The maths of life and death—the secret weapon in the fight against disease

June 15 2017, by Christian Yates

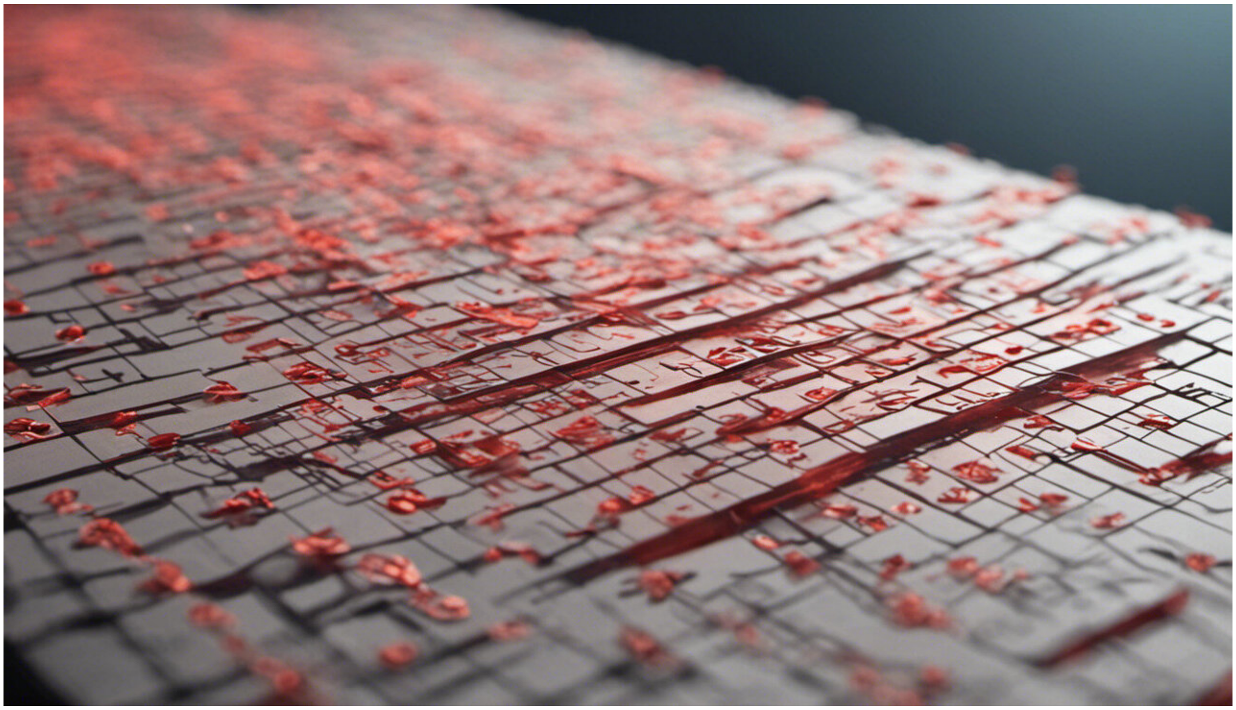
Credit: AI-generated image (disclaimer)

Maths is the language of science. It crops up everywhere from physics to engineering and chemistry – aiding us in understanding the origins of the universe and building bridges that won't collapse in the wind. Perhaps a little more surprisingly, maths is also increasingly integral to biology.

For hundreds of years mathematics has been used, to great effect, to model relatively simple physical systems. Newton's universal law of gravitation is a fine example. Relatively simple observations led to a rule which, with great accuracy, describes the motion of celestial bodies billions of miles away. Traditionally, biology has been viewed as too complicated to submit to such mathematical treatment.

Biological systems are often classified as "complex". Complexity in this sense means that, due to the complicated interaction of many sub-components, biological systems can exhibit what we call emergent behaviour – the system as a whole demonstrates properties which the individual components acting alone cannot. This biocomplexity has often been mistaken for vitalism, the misconception that biological processes are dependent on a force or principle distinct from the laws of physics and chemistry. Consequently, it has been assumed that complex biological systems are not amenable to mathematical treatment.

There were some early dissenters. Famous computer scientist and World War II code-breaker Alan Turing was one of the first to suggest that biological phenomena could be studied and understood mathematically. In 1952 he proposed a pair of beautiful mathematical equations which provide an explanation for how pigmentation patterns might form on animals' coats.



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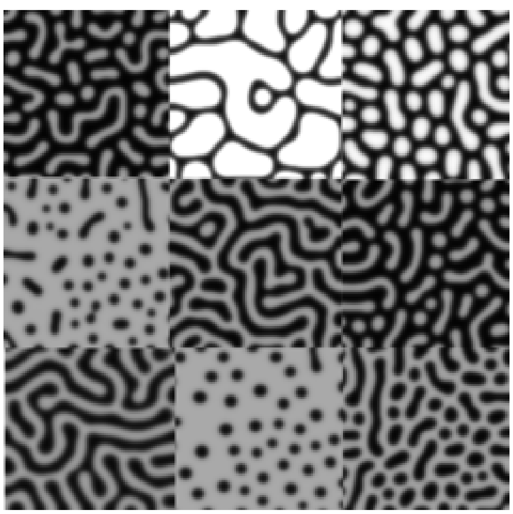
Not only was his work beautiful, it was also counter-intuitive – the sort of work that only a brilliant mind like Turing's could ever have dreamed up. Even more of a pity, then, that he was so poorly treated under the draconian anti-homosexuality laws of the time. After a course of "corrective" hormone treatment, he killed himself just two years later.

An emerging field

Since then, the field of mathematical biology has exploded. In recent years, increasingly detailed experimental procedures have lead to a huge influx in the biological data available to scientists. This data is being used to generate hypotheses about the complexity of previously abstruse biological systems. In order to test these hypotheses, they must be written down in the form of a model which can be interrogated to determine whether it correctly mimics the biological observations. Mathematics is the natural language in which to do this.

In addition, the advent of, and subsequent increase in, computational ability over the last 60 years has enabled us to suggest and then interrogate complex mathematical models of biological systems. The realisation that biological systems can be treated mathematically, coupled with the computational ability to build and investigate detailed biological models, has led to the dramatic increase in the popularity of mathematical biology.



Examples of different types of Turing patterns. Credit: Kit Yates

Maths has become a vital weapon in the scientific armoury we have to tackle some of the most pressing questions in medical, biological and ecological science in the 21st century. By describing biological systems mathematically and then using the resulting models, we can gain insights that are impossible to access though experiments and verbal reasoning alone. Mathematical biology is incredibly important if we want to change biology from a descriptive into a predictive science – giving us power, for example, to avert pandemics or to alter the effects of debilitating diseases.

A new weapon

Over the last 50 years, for example, mathematical biologists have built increasingly complex computational representations of the heart's physiology. Today, these highly sophisticated models are being used in an attempt to understand better the complicated functioning of the human heart. Computer simulations of heart function allow us to make predictions about how the heart will interact with candidate drugs, designed to improve its function, without having to undertake expensive and potentially risky clinical trials.

We use mathematical biology to study disease as well. On an individual scale, researchers have elucidated the mechanisms by which our immune systems battles with viruses through mathematical immunology and suggested potential interventions for tipping the scales in our favour. On a wider scale, mathematical biologists have proposed mechanisms that can be used to control the spread of deadly epidemics like Ebola, and to ensure the finite resources dedicated to this purpose are employed in the most efficient way possible.

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Mathematical biology is even being used to inform policy. There has been research done on fisheries for example, using mathematical modelling to set realistic quotas in order to ensure we do not overfish our seas and that we protect some of our most important species.

The increased comprehension gleaned by taking a mathematical approach can lead to better understanding of biology at a range of different scales. At the Centre for Mathematical Biology in Bath, for example, we study a number of pressing biological problems. At one end of the spectrum, we try to develop strategies for averting the devastating effects of locust plagues comprising up to a billion individuals. At the other end, we try to elucidate the mechanisms that give rise to the correct development of the embryo.

Although mathematical biology has traditionally been the domain of applied mathematicians, it is clear that mathematicians who self-classify as pure have a role to play in the mathematical biology revolution. The pure discipline of topology is being used to understand the knotty problem of DNA packing and algebraic geometry is being used to select the most appropriate model of biochemical interaction networks.

As the profile of mathematical biology continues to rise, emerging and established scientists from disciplines across the scientific spectrum will be drawn to tackle the rich range of important and novel problems that biology has to offer.

Turing's revolutionary idea, although not fully appreciated in his time, demonstrated that there was no need to appeal to vitalism – the god in the machine – to understand biological processes. Chemical and physical laws encoded in mathematics, or "mathematical biology" as we now call it, could do just fine.

This article was originally published on The Conversation. Read the original article.

Provided by The Conversation

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