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2012 – The Alan Turing Year

Alan Mathison Turing, one of the most influential scientific figures of the 20th century, was born on June 23, 1912. On the occasion of the centenary anniversary of his birth, we asked a number of cognitive (neuro)scientists to tell us what, in their view, the legacy of Alan Turing for the cognitive and brain sciences is.

By formulating the idea of what is now known as a 'Universal Turing Machine', Alan Turing planted the seed, the critical idea, that nervous systems compute. That is, the series of biophysical and biochemical transformations that occur when light strikes our eyes and evokes electrical activity deep in our cortex can be profitably viewed as carrying out specific algorithms. Together with his operational definition of what is meant by 'intelligence' – the famed Turing test – his influence on humanity's ongoing exploration of natural and artificial intelligence has been immense.

Christof Koch, Allen Institute for Brain Science and California Institute of Technology

Compute is what a brain does for a living (usually by being a part of an embodied and situated biological information processing system). Turing's legacy for the cognitive and brain sciences can therefore be summarized by observing that, just as nothing in biology makes sense except in the light of evolution (as Dobzhansky famously remarked), nothing about the mind/brain makes sense except in the light of computation. While analog computation in continuous dynamical systems, to whose theory and applications in biology Turing also contributed, is a great conceptual tool in itself, the discrete Turing Machine formalism is particularly well-suited for understanding hierarchical abstraction and component reuse – two of evolution's magic tricks, without which complex brains and complex behaviors would have been impossible. In the history of science, the work of Alan Turing thus merits a place right next to that of Charles Darwin.

Shimon Edelman, Cornell University

Alan Turing was a man for all seasons of science and engineering. He is best known for the Turing machine, which led to a theory of computable functions and practical digital computers with stored programs. However, in biology he was a pioneer in suggesting how shapes like limbs and wings could develop from an embryo using morphogens – small molecules that diffuse and react with other molecules in reaction-diffusion networks. Although the details were wrong because almost nothing was known at the time about the molecular mechanisms of development, morphogens have since been discovered that are involved in pattern formation, for which a Nobel Prize has been awarded.

Turing, A. M. (1952) The chemical basis of morphogenesis. *Philos. Transact. R. Soc. Lond. B. Biol. Sci.* 237, 37–72

Terrence J. Sejnowski, Salk Institute

Alan Turing may have done more to advance the scientific investigation of intelligence than any other figure in the 20th century. As the creator not only of the Turing Machine but also the Turing Test, he is justifiably well known. Less well known, but equally important for our field, is Turing's observation that human intelligence might have a somewhat different basis than machine intelligence. In a striking report he wrote in 1948 on Intelligent Machinery (http://www.alanturing.net/turing_archive/archive/l/l32/L32-001.html), he asked whether machines would ever surpass human intelligence (he could see no reason why they should not), distinguished between discrete and continuous information processing machines, and noted that human brains were not really discrete information processors like digital computers. He classified the human mind as an 'unorganized machine' made up of pseudo-randomly connected simple processing components, much like a neural network, then speculated upon how an experience- dependent learning process might train such a machine to behave intelligently, when provided with reinforcement signals. While it would be a stretch to say Turing pioneered the field of neural network modeling of human cognition, it is clear that he distinguished more than many subsequent cognitive scientists did between human intelligence and the kind of intelligence embodied in the standard digital computer.

James L. McClelland, Stanford University

Alan Turing famously asserted that 'the human mind is the equivalent not to the brain itself, but instead to the pattern of information processing supported by the brain'. This statement presages by fifty years what has now become a central concern in systems neuroscience. Arguably, it is Turing's contribution to cryptanalysis, not his better known ideas on a universal computing machine, that has had the more substantial impact. I would argue that some of the very best work in systems neuroscience over the past ten to twenty years reprises the very approaches Turing and his colleagues used in code breaking, evidenced, for example, in a shared use of model comparison, Bayes Factor, Empirical Bayes, and sequential analysis. The pervasive use of these approaches makes a compelling case for Turing being the first theoretical neuroscientist.

Raymond J. Dolan, University College London

Alan Turing changed permanently how we think about both minds and machines, in complementary ways. He envisioned how we might start to build machines that were more like human minds, and how we might start to understand minds as a species of machines. Though he did not anticipate all of our current best ideas on how to engineer machine intelligence or reverse-engineer human intelligence, I would like to think that he would have recognized and embraced some of these ideas as his legacy – and probably even invented some of them himself, had he lived long enough. In particular, recent work in artificial intelligence and cognitive modeling based on the notion of 'probabilistic programs' represents the fusion of two concepts that Turing pioneered: probabilistic inference engines (of which he built one of the first, as part of his work on cracking the Enigma code in World War II) that operate over universal languages for computation (for which he is famous through the Church-Turing thesis).

Joshua B. Tenenbaum, Massachusetts Institute of Technology

Principles of simplicity and power that actually work are rare but fundamental to scientific progress. I first learned of Turing when I was captivated by the wonderful story that emerged in 1974 of his role in breaking the Enigma code, an achievement said by Eisenhower to have shortened the Second World War by two years. Father of modern computing and pioneer of artificial intelligence that he was, most influential for me is the principled statistical approach to making decisions that was the foundation of his cryptanalysis. [Re-]discovered independently by several others, and introduced into neuroscience by Gerhard Werner and Vernon Mountcastle in the 1960s, Turing's method uses the computation of sequential probability ratios to integrate information. As my colleague Mike Shadlen has observed, this deceptively simple principle unifies and clarifies decision making problems as diverse as solving a German naval code, choosing a mate or a place to forage, and deciding which direction a messy visual stimulus moves.

J. Anthony Movshon, New York University

Editor's note

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