one.

Why opera?

I had wanted to write an opera for a long time, but there was research to do, labs to run. In 2011, at the Institute for Evolutionary Biology in Barcelona, Spain, I was exploring how evolutionary thinking could shed light on the origins of language. Next door was neuropsychiatrist Oscar Vilarroya, who is a respected author and playwright in Spain. We started collaborating. He writes the libretto and I write the score. I hear the music in my head, then I try to recreate it mentally to pin down what each instrument should be playing. I choose a harmonic framework and a rhythmic structure, and I fill in each instrument's contribution, using the computer as an editing tool until the music resembles what I heard originally. Our first opera, *Casparo*, tells the tale of a robot that achieves human intelligence, and premiered in Barcelona in 2011.

Fausto
Premieres 18 September at La Monnaie, Brussels. Public performance at the And& Summit/ Festival in Leuven, Belgium, in May 2018.

Has your work on the origins of language fed into your music?

With both, I'm exploring how meaning gets expressed. One way is through syntax. You change the meaning of a sentence by swapping the subject and object. Something similar is true of music: a certain chord, ▶

played at a certain time, may generate sadness, which is meaning. It's part of the musical grammar that European culture invented, which allows composers to convey moods or emotions. It wouldn't mean the same to someone raised in a different culture. I once heard a well-known opera with a computer scientist from India. He told me that all arias sounded the same to him. For him, meaning came through rhythms and harmonics associated with Indian classical music. In fact, the formal mechanisms that we use in computing to generate and recognize syntactic structures are the same for music and language — both involve the hierarchical organization of the constitutive elements.

Tell me about your new opera, *Fausto*.
We wanted to explore the impact of information technology on humanity, so we transported Faust to the modern world. The original Faust sells his soul to the demon Mephistopheles in exchange for eternal youth and knowledge. Our Fausto is a hipster who is addicted to social media and virtual reality. Devastated by the suicide of Marguerita, who loved him, he makes a pact with Mephistopheles: in exchange for virtual communion with her, he will upload his mind and leave his body to Mephistopheles. It's a cautionary tale. Humans are being drawn into virtual worlds, and the question of how we might upload our minds to enjoy eternal life is being discussed. I see this as a dangerous trajectory. Our minds are embodied both physically and socially, as Mephistopheles knows. It is the reason he wants bodies — so that, by inhabiting them, virtual agents like him can feel fully human. Fausto only realizes it as his mind is uploading: he'll never have real love in a virtual world.

Will there be a role for new technologies in the opera?
The actors will wear virtual-reality glasses, and the audience will be able to see what they are seeing, which will be projected onto a screen. This will heighten the sense of blurred boundaries. Is Marguerita real or virtual? Dead or alive? Could Mephistopheles be an app? We want to create an atmosphere of uncertainty similar to the one in which artificial-intelligence researchers find themselves today, with respect to one important question. That is, are humans just information processors, or are there extra elements, such as consciousness, that we might never be able to capture? ■

INTERVIEW BY LAURA SPINNEY.
This interview has been edited for length and clarity.

Early Chinese typewriters had thousands of keys to search through.

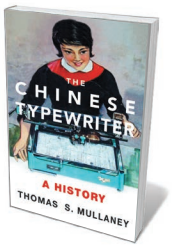
HISTORY OF TECHNOLOGY

How China sidestepped QWERTY

Raja Adal investigates the 150-year history of a typewriter able to reproduce thousands of characters.

When the A key is pressed on a QWERTY keyboard, the letter 'a' appears on the screen. When that key is pressed in a standard Chinese word-processing program, however, it triggers a dozen or so Chinese characters that are pronounced 'a'. Thomas Mullaney's *The Chinese Typewriter* tells the story of the technolinguistic innovations behind the Chinese typewriter, and how they led to input methods used in Chinese computers today.

Improving typing speed was a priority. At stake was not only the recognition of Chinese as a modern language but also, for the millions of Chinese people employed in producing government and business documents, potentially enormous gains in productivity. The economic, cultural and geopolitical stakes were so high that, for 150 years, engineers and linguists from within China and beyond — including the Soviet Union, Japan and the United States — wrestled with the challenge of typing Chinese characters. The problem was sheer number: anything from 2,000 to 8,000 Chinese characters (called kanji in Japanese and hanja in Korean) are considered a basic requirement for a viable Chinese typewriter.



The Chinese Typewriter: A History
THOMAS S. MULLANEY
MIT Press: 2017.

Early designs, Mullaney shows, accommodated this sea of characters by putting them on individual slugs in a rectangular tray bed. The typist had to hunt and peck for the desired character, which a mechanical arm would then project onto the page. That challenge led to fascinating taxonomic innovations aimed at efficiency. Instead