THE ONCE AND FUTURE TURING: COMPUTING THE WORLD

Alan Turing (1912–1954) made seminal contributions to mathematical logic, computation, computer science, artificial intelligence, cryptography and theoretical biology.

In this volume, outstanding scientific thinkers take a fresh look at the great range of Turing's contributions, on how the subjects have developed since his time, and how they might develop still further.

These specially commissioned essays will provoke and engross the reader who wishes to understand better the lasting significance of one of the twentieth century's deepest thinkers.

Until his death in 2015, S. BARRY COOPER was Professor of Mathematical Logic at the University of Leeds. He was both a leading figure in the theory of Turing computability, and a noted advocate of multidisciplinary research, especially in connection with the theoretical and practical limits of the computable. As President of Computability in Europe, he was responsible for many international conferences. He chaired the Turing Centenary Committee, and edited the prize-winning critical edition of Turing's publications: *Alan Turing – His Work and Impact.*

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Computing the World

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Preface

This volume was the inspiration of the mathematical logician Barry Cooper. In 2007 he was already planning a conference to mark the centenary of Alan Turing's birth, but this was just the start of his huge and energetic dedication to a renaissance of Turing studies. In 2009, while taking on the project of a new critical edition of Turing's papers, he also raised with Cambridge University Press (and with me) an idea for a book about 'Turing and the future of computing'. After correspondence with David Tranah and Silvia Barbina of the Press, Barry and I conceived it as an opportunity for leading scientific thinkers to bring exciting and challenging aspects of Turing's legacy to a wider readership.

In 2010, we settled on the title of *The Once and Future Turing*, and extended invitations on this basis. Our enterprise rested on Barry Cooper's networking power, arising from his role as chair of *Computability in Europe* and countless conference committees. More profoundly, it was steeped in his intellectual quest to see logic interact with new advances in physical and human sciences. His very individual vision of 'computing the world' is prominent in the subtitle and introductions for the five Parts of the book, which were mainly his responsibility. My own contributions, including the overall introduction, revolved around the *Turing Once*. Barry wrote for the *Turing Future*.

Unfortunately, just as this book was in the last stages of preparation, he met a rather sudden death. It was a particular sadness for him that he was not able to see the publication of this book. He expressed heartfelt thanks to everyone involved at Cambridge University Press, a gratitude I keenly share, and, above all, to the generous work of the distinguished and ever-patient contributors. Their writing, in so many different ways, reflects the magic of time and human life and will speak to a future that neither Alan Turing nor Barry Cooper could live to see.

Andrew Hodges
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Introduction

Alan Turing's short life ran from 1912 to 1954. The inspiration for this volume lay in the centenary of his birth. But Barry Cooper and I, as editors, wanted the word 'future' in our title, as well as a reference to the past. We chose the provocative title *The Once and Future Turing*, alluding to the legend of King Arthur's tomb. We invited a range of distinguished contributors to give us snapshots of scientific work which rest upon Turing's original discoveries, and share the spirit of his thought, but which also give a glimpse of something lying beyond the present. The result is a volume of 15 papers, whose authors responded to our prompting in utterly different ways.

Turing himself was not reticent about advancing visions of the future. Famously, he did so in his classic 1950 paper 'Computing machinery and intelligence'. He was not always right. Few people would claim that his 50-year prediction for machine intelligence, cautiously phrased as it was, has been fulfilled. On the other hand, he underestimated the potential for fast, cheap, huge-scale computing. His 1948 picture of the future of computer hardware correctly identified the speed of light as the critical constraint governing computing speed. But his assumption of centimetre-scale electronic components overlooked the enormous potential for miniaturisation. Turing's foresight was more strikingly demonstrated by his 1946 observations about the power of the universal machine and the future of what would now be called the software industry; 'every known process has got to be translated into instruction table form . . . '

In 1946 he could speak with the confidence of being the mastermind of the Anglo-American crypto war – with its own legacy for the future of international relations, which, to say the least, has not yet been evaluated. In 1939 he and Gordon Welchman had pulled off the feat of persuading the British authorities to make a huge investment in the untried technology of the Turing Bombe, on the conviction, correct as it turned out, that its logical brilliance would transform British fortunes. This vision was not his alone. To beat Hitler, Bletchley Park seems to have borrowed from the future, scientifically, organisationally and socially, as if the sixties had arrived before the forties. But Turing had always had a particular note of confidence in his own vision. In 1936 he chose the unmathematical but suggestive word 'invent': "*The universal computing machine*. It is possible to invent a single machine which can be used to compute any computable sequence ..." And in that same year he clearly foresaw the coming of war with Germany and the significance of cryptology to it. After the war, his confidence was not seriously dented by his inability to retain control of practical computer development. His mathematical theory of biological growth, with its hands-on computer experimentation, lacked any significant external support. Yet this isolation did not affect his enthusiasm, even though he would have had to wait until the 1970s to see his models taken seriously and until the 1990s to see the kind of computer power that they needed.

For Turing, Cambridge was the closest he had to an intellectual home but he never behaved as Cambridge expected. Turing completely ignored the distinction between 'pure' and 'applied' mathematics, which dominated the Cambridge faculty. Instead, he exemplified the prophetic capacity of mathematics, anticipating rather than following scientific observation. *Metamagical*, we might call it, coopting the word coined by Douglas Hofstadter, one of our contributors.

Before returning to this theme, which runs through this volume, here is something new about Alan Turing's life. For those already familiar with his extraordinary story, it will add a significant nugget. For those not so familiar, this vignette will give a taste of why his individual life has become such a source of fascination to a wide public, touching bases well beyond mathematics, science and technology. In 2013, long after we had chosen our title, the Bodleian Library at Oxford ran an exhibition on 'Magical Books, from the Middle Ages to Middle-earth'. At its entrance was that Arthurian inscription *Rex quondam, Rexque futurus*. But inside was featured the more recent work of Alan Garner, most famous for his novel *The Owl Service*. Here lies the magical connection: Alan Garner had been Alan Turing's training partner; they had run a thousand miles together through Cheshire country lanes in 1951–1952.

The meeting arose in 1951, as fellow athletes spotted each other on the road. Alan Garner was only 17, a classics sixth-former at Manchester Grammar School. But from the outset Garner felt himself treated as an equal, something he could appreciate because of his school's special ambience (a culture that yet another Alan has evoked in *The History Boys*). Equality also followed from matching prowess, Turing was already famous in amateur athletics for his long distance races and Garner was just about to become a seriously competitive young sprinter. Equality also was found in banter of the kind that would now be called 'no bullshit', full of word play and scurrilous humour. It came as no surprise to Garner when Turing asked him if he thought intelligent machinery was possible. After running silently for ten minutes, he said no. Turing did not argue. "Why learn classical languages?", Turing asked, and Garner said, "you have to learn to use your brain in a different way": the kind of answer that Turing would have appreciated.

Their chat kept away from the personal: it was focused on sustaining the six or seven miles of running. But once, probably late in 1951, Turing mentioned the story of Snow White. "You too!" said Garner, amazed. For he connected it immediately with a singular event from his childhood. When five years old, *Snow White and the Seven Dwarfs* had terrified him with the vision of the poisoned apple. Turing responded with immediate empathy, and their shared trauma – as Garner saw it – remained a bond. "He used to go over the scene in detail, dwelling on the ambiguity of the apple, red on one side, green on the other, one of which gave death."

The interaction overlapped with the period of Turing's trial and punishment as a gay man. Turing never spoke of what he was undergoing and somehow Garner only heard the news late in 1952, when he was warned by the police not to associate with Turing. Garner was very angry at this, and at what he learned had happened, and he never had the least sense of having been approached in any predatory way. And yet, inevitably, it ended sadly. Alan Garner painfully recalls seeing Turing for the last time in 1953, as a fellow passenger on the bus from Wilmslow to Manchester. Being with his girl-friend, Garner found it too difficult to say anything appropriate and so he pretended not to have noticed Turing's presence. This incident, so redolent of the fiction and film of final teenage years, was soon followed by Garner's departure to National Service, where he heard of Turing's death. Alan Garner revealed nothing of this until 60 years later in a column for *The Observer* newspaper. There must be many other stranger-than-fiction Turing encounters which will never be known. But perhaps there was none in which Turing found his own apple, the symbol of his death in 1954, so directly reflected.

In 2012 I heard Alan Garner tell this story as if it were yesterday, and it made direct contact with the 60-year sweep of history we are now marking. The time-shifting experience was accentuated by the towering presence of the Jodrell Bank radio telescope, adjacent to the ancient building that Alan and Griselda Garner have made their home and archaeological base. The telescope was itself an outpost of dynamic Manchester University science and, just like the computer, it was the outcome of Second World War technology turned to science after 1945. Now it is accepted and woven into the infrastructure of astronomy and of cosmology, but in 1954 it was all new. The scale and age of the cosmos was then unknown, with everything to unfold in the following decades. The scene emphasised the would-have-been that was cut off in 1954, the great scope of new discoveries that a living Turing might have made in such a creative period.

Barry Cooper, as co-editor, put the subtitle 'Computing the world' into our time-travelling title, and the suggestion of limitless horizons is entirely appropriate for

Turing, who refused to remain confined to any one area of thought. In his last notes of 1953–1954, Turing showed that he was thinking about fundamental physics, showing the influence of Dirac, with notes on spinors and some ideas about the reformulation of quantum mechanics. Some critics have probably regarded these as mere scribbles or perhaps as signs of incipient madness. But the mystical-sounding ‘Light cone of the creation’, in his last postcards, was correctly prophetic: the geometry of light has proved to be a key idea in modern theoretical physics, and the light cone of the Big Bang is made a precise mathematical idea in the work of another contributor to this volume, Roger Penrose. Turing’s apparently weird dictum ‘Particles are founts’ actually referred to the idea that fundamental particles and forces are representations of symmetry groups: one of the greatest discoveries of the late twentieth century was that the sub-nuclear *quarks* are described by the symmetry group $SU(3)$.

My interest is not unbiased: my own work in mathematics has been in developing Roger Penrose’s ideas, using the ‘twistor’ geometry based on light cones to supersede the Feynman diagrams which form the central pillar of particle physics. Actually, Richard Feynman himself bears comparison with Alan Turing, his late-1940s work in fundamental physics, after his emergence from the atomic bomb project, being the analogue of Turing’s computer. Strikingly, Feynman also wrote some of the most personal and popular books in science, with vignettes of life that say more about the culture of science than any textbook. And there was a closer connection. When Mrs Eisenhart emitted the immortal words ‘Surely you’re joking, Mr Feynman’, she had only recently bid farewell to Alan Turing’s equally awkward participation in the same suffocating Princeton Graduate College tea parties. Later, Feynman started the early thinking about quantum computing: he and Turing could have found common ground. Above all, they famously shared the playful and no-bullshit mentality, speaking their mind to authority without much heed for diplomacy.

But there were obvious differences: it was much less easy for Turing to be the honest man he longed to be. The crypto work at Bletchley Park remained far more secret than the atomic bomb, and Turing’s sexuality was not just unconventional in Feynman’s way: it was taboo, unmentionable, criminal and a state security issue. The freedom notionally fought for in the Second World War had not been completely forgotten, and speaking one’s mind was not totally impossible. News of the early Scandinavian gay rights movement may well have inspired Turing to visit Norway in summer 1952. (And sixth-former Alan Garner proudly wrote an alpha-plus essay on classical Greek sexuality in that year.) By such small acts of resistance did change seep through. But not until the 1970s was the industrial-scale success of Bletchley Park codebreaking revealed, and only then did it become acceptable to mention the sexuality of its chief scientific figure.

The modern situation is very different, and the eager response of so many contributors to this volume reflects the serious interest now taken in everything Alan Turing was and did. It is hard to know what Turing himself would have thought of this renaissance or of his future place in science and history. He was never sure whether he was a reticent back-room boy or whether he deserved public attention as a special individual. His 1950 paper has an intense personal subtext: whilst its subject is 'intelligent machinery', Turing addressed it in a way that insisted 'I am human', and drew attention to himself as vividly as any media-savvy academic might today. In a world of 'publish or perish', Turing did a fine compromise between the two. Feynman's *Lectures on Physics* are famous, but there were no corresponding Turing *Lectures on Logic and Computing*, which could, if he had so chosen, have stamped his name on the whole new field of computer science. The 1950 paper was published and became one of the most cited in modern philosophy. The 1948 paper perished (at least until 1968) and no-one knew of the neural net models (described by Christof Teuscher in this volume).

That 1948 paper contained a Stoic picture of his place in scientific advance: "...the search for new techniques must be regarded as carried out by the human community as a whole, rather than by individuals." Turing kept remarkably quiet about his own intellectual history, referring to his 1936 universal machine when describing the nature of computers but never giving an explanation of how he arrived at it or how his 'practical universal computing machine' came into being. Official secrecy would have been a problem (he could never have explained how he came to have his knowledge of digital electronics), but he could have found a way round it. He gave no assessment of his relationship with John von Neumann, a subject that has given subsequent historians much trouble in elucidating. The nearest thing we have comes in the report on the sports page of the *Evening News*, after an athletics meeting of 26 December 1946, that he "gives credit for the donkey work on the ACE to Americans". When, in 1953, a first semi-popular book on computers, *Faster than Thought*, gave him space to set out his analysis, he gave the fundamental principle thus:

> If one can explain quite unambiguously in English, with the aid of mathematical symbols if required, how a calculation is to be done, then it is always possible to programme any digital computer to do that calculation, provided the storage capacity is adequate.

Into this one sentence are crammed both Turing's definition of computability and his conception of the computer as a universal machine. But no reader could possibly have understood its significance. (It is also, to the eye of a modern logician or philosopher, used to enforcing the subtlest distinctions in the expression of Church's Thesis, irresponsibly cavalier. Turing did not improve the precision by adding "This is not the sort of thing that admits of clear-cut proof, but amongst workers in the field it is regarded as being clear as day.") The editor of the volume, B.V. Bowden, summarised his reputation thus:

> Türing machine: In 1936 Dr Turing wrote a paper on the design and limitations of computing machines. For this reason they are sometimes known by his name. The umlaut is an unearned and undesirable addition, due, presumably, to an impression that anything so incomprehensible must be Teutonic.

After 1954 his reputation went into an even deeper Sleeping Death, partly because of this tendency to dig his own grave in his own lifetime, but also because of the blight around his trial and death. But the emergence of computer science as an engineering discipline, distinct from mathematics, did not favour him. (The establishment of the A.M. Turing Award by the Association for Computing Machinery was an odd exception.) Another factor might be that some mathematicians for too long regarded computing as beneath their dignity, even when complexity theory in the 1970s showed the mathematical depth of digital computing. All that has changed, in no small measure thanks to the power of the universal machine in transforming social communication. Turing's era now appears as a Dark Age, and in quite a literal sense, because of the dearth of historical texts. In probing the origin of the computer in the 1940s, historians find themselves arguing over second-hand stories from oral history rather than following the step-by-step documentation of intellectual process. The Arthurian legend has more relevance than might be expected to the *quondam* Turing. But now it is time to open the door to the Turing *futurus*.