THIS WEEK

Transformational thinking

The mathematics of Joseph Fourier, born 250 years ago this week, shows the value of intellectual boldness — influencing everything from data processing to machine-learning algorithms.

When you listen to digital music, the harmonies and chords that you hear have probably been reconstructed from a file that stored them as components of different frequencies, broken down by a process known as Fourier analysis. As you listen, the cochleae in your ears repeat the process — separating the sounds into those same sinusoidal components before sending electrical signals to the brain, which puts the components together again.

Fourier analysis allows complex waveforms to be understood and analysed by breaking them down into simpler signals. And it's a shining example of the power and value of intellectual boldness.

The roots of the idea go back to the mid-1700s, when the Italian mathematical physicist Joseph-Louis Lagrange and others studied the vibration of strings and the propagation of sound. But it was one of Lagrange's pupils, Joseph Fourier, who in 1822 truly founded the field that carries his name.

Fourier was born 250 years ago this week, on 21 March 1768. Today, there is virtually no branch of science, technology and engineering that is left untouched by his ideas. Modern versions and analogues of his theory help researchers to analyse their data in almost every discipline, powering everything from YouTube's videos to machine-learning techniques.

Among the scientists who benefited is Ingrid Daubechies, an applied mathematician, who in the 1980s helped to develop the theory of wavelets, which generalized Fourier analysis and opened up previously inaccessible problems. Wavelets were one of the main data-analysis tools used to detect gravitational waves for the first time in 2015, to worldwide acclaim. "He's one of my heroes," Daubechies says.

Before he inspired a revolution in science, Fourier helped to trigger one in his native France. He came of age in the ferment of the 1790s and signed up as a committed *révolutionnaire français* — a decision that almost led to him losing his head to the guillotine during the Reign of Terror that followed the establishment of the First Republic. He joined the army of Napoleon Bonaparte on his invasion of North Africa, alongside dozens of other experts in science, medicine and engineering. With colonial zeal, Napoleon claimed that these intellectuals would help to spread the civilizing values of the Enlightenment.

Fourier worked in Egypt as an administrator, where his efficiency and smart ideas prompted Napoleon to earmark him for a similar position home in France. Back in gloomy northern Europe, Fourier became obsessed with heat and started to apply his mathematical skills to understanding how heat was transferred. He is widely credited as the first scientist to discuss how the greenhouse effect could warm the planet.

He also wanted to understand how heat propagates in a solid object. He discovered the equation that governs this, and showed how to solve it — predicting how the temperature distribution will evolve, starting from the known distribution at an initial time. To do so, he broke the temperature profile down into trigonometric functions, as if it were a sound wave. Crucially, his analysis included functions for which temperature was allowed to have 'discontinuities', or abrupt jumps. This possibility horrified mathematicians at the time, who were much more comfortable with smooth curves that promised aesthetic simplicity. Fourier stuck to his guns and, as he developed his ideas, started to win his critics over.

Beyond breaking down a function into frequencies, Fourier created a 'dual' profile that encodes all those frequencies, and that became known as the Fourier transform. In the twentieth century, the Fourier transform became central to quantum mechanics, showing how physical quantities such as position and momentum are 'dual', or complementary, to each other. This means that they cannot be known simultaneously with arbitrary precision: this 'Heisenberg uncertainty' is now seen as one of the fundamental principles of nature. And crystallographers now understand that the X-ray diffraction patterns of a crystal are the Fourier transform of the crystal's structure.

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Modern incarnations of Fourier analysis include the 'fast Fourier transform' and 'discrete Fourier transform', which allow faster and more-efficient processing of large amounts of information, including data produced by astronomers.

Fourier would surely be delighted that his ideas have endured. Writing to a friend 229 years ago, he lamented his lack of achievement up to that point: "Yesterday was my 21st birthday; at that age Newton and Pascal had already acquired many claims to immortality."

He succeeded in his fifties. Patience is a virtue, but so is a willingness to pursue intuition to conclusions that conventional wisdom deems illogical. Fourier did that and so stands as a scientific giant who should be remembered and appreciated by researchers everywhere. ∎

Getting engaged

Dialogue with the public requires a willingness to accept uncomfortable truths.

Earlier this month, the United Kingdom's Royal Society released the results of a survey of public attitudes to genome-editing technologies. It reported a curious finding: whereas bioethicists like to make the distinction between changes that will and won't be inherited by future generations, the survey respondents didn't. They seemed just as comfortable with genome editing to correct a genetic disorder in embryos as in adult cells. Previous exercises showed the same sentiment.