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(*b*. London, England, 23 June 1912;

d. Wilmslow, England, 7 June 1954), *mathematics, mathematical logic, computer technology*. For the original article on Turing see *DSB*, vol. 13.

It is perhaps not surprising that so many discussions of Turing's work have been confined to the esoteric realms of mathematics, logic, and philosophy given that his name is most often associated with a class of abstract machines within computability theory or in connection to a deliberately provocative test he proposed to determine whether a machine could think. However, as the significance of the computer looms ever larger, so too has general interest grown in Turing's work. In the time since van Rootselaar's original *DSB* entry, Turing scholarship has advanced to uncover the full extent of Turing's influence across a wide range of disciplines, including, mathematics, logic, cryptology, computer engineering (both hardware and software), artificial intelligence, cognitive science, philosophy, and biology. In addition, several biographies have since been published that bring to light many of the idiosyncratic qualities that defined Turing's life and research. While none of this scholarship alters the basic biographic contours presented by van Rootselaar, it does provide a richer context in which Turing's contributions can be seen to extend beyond mathematical logic or bold comments about thinking machines.

Entscheidungsproblem. One area where the scholarship has deepened concerns the publication date and significance of Turing's "On Computable Numbers, with an Application to the *Entscheidungsproblem*." Whereas the original *DSB* entry gives a publication date of 1937 and implies that the work was undertaken while Turing was at Princeton, more recent scholarship gives a date of 1936 (or sometimes as 1936–1937) and very clearly establishes that Turing had worked out his solution to the *Entscheidungsproblem* independently. Although the *Entscheidungsproblem* was at the time the outstanding problem of mathematical logic, the significance of Turing's independent solution lies not so much with any claim to priority (which is due to Alonzo Church), but, rather, the formal characterization Turing gave to intuitions about effective computation. Indeed, the fact that the unsolvability of the *Entscheidungsproblem* had a decapitating impact on David Hilbert's quest for a purely formal mathematics almost seems incidental as scholars have instead celebrated Turing's analysis of effective computation as the most influential among his contemporaries. Inspired by the human computer (i.e., the human engaged in computation), Turing described a notional machine that could read and write symbols along a segmented tape. The machine itself would be capable of assuming various internal states that, together with the input of a single symbol along the tape, could lead to a few primitive atomic actions. Based on the current state and the current symbol, each configuration specifies a change (or not) of symbol, a move right or left, and a next state. Working under some straightforward assumptions about the finite and discrete nature of the machine, Turing was able to demonstrate the wide range of numbers (equivalently, the wide class of functions) that could be computed and, moreover, able to specify a single machine, the universal machine, that would be capable of simulating the computations of any such machine. Turing's characterization has come to be seen as a more compelling account of what it means to be effective, mechanical, or algorithmic than any of the various extensionally equivalent formulations offered by his contemporaries.

Practical Computing. Scholarship has also deepened with respect to the contributions Turing made to the development of working electronic computers. Again, in terms of priority Turing misses out, as credit is most often given to John von Neumann for the first specification of the electronic stored-program computer. Nevertheless, scholars have continued to uncover Turing's contributions not just to developments in England but also to von Neumann's thinking. Scholars also point out that Turing's understanding of the significance of software was probably deeper than that of his contemporaries. While Turing's observations about computing might seem pedestrian by twenty-first-century standards, they are remarkable considering that Turing was anticipating practice which had yet to be fully realized in his time. In a similar spirit, some scholars have attributed to Turing the anticipation of so-called hypercomputers, machines capable of outstripping the bounds of computing as they are traditionally conceived. Although such attributions depend on a controversial reading of Turing's work, they have precipitated a lively debate

that touches on issues of mechanism, the limits of computation, and the proper interpretation of the Church-Turing thesis (roughly, the claim that the intuitive notion of effective computation can be identified with the class of functions computed by a Turing machine).

Turing scholarship has also broadened in several respects. First, some of Turing's less known works and other unpublished sources are receiving attention as possible antecedents to contemporary discussions of theoretical biology, "artificial life," machine learning, and connectionism. Second, as computers have become more powerful and the possibility of artificial intelligence becomes less remote in the popular imagination, Turing's once seemingly bold comments about machine intelligence have found a new audience. Of course, not all of the popular interest in machine intelligence and the mind's workings mentions, much less centers on, Turing, but enough of it does to breathe new life into the secondary literature. Finally, it is worth noting the great extent to which cognitive science in general has been shaped either directly by computational views of mind or in reaction to them. As the computational view of mind has come under increasing scrutiny, so too have more foundational questions about the nature of computing itself and the role it plays in our understanding of mind. Although these questions do not illuminate the historical Turing, they often invite the reexamination of the Turing machine and its role and significance in cognitive science.

Biographies of Turing emphasize his solitary tendencies and his unwillingness to conform to convention. It is often suggested that these are exactly the qualities that allowed Turing to bring such fresh perspective to difficult problems. It is also often suggested that these same qualities might have compounded the difficulties that ensued after Turing's arrest and "treatment" for homosexual behavior, then illegal in England. Considered a security risk, and subject to surveillance, Turing eventually committed suicide.

SUPPLEMENTARY BIBLIOGRAPHY

Several Web sites maintain Turing bibliographies along with online access to many primary and secondary sources. A good place to start is the Alan Turing Home Page (http://www.turing.org.uk/), maintained by the Turing biographer Andrew Hodges. Slightly less user friendly but containing digital facsimiles of many of Turing's unpublished works is the Turing Digital Archive (http://www.turingarchive.org/). Digital facsimiles of Turing's work are also available from the Turing Archive for the History of Computing (http://www.alanturing.net/).

WORKS BY TURING

The Undecidable: Basic Papers on Undecidable Propositions, Unsolvable Problems, and Computable Functions. Edited by Martin Davis. New York: Raven Press, 1965. Reprint, Mineola, NY: Dover, 2004. A collection of classic works of computability theory by Turing and his contemporaries.

Collected Works of A. M. Turing. Vol. 1, *Mechanical Intelligence*, edited by D. C. Ince. Vol. 2, *Pure Mathematics*, edited by J. L. Britton. Vol. 3, *Morphogenesis*, edited by P. T. Saunders. Vol. 4, *Mathematical Logic*, edited by R. O. Gandy and C. E. M. Yates. Amsterdam; New York: Elsevier Science, 1992, 2001.

The Essential Turing: Seminal Writings in Computing, Logic, Philosophy, Artificial Intelligence, and Artificial Life, plus the Secrets of Enigma. Edited by B. Jack Copeland. New York: Oxford University Press, 2004. A single volume that contains Turing's most influential work.

OTHER SOURCES

Herken, Rolf, ed. *The Universal Turing Machine: A Half-Century Survey*. Oxford: Oxford University Press, 1988. An excellent collection of commentaries on Turing's influence from the perspectives of leading mathematicians and logicians.

Hodges, Andrew. *Alan Turing: The Enigma*. New York: Simon & Schuster, 1983. Reprint, New York: Walker 2000. The authoritative biography of Turing.

———. *Turing: A Natural Philosopher*. London: Phoenix, 1997.A very concise, very accessible biography.

Leavitt, David. *The Man Who Knew Too Much: Alan Turing and the Invention of the Computer*. New York: Atlas Books, 2006. A good read, but occasionally misleading in its technical detail and presents some strained speculation about motives.

Scheutz, Matthias, ed. *Computationalism: New Directions*. Cambridge, MA: MIT Press, 2002. A book more about Turing's ideas than about Turing himself. A useful starting point into the vast secondary literature concerning computation, the philosophy of mind, and cognitive science.

Teuscher, Christof, ed. *Alan Turing: Life and Legacy of a Great Thinker*. Berlin: Springer, 2004. A wide-ranging collection of commentary on Turing.

Walter Warwick