

Appendix: Turing's Biomathematics

Nobody who heard Turing talk about his theory — and he spoke to mathematicians, chemists, physiologists, zoologists and botanists — had much idea of what his mathematics was. It contained an idea of genius, simple enough to explain to an applied mathematician in a few lines today.³⁴³ But Turing never gave a lay account of his mathematics, sWo here is mine.³⁴⁴

Giving the missionaries bicycles

Imagine a tropical island, with an impenetrable mountainous interior and a lush ring of habitable sea-fringed forest. This paradise is at first inhabited by a group of noble savages, whose specific lack of civilisation is that they are competent hunter-gatherers but occasional cannibals. Despite the occasional feast, for the most part the population is constrained by the amount of food they can sustainably extract from their habitat. They move around, and when they 'happen to pass by' each other enough births happen to balance the inevitable deaths. Because the supply of plant food is evenly spread, so is the population: even if a particularly big feast on one side of the island requires a few extra sacrifices or encourages the survivors to seize the moment and pass by each other a little more, emigration and birth and malnutrition eventually smooth out the temporary local blip. Then the missionaries arrive. A sub-mission of theirs is to do Science and they plot the population density around the island. This shows an uninteresting flat graph; the savages are unable to organise themselves. A constant small re-supply of missionaries keeps arriving, but with guns, germs and steel they also convert a fraction of the population. Since it is a condition of being a missionary to be celibate, the population falls a little. But the underlying food supply is uniform, and so wherever you go you find the same number of cannibals and a few missionaries, in what the scientific reports back to the sponsoring Academy call a uniform distribution.

Now we can see Turing's stroke of genius: *he gave the missionaries bicycles*.³⁴⁵ Because the missionaries can move around more quickly, something new happens. Now, when there is a

local blip that changes the balance between missionaries and cannibals, it doesn't get smoothed out. For if there is a temporary local excess of missionaries, the short term will see relatively more missionaries than cannibals arrive from the rest of the island, so even more conversion than normal occurs. This instability becomes magnified, stopping only later when the cannibals belatedly turn up for the feast. This effect relies on a balance of speed and time, so it has a characteristic distance: for each local peak of missionaries there will be a trough a particular distance away, which in turn induces a further peak so on all the way around the island. When the report to the Academy is due, the graph is no longer flat. The cannibals have arranged themselves into civilised groups.

Returning from these Western fantasies to Turing's actual paper, he showed that, starting from a blank canvas, he could generate a characteristic length-scale. Given that, spots and stripes and all things math-biological can emerge. Turing simply presents this as a model with no discussion of why it has been chosen over rivals. I have long puzzled about how Turing came to discover the Turing Instability. He acknowledged Waddington's idea of 'evocators' as an example of his own morphogens, a word Turing invented for unnamed biochemicals that could react and diffuse across his canvas, but did he deliberately construct a system of equations for them that would have the right property or did he discover it when analysing what he thought a plausible model? The technology for this analysis is, in the jargon of applied mathematics, a linearization into Fourier modes, which had been around for decades and well known to any mathematician. Turing was familiar from electronics with the possibility that instability could be encoded in a system, as was FC Williams.³⁴⁶ And in Turing's role as an applications consultant he might have had to think about how to design crystallographic algorithms in Fourier space.

The majority of the mathematics in Turing's paper is concerned with what happens on the thin outer ring of the island, keeping track of the number of missionaries per mile as we go around the beach. Some calculations, such as working out how fast the bicycles need to go to generate instability, can be calculated by hand, perhaps with a few turns on a mechanical calculator: he had a Brunsviga machine at home to do just this. But others are more complicated. To cope with this, the beach can be broken up into little sub-beaches, each of which is approximately constant in its

missionary load. Take too few sub-beaches and you can't have a pattern; take too many and the calculations become overwhelming to a human. So Turing compromised on 20 sub-beaches, multiplying his computing load by 20, and thus produced a Figure in which a random starter pattern evolves to a series of three stripes. This is one of four separate runs he reports under different conditions, and, he says, 'some' of these results were with the aid of the computer. Given a first chance on the Ferranti Mark I at the beginning of September and the submission of his paper on the 9th of November, he must have worked remarkably fast and accurately in programming the machine.³⁴⁷

In a Year or Two: Turing's Fibonacci strategy

The second remarkable attack Turing made on developmental biology was to develop a theory of the appearance of Fibonacci structure. Turing had created a mechanism for making spots appear, and the spots were separated by a typical length-scale, which depended on a complicated but tractable way on the numbers put into the model. The number of spots one might see developing in a narrow ring of tissue, as he used in his 1952 paper, would depend not only on that length-scale but the circumference of the ring. But now suppose the ring is no longer narrow, so that patterns can develop across as well along it, in a way where the placement of new spots depends on where the older ones went. What Turing saw was that this dynamic model could allow the pattern to get more and more complicated as the inter-spot distance got smaller. What emerges is a lattice of points, gently stretched as the geometry of the underlying biological ring where spot-formation is happening changes. Lattices are regular objects, amenable to mathematics, and in this case they can be usefully described by pairs of integers; simple lattices at the beginning of development have small pairs like (0,1) and (1,1) and (1,2); more complicated lattices, evolving from these as the lattices stretched to fit the new geometry of the growing plan, might be described as (1,3), or (2,3). And this is where Turing quickly isolated a problem to prove. Independently of the model assumptions, it turns out to be an unavoidable feature of geometry that a (1,2) pattern can only evolve to either a (1,3) or a (2,3): more generally that if there are two numbers, then the sum of the two will appear in the more complicated lattice paired with either the smaller

or the larger of the two. The latter choice — in this case going from a (1,2) not to a (1,3) but to a (2,3) — preserves the property that the pairs of numbers involved will always be Fibonacci numbers, for then the next pair will be (3,5) and then (5,8) and so on. Turing called this the 'H of GP': the Hypothesis of Geometrical Phyllotaxis and it is this hypothesis he was using the Ferranti Mark I to test. He was right: the 'H of GP' does hold for a wide family of mathematical models of spot formation in growing tissue. But Turing never managed to prove it in his lifetime and the mathematicians and physicists — not botanists — who carried out that proof many decades later did so in ignorance of Turing's work.

The framing of the 'H of GP' must have been the reason why Turing was confident in 1951 that he could get himself a good theory in 'a year or two'.³⁴⁸

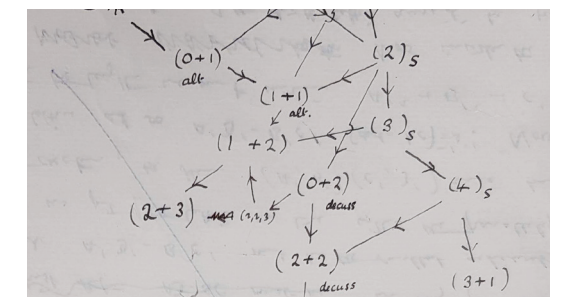


Figure 122. Turing's 'tree' classifying possible shifts between patterns



Figure 123. Classifications of leaf-placement on plant stems from Bonnet's eighteenth century text on plant growth. In the fourth example, the leaves are arranged in a spiral and if the bottom leaf is labelled as leaf 0 and numbering is continued upwards, then leaf 0 is closest to leaves 1 and 2: this is why pattern this can be described as a (1,2) spiral.

Acknowledgements

We like to identify with our heroes. My own first identification with Turing's story came, not from through his work on the *Entscheidungsproblem* or the Enigma or the Knutsford Quarter Sessions or even that he had more-or-less singlehandedly created the discipline of mathematical biology that I was to follow as my career, but because he had, like me, disappointed his Cambridge tutors by failing to get a First in his end of first year mathematics exam. Perhaps I, like he, could go on from this to become an FRS at the age of 41. Sadly, my correspondence with Turing in achievement ended with that exam result. No-one will ever name an Instability after me. I was though proud to become a Fellow of Turing's old college, later discovering that is a distinction that only matters to those to whom it applies, but which did give me a privileged push that started this book off two decades ago, and I'm grateful to King's College and the wider intellectual world it opinionatedly introduced me to.

The second identification came when I followed Turing in moving from what I thought a romantic Cambridge to a hard-headed Manchester. In 1953 Francis Crick was so thrilled to work out the structure of DNA that he went across the road to Cambridge's Eagle pub, burst in and announced he had discovered the secret of life. It is a story that the Cambridge tour guides love to mention, although often neglecting to mention that he was reputed to say this *every* night. Two decades ago I arrived in a Manchester that I wrongly thought did not have such storied places. I needed to find remarkable tales in the stones of Manchester too: and I eventually realised what I should have done before: that virtue is not located in the pub. It was in this sometimes ugly, sometimes thrilling, always self-boasting city, that I found the most productive work of my life, with rewarding colleagues and supportive friends, and indeed quite good pubs. Manchester became my city, and a home in which to negotiate love and grief and love again, and my thanks are due to the many Mancunians who helped me on that path.

Almost all of the archivists I have needed help from have provided it with grace. But I am particularly grateful to those who have taken the trouble to find out about my enquiry and to offer extra suggestions: these include Fiona Colbert, Elizabeth Ennion-Smith, Patricia McGuire, Kathryn McKee, Lizette Royer Barton, James Peters, Lewis Pollard, Jan Shearsmith and Catherine Twilley.

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Notes

The standard, and best, biography of Alan Turing is still Andrew Hodges' extraordinary achievement of the 1980s (Hodges 1983). Page references to *Alan Turing The Enigma* (ATTE) are to the 2014 paperback edition (Hodges 2014).

The computer that ran from June 1948 was called the Small-Scale Experimental Machine, or Baby or sometimes the Mark I. The subsequent prototype machines, also built by Williams' team in the University, were sometimes called MADM, but more usually also the 'Mark I'; the team called the Mark I which ran from April 1949 to October 1949 'the improved machine' and another which ran from then until August 1950 'the large-scale machine': the machine that Ferranti built based on these is called here the 'Ferranti Mark I'. Ferranti built nine of these, the first two going to Manchester and Toronto universities. The following seven were of an improved design named the Mark I* (Campbell-Kelly 1980). I am mindful that I use the words 'mind' and 'brain' synonymously. 'The war' means the worldwide war that started in 1939; 'GCHQ' and Bletchley Park are used interchangeably although the former was called GC&CS until after it left Bletchley Park first for Eastcote soon after the end of that war and then finally Cheltenham. Piccadilly Station was once London Road. Housing statistics are for the City of Manchester itself but I have used 'here' for a Manchester which includes Salford, Moston and Hyde, Wilmslow and Altrincham and, just about, Glossop. 'The University' is that of Manchester, which encompasses Owen's College, the Victoria University and even UMIST, but not what is now Manchester Metropolitan University. 'Computing' means stored-program electronic general-purpose machine computing. I use 'gay' to refer to male homosexuality: female sexual practice beyond monogamous heterosexuality barely appears, but not for want of looking. In terms of attention, I never expected this University-centred history to say much about working-class life, but only reflecting on my text am I aware of its imbalance in the representation of race. There were black faces on the Oxford Road in 1949, even in the University Staff House in the person Jof Arthur Lewis, Nobel winning Professor of Economics, but the accounts of academic and engineering life I quarried recall only an ethnically homogeneous world.

Lyn Lloyd Irvine retained her maiden name in her writing, but called herself Mrs Newman throughout her life as a married woman. (Mr) Pat Blackett was perhaps referred to on occasion as Professor Patrick Maynard Stuart Blackett, Baron Blackett OM CH PRS.

The quotation on the flyleaf from Peck and Ward (2002) uses 'perverse' to mean taking a pleasurable interest in the signs of industrial decay; the quote from *The Guardian* is via Read (1964).

Primary Sources

AMT: Papers of Alan Turing at King's College, Cambridge.

LP: Papers of Dorothy Emmet at Lucy Cavendish College, Cambridge.

MMC, NAHC, TUR, UCS, VCA: University of Manchester.

MSI: Archives of The Science Museum Group, held at the Museum of Science and Industry, Manchester.

JEFFREYS, NEWMANL, NEWMANM: St John's College, Cambridge. One of Lyn's richest correspondences is with Lady Antoinette Esher. Her letters to Esher are in NEWMANL/A/3, here abbreviated as ESHER.

STRACHEY: Papers of Christopher Strachey in the Bodleian Library Oxford,

TGA: Tate Gallery archives.

TNA: The National Archives, London.

Endnotes

- 1 'If he is to stay...' (ATTE p34).
- 2 On Manchester science at the time see [Sumner \(2016\)](#). The undergraduate intake was small, but mathematics was no backwater in 1930: the Professor was Mordell, a pure mathematician of some significance, who was appointed to Cambridge after the war and thus made a Manchester vacancy for Max Newman.
- 3 Turing was not at first outstanding academically. He did win a scholarship to King's, worth £80 a year, which Sherborne supplemented with an additional £30. But he only went to King's because he failed to get into Trinity College, which considered itself the natural location for the most high-flying mathematicians, and he failed to achieve a First in his first-year exams. Turing's prestigious later Fellowship paid £300 per year, with free meals and subsidised accommodation in the College, simultaneously grand and spartan.
- 4 Dermot Turing ([Turing 2015](#)) has more on the Apostles in relation to Turing. On the Heretics see [Howarth \(1978\)](#) and ([Sargant Florence 1968](#)).
- 5 Russell, with his co-worker Whitehead, was the most significant British thinker — until Turing — in this field of mathematical logic, but at the time it was largely a German field, dominated by Frege, Gödel, and Hilbert. Another disciple was a young Hungarian, John von Neumann, who exported the school to Princeton in the US, and there played a comparable theoretical and practical role to Turing in the development of the computer.
- 6 'the first-rank' from Newman's 1976 audio interview with Christopher Evans ([Newman 1976](#)). There have been a number of attempts to understand how Turing arrived at the Turing Machine: one intriguing hypothesis is that he was influenced by the data-processing duties of his India Office father ([Agar 2003](#)).
- 7 'men of the Professor type': ([Erskine 1986](#)).
- 8 Turing went to the NPL in October 1945. On the plans, problems and heritage of the ACE see ([Copeland 2005](#)).
- 9 One unnamed Oxford professor is said to have estimated around 106 neurons in the human brain; Turing couldn't find anyone to give him a direct answer in 1948, but made his own estimate a thousand times larger at 109. By the time his speculations on machine intelligence were causing him to be taken more seriously by biologists in 1951, Turing was in correspondence with leading physiologist JZ Young about the implications of there being around 1010 (ATTE p486 and 548). Current estimates are around 109.
- 10 Historian AJP Taylor ([Taylor 1957](#)). Taylor's view of Manchester has been critiqued by subsequent historians ([Savage and Wolff 2015](#)).
- 11 Noel Hush arrived from Australia as a 25-year-old chemist in 1949 ([Hush 2011](#)).
- 12 Post-war Manchester: ([Kidd and Wyke 2016](#)). The industrial base of the region: ([Timmins 1998](#)) and the history of the University: ([Pullan and Abendstern 2000](#)).
- 13 Pre-war industry and the growth of Trafford Park: ([Kidd 2006](#)).
- 14 Women had been permanently employed by Ferranti since the 1914–18 war; pre-war Ferranti had employed only single women but during the war the percentage of married women had risen to over 40%. The supervisor of women workers, Miss CM Forbes, reported their outlook was 'rather different from that of men. Most of them are not only happy on repetition work, but some, particularly housewives, prefer it "because we don't have to think"'. Although the majority belong to trade unions, the women tend to be less union-minded than the men, and the closed shop-principle is not as rigid' ([Gwyer 1949](#)). Forbes had worked for the firm since 1915 and was awarded an MBE in 1950 ([Gwyer 1950](#)).
- 15 'Everything they've got' was the proposal of a Brunner, Mond chemist called Francis Freeth ([Kennedy 1993](#)).
- 16 The Department for Scientific and Industrial Research was set up in 1916 as a way of organising science into producing commodities of importance for war; funds to Universities were channelled through the University Grants Council from 1919. ([Reader 1975](#)) is a corporate history of ICI during this period.
- 17 'Blackley': the original factory was set up in 1864 by Ivan Levinstein. The Pharmaceutical Division was set up in 1938. Paludrine ([Kennedy 1993](#)). One of its developers, Garnet Davy, who had been drafted to Blackley from the University of Cardiff by the Ministry of Supply, said he would otherwise never have gone into industry, 'being cursed with academic snobbery like so many people in this country'.
- 18 'You couldn't open the window': Frank Rose recalled in ([Kennedy 1993](#)). The Stockport victim was his colleague Frank Curd ([Hill 2016](#)).
- 19 Alderley Park: it was a Bury-born dye chemist with a Manchester BSc, Cecil Cronshaw, who overruled Bogue ([Hill 2016](#)).
- 20 The Bogues lived at 28 Hartley Road, Altrincham.
- 21 The Simons: ([Duxbury-Neumann 2017](#)).
- 22 Collapse in defence orders: ([Gandy 2013](#)).
- 23 Wartime bombing in Manchester: ([Anonymous 1995](#)).
- 24 Bernard Lovell's lament: ([Lovell 1990](#)). Lovell was yet another of Blackett's recruits to Manchester.
- 25 Houses falling down in 1944: City Surveyor Rowland Nicholas, 1962, cited in ([Parkinson-Bailey 2000](#)). 'Dismal': compare ([Sumner 2013](#)). Ernest Simon: ([Manchester Luncheon Club 1947](#)).
- 26 London Road Fire Station: ([Thomas 2003](#)).
- 27 First impressions: Shapley: ([Shapley 1996](#)), Taylor ([Taylor 1983](#)), Bethe ([Schweber 2012](#)), Peierls: ([Peierls 1985](#)) quoted in ([Froese Fischer 2003](#)), Kermode ([Kermode 1997](#)), Tootill (2009), Barbirolli: ([Rigby 1948](#)), Lovell: ([Lovell 1990](#)) Hush: ([Hush 2011](#)); Woods: ([Berners-Lee 2011](#)) and ([Berners-Lee 2001](#)); John Polanyi: ([Wigner and Hodgkin 1977](#)). Kellermann: ([Kellermann 2010](#)). The attitude that air pollution was inextricably linked to affluence was certainly present in Victorian Manchester: ([Mosley 2004](#)).
- 28 Smoke control in post-war Manchester: ([Dodge 2018](#), [Mosley 2013](#)).
- 29 The visual richness and counterfactual nature of the *City Plan* is discussed in ([Perkins and Dodge 2012](#)). On slum clearance: ([Shapely 2016](#)). One of the delays in slum clearance was the reluctance of suburban and rural communities outside Manchester to accept relocated working class migration.
- 30 Wythenshawe: ([Kidd and Wyke 2016](#)).
- 31 Water history ([Manchester Corporation 1974](#); [City Treasurer's Department 1946](#)). Water had been drawn from Longdendale since 1848, and then via a long aqueduct from Thirlmere in the Lake District from 1898. Lyn Newman records the threats to cut water off in (ESHER 29 Oct 1947 & 10 Nov 1947).
- 32 'The climate' ([The Manchester Joint Research Council 1954](#)). 'snooty' ([Streat 1987](#)).
- 33 Kermode ([Kermode 1997](#)).
- 34 'career train south': ([Wilson 2008](#)). 'special opportunities': (VCA/7/708). Peppered moth: Note 332.
- 35 'Only man' ([Lovell 1990](#)). See also ([Kellermann 2010](#)).
- 36 On Pat Blackett, see the articles by Anderson ([Anderson 2013b](#), [2007c](#)), Lovell ([Lovell 1988](#)) and the full-length study by Nye ([Nye 2004](#)). Oppenheimer undoubtedly told friends that he had left a poisoned apple — the cyanide detail seems to be a later addition — but biographers disagree on how serious his intention was. See ([Monk 2012](#)) or ([Bird and Sherwin 2006](#)).
- 37 'handsomest...' is from ([Zichichi 2016](#)).
- 38 The history of the Half Moon Club is still to be written but see Teulon Porter's unpublished autobiography ([Teulon Porter 1962](#)).
- 39 'Didsbury' see Chapter 6 of ([Nye 2011](#)). The Blacketts at first lived in a modest house at 238 Wilmslow Road, Didsbury, but by 1949 had moved to a flat in a grand villa, The Oaks, close by on Oak Drive, and adjacent to the home from where CP Scott had daily cycled to edit *The Manchester Guardian* (TNA KV/2/3217/84).
- 40 'rare language' ([Lovell 1990](#)); Nobel party ([Nye 2004](#)).
- 41 *Guernica*: ([Schofield 2017](#); [Nye 2004](#)), ([Desmarais 2010](#)).
- 42 Blackett's security file is in the National Archives (TNA/PF/44137). See also ([Agar 2016](#)).
- 43 AJP Taylor on Blackett: ([Taylor 1983: 227](#)).
- 44 There is no full-length biography of Max Newman but there is a short memoir by his son ([Newman 2006](#)) and a Royal Society biography ([Adams 1985](#)); I draw heavily on rival articles by Anderson ([Anderson 2007b](#), [2009b](#), [2010](#), [2013a](#)) and Copeland ([Copeland 2011b](#), [2011a](#)). On Newman the logician,

- and the influence of Penrose see (Grattan-Guinness 2012). Newman is mentioned in a number of memoirs of Cambridge in the 1920s and 1930s by Stevie Smith, (Spalding 2002), Frances Partridge (Partridge 2001) and especially Margaret Gardiner (Gardiner 1988) at the Heretics; a complex portrait of him over the decades emerges in his wife's unpublished letters now in St John's College Cambridge at NEWMANL. His own papers are at NEWMANM.
- 45 Not on the list: (Turing 2015). The Blackett letter: (NEWMANM/3/1 Blackett 26 Jul 1942). Newman unhappy at Bletchley: (Good 2006).
- 46 On Bletchley Park, there are many historical accounts including ATTE. The film *The Imitation Game* is best treated as fiction (von Tunzelmann 2014).
- 47 Newman's knowledge of the use of electronics for radioactivity counts at the Cavendish is stated in (Copeland 2017c); that it was via Blackett is my speculation.
- 48 'overlooked' (Good 1982).
- 49 Lyn's letters are held in St John's College Cambridge. 'Pride': (ESHER 5 May 1948); utterly appalled: (NEWMANL/A/2/Weyl/64 12 Mar 1945).
- 50 The appointment file is (VCA/7/10/1/2).
- 51 Newman and GCHQ (TNA/HW/64/59). Chassis from a Colossus (Anderson 2004); (Copeland 2017a).
- 52 'hundred times': The junior staff, Rees and Good, that Newman first recruited to the laboratory, were initially on salaries of £350 and £450 respectively.
- 53 'urgent appeals': (VCA/7/318/2 Newman to Vice-Chancellor 9 Jun 1946).
- 54 'Calculating machine laboratory'. By the time of its first official report in March 1948, the name had changed to *Computing Machine Laboratory* but there is no explicit record of the reason (VCA/7/318 and VCA/7/71).
- 55 Discarded cloud chamber: from the Manchester 60 website (Thomas 2017).
- 56 Max Newman's diary 6 Dec 1948 (NEWMANM/4/19).
- 57 Layby: (NAHC/SHL/FA1).
- 58 There is only one brief biographical sketch in print of Lyn Irvine (Newman 2002).
- 59 In 1929, years before Max, the Woolfs had set Lyn up on a dinner date with Max's close friend Richard Braithwaite, recently widowed. It doesn't seem to have been a romantic success, perhaps because Braithwaite nearly burst into tears when the Woolfs turned the conversation to sodomy (Woolf 1978). Braithwaite did finally have romantic success with Margaret Masterman, who had been one of Wittgenstein's disciples; many years later in retirement Dorothy Emmet set up home in Cambridge with the couple.
- 60 Lyn 'string and struggle' was a family phrase created by William aged 5 (ESHER 3 Nov 1948); Costanza's visit in 1947 (ESHER 17 Jun 1947). 'Complicated and angular' (ESHER 1 Nov 1950). 'Kink' (ESHER 1 Apr 1957): she added later that 'The material seems to me of the greatest interest but should have been digested over a considerable period by someone with literary talent' (ESHER 3 Dec 1957).
- 61 Some non-stop trains from Altrincham to Manchester Central (now the Exhibition Centre) took 14 minutes (Knight 1999).
- 62 Poorer in Manchester (NEWMANL/A/2/Weyl/70 4 Oct 1946); she desires pigeonholes: (ESHER 19 Mar 1947); 'BORING': (ESHER 23 Jul 1949); the Cartwright slight: (ESHER 6 May 1948); the lack of good bookshops: (ESHER 12 Apr 1947); desires pigeonholes: (ESHER 19 Mar 1947).
- 63 'chickens': the migrant refugee Mathematics lecturer Walter Lederman was grateful to be asked to stay in the Newmans' house while they were in Criccieth, but first he had to learn how to feed the chickens (Ledermann 2009b).
- 64 These included Garrett Birkhoff, Mary Cartwright, Haskell Curry (NEWMANM/2/3/17), Max Born (NEWMANM/2/4/2), and Brouwer (NEWMANM/2/7/5).
- 65 Growth of Cheadle Hulme: (Parkinson-Bailey 2000).
- 66 The Bogues: (ESHER/17 Jan 1949). Epilepsy: (ESHER/20 Jul 1951).
- 67 'Nash': (ESHER 26 Feb 1950).
- 68 'Daily Mail': (ESHER/1 Jun 1954). Irvine had written to *The Times* on 22 Apr 1954.
- 69 Max not getting Rouse-Ball Chair: (ESHER/26 Feb 1950). Bowdon views: (ESHER 19 Mar 1955). The appointment would probably have been determined by a judgement on the quality of Max Newman's mathematics, which was unlikely to be as high as Lyn thought. Though a creative mathematician, today he is considered influential through his able leadership of a strong department (Hoffmann 1984) rather than through his own contributions. I'm grateful to Martin Hyland for discussion on this point.
- 70 'mathematical logic': (McGuinness 1988). Kite-flying may have had a profound influence: Sterrett has argued that it was Wittgenstein's Manchester applied mathematical experience of representing the world through simplified models that gave birth to his first philosophy (Sterrett 2006).
- 71 Newman 'drowned at birth': (Partridge 1981). At one stage Newman took over as the supervisor of Wittgenstein's PhD student, Alice Ambrose, because she and Wittgenstein had rowed over her lack of meek discipleship. (McGuinness 2008).
- 72 A modern opinion is that Wittgenstein's thesis would fail a PhD because of its lack of scholarly apparatus (Goldstein 1999).
- 73 Floyd (Floyd 2017) has recently argued that Turing and Wittgenstein had more intellectual common ground and more influence on each other than this more standard account.
- 74 "odd fish" and "special train": (McGuinness 1988) and (Flowers 1999). The friend was William Eccles, whom Wittgenstein met while staying at the Grouse Inn in Glossop for his kite experiments; Eccles spent the rest of his career working for Metropolitan Vickers. When Wittgenstein returned to Manchester he lived at what is now 154 Palatine Road.
- 75 I rely largely on a biography of Hartree by his last student (Froese Fischer 2003).
- 76 (Froese Fischer 2003).
- 77 Uranium separation: (Howlett 1993).
- 78 '1000-times' is Hartree's own estimation from *The Daily Telegraph* 7 Nov 1947 reproduced in (Copeland 2005).
- 79 The fate of the differential analyser: (VCA/7/71).
- 80 On the need for four machines, the Hartree quote is, unlike most, remembered as a direct statement, specific in time and place, albeit two decades later (Swann 1975). On the lack of applications for the new machines, see (McGregor Ross 2005).
- 81 'Nazism' from *The Daily Telegraph* 7 Nov 1947 reproduced in (Copeland 2005).
- 82 '£5000' is an oral memory of Tony Brooker (p626 of ATTE) and seems implausibly, but not impossibly high. For comparison, at the end of the war Newman was earning £950 at GCHQ. Turing was offered £1200 as the Deputy Director in Manchester (ATTE p496).
- 83 MIT invitation: (TUR Add/35). 'Nancy' ATTE p497. The Nancy job seems to have been via Norbert Wiener. The 1938 Princeton Institute of Advanced Studies job had offered \$1500 a year.
- 84 See the Notes for the different machine names.
- 85 'World's first': I have already described the wartime Colossus as a world's first. With suitable definitions, the medals in this race can be awarded elsewhere in the world, or multiple times to Manchester. The Manchester Baby of Williams is the first computer to run a program stored in a practical electronic memory; its successor Ferranti Mark I of 1951 marks the first commercial purchase of an electronic computer. Williams (Williams 1997) is a good general introduction to the history of computing technology.
- 86 Flowers as first choice is implicit in the note of Womersley cited in (Turing 2015).
- 87 Manchester's Professor of electromechanical engineering, Willis Jackson, had just moved to Imperial College London, and Williams was installed as the replacement Professor of Electro-technics. Williams himself and Lovell, Blackett's Royal Society biographer, both thought it likely that Blackett was primarily responsible for Williams' appointment (Lovell 1975). By contrast Kilburn told Simon Lavington that Blackett could not have been responsible, on the grounds that Williams was third choice for the post (MAN/MUC/9/44). It is true that initially, Williams was not the front-runner, and was more or less unknown to Willis Jackson, despite being acknowledged as one of the most brilliant circuit designers in the country. The appointment file is VCA/7/46.
- 88 Williams was born in Romiley, about 10 miles south east of Manchester (Anderson 2007a).
- 89 On William's avoidance of Turing, Anderson writes plausibly, albeit without a source, that 'Turing's weltanschauung was so at odds with his own that working together might have been problematic' (Anderson 2007a).
- 90 'Williams moved on' (Anderson 2007a).

- 91 'Boddingtons': it's not clear from the context if this is a direct quote from Williams (Copeland 2012). Freddie vs FC: Simon Lavington. 'Timperley': Williams lived at Oakacre, 113 Park Road, Timperley. Oakacre was a little further south than where James Joule had lived in Sale a lifetime earlier, but not as far south as the Newmans in Bowdon. Nevertheless is a house of some scale.
- 92 Kilburn's holidays not too far from Manchester (Wilkes and Kahn 2003) and (NAHC/MUC/8/1); Manchester United season ticket holder (NAHC/MUC/7/18).
- 93 Kilburn and chemistry: (University of Manchester Department of Computer Science 1998).
- 94 'Applied mathematics camp': (Bowker and Giordano 1993). At the time Imperial College was shortening its mathematics courses to two years with the explicit goal of generating trained staff for the engineering war effort (Brooker 2010); the Cambridge course was also shortened for two years and may well have had the same intention.
- 95 Kilburn 'more of an engineer' from (Howarth 1982).
- 96 Dewsbury: (Edwards 2010). The train detail is Kilburn's memory (Howarth 1982); much closer in time, Turing said Newman had made up the routine and that Kilburn had 'put them through on the machine' (TUR Add/28). From 1951 to 1959 the Kilburns lived at 13 Tewkesbury Avenue, Davyhulme, moving to 11 Carlton Crescent, Urmston around the time he was appointed to a Professorship.
- 97 'great loyalty': (Anderson 2009a)
- 98 It's sometimes said that there was never a Director, but Kilburn, with William's knowledge, was describing himself as exactly this to Ferranti in 1951 in a side consulting agreement: (NAHC/MUC/5/156).
- 99 'standardised'. CRTs were already being made in Manchester for radar work. The CRTs for the first prototypes were supplied by GEC in London, but Ferranti did later produce customised CRTs for the machines (Edwards 2010).
- 100 (ATTE p491). The resulting Williams memory consisted of a CRT tube with a detection head covering it, and sometimes with a second tube electronically duplicating the first so the memory could be inspected. Kilburn had an increasing role: all the patents except the very first were jointly held by the two men and Lavington suggests the memory device is most fairly called the Williams-Kilburn tube (Lavington 2012); Kilburn gave a lay explanation of the basic principle in (Howarth 1982).
- 101 'instructions from Newman' (Williams 1976) as transcribed in (NAHC/MUC/9/33).
- 102 'Out of the creative process': the later revisionist histories have argued that the instruction sets were designed with much input from mathematicians, especially Jack Good (Copeland 2017a): but what there was not was a formal design process under the control of the mathematicians.
- 103 The Lockspeiser visit: (Wilson 2000) and (Streat 1987).
- 104 Lockspeiser had just moved from being Chief Scientist at the Ministry of Supply and was technically the Secretary of the Department of Scientific and Industrial Research (Edwards 1994).
- 105 Compulsory Purchase Inquiry: *The Manchester Guardian* 30 Mar 1950.
- 106 The Mathematics department was located on the top floor.
- 107 Glazed tiling: (Schuster 1900). A 1912 plan shows the room intended as a 'Magnetism Test' room.
- 108 Hartree's Differential Analyser, in a different room of the 1909 physics building, was also described as in a 'lavatory-tiled basement' (Howlett 1996).
- 109 The plans for the 1951 building show first-floor offices, with one each for Mr Kilburn, Mr Turing, Engineers and Mathematicians, Typist, and Machine Operators.
- 110 'like an oracle' (Pullan and Abendstern 2000). The building was planned in 1951 to be finished by the summer of 1953 but was delayed, partly by an electricians' strike, until the summer of 1954 (NAHC/MUC/1/C/1).
- 111 'dinner at the Blacketts' (NAHC/MUC/1/B/8): the same file records 'regret' that the \$1000 could not be disguised as something that was not a fee.
- 112 Turing's consultancy with Ferranti was confirmed in July 1951: (MAN/Tur_Add/22).
- 113 'consultancy': (NAHC/MUC/1/B/4) and (TUR Add/135).
- 114 'unapproachable and rude': (Edwards 2010)
- 115 'excellent tutorial': (Sumner 1994).
- 116 Manchester rain: (ATTE p503).
- 117 'not trying to be funny' is a comment of Maurice Wilkes who was the leader of the Cambridge computer project (Wilkes 1968).
- 118 'shabby ...' (ATTE p559). April 1951: (NAHC/MUC/5/102).
- 119 (ATTE p506).
- 120 (ATTE p515). GCHQ had been developing their own random-number generator (Donald Duck) for some years and Simon Lavington suggests they would be unlikely to have used the Ferranti Mark I's facility for production purposes, but it may have been important for research.
- 121 The successor machine was the 'Colorob': (Lavington 2006).
- 122 This sentence is mainly here for the internal rhymes, but in the minds of the 1945 funders was the plan that Cambridge computing would be stronger at numerical problems and Manchester at logical ones.
- 123 'violin': (ATTE p521). Turing lodged at 25 Nursery Road (AMT/A/35).
- 124 William Newman & the rhododendron leaf: (Turing 2015).
- 125 'mucky': (ATTE p497).
- 126 running to work: (ATTE p497); see also (Bennett 1996).
- 127 'Democratic': (Scott and Bent 1984; Hill and Shuttleworth 2003).
- 128 Turing and Garner: (ATTE pxxv: this is not in earlier editions). Garner did not know of Turing's conviction and was later warned by the police to stay away from him (Hodges 2016a).
- 129 A confirmation that Turing was a consultant to GCHQ at one time is in (Murray 1975).
- 130 Roy Webb: (ATTE p537). It is possible that Turing chose Wilmslow simply because of this connection.
- 131 'We had built a network of railways...': (Jha 1998).
- 132 Emanuel Freud had emigrated from Vienna to run a business at 61 Bloom Street, now the Musicians Union office. The postcard is in (Freud 2002).
- 133 Lyn on Turing from her preface to (Turing 1959); they had rented the house from a Manchester solicitor Niel Pearson and his wife Ruth; Pearson would later be the chair of the '51 Society.
- 134 Russell was living more or less permanently at Penrallt Goch, Llan Ffestiniog, Merioneth (NewmanM/2/15/9); 'senile': (NewmanM/2/3/5). Hartree also holidayed at Portmadoc (VCA/7/71/3). The Polanyis had been to visit the Blacketts at their cottage at Penparc, Llanfrothorn, Penrhyndeudrath in 1939 (Nye 2007). 'Manchester gang' was the Blacketts, Pearsons and Newmans in 1948 (ESHER 23 Jun 1948); 'chores' (ESHER 2 Aug 1949); Hobsbawm: (Hobsbawm 2002) cited in (Nye 2004).
- 135 (ESHER 17 Jun 1947) and around 8 Jun 1952 or 25 Nov 1952. The Newmans replaced their Morris with a Daimler in 1955 (ESHER/19 Mar 1955). The Red Witch: (Nye 2004).
- 136 Emmet's travels: (LP/17/6/4/1). Turing and Clarke: (ATTE p272).
- 137 Norway and Kjell (ATTE p599). Norwegian grammar (ATT p604).
- 138 AMT/F to PN Furbank 12 Jul 1953.
- 139 (TUR Add/100). Hodges suggests that Turing may have belatedly realised that his importance to the state meant a loss of privacy and that he would find it increasingly difficult to slip unnoticed into different worlds on these trips.
- 140 Audrey Bates was headhunted to Toronto in 1953 (DTIC 1979, Pedwell, 2017 #1166); Popplewell was giving lectures in Argentina in the 1960s (Impagliazzo 2006). 'I detest America': (TUR Add/107 20 Feb 1953) to Donald Mackay about a Macy conference.
- 141 'wildly innocent': (ESHER 24 Jun 1949).
- 142 '1946' The Times, 1 Nov 1946, and The Manchester Guardian of 2 Nov 1946. The Nature report was drawn on in a presidential address to the British Institution of Radio Engineers, which was in turn reported in The Times, perhaps because it had been given by Lord Mountbatten: (Sumner 2014) and (Martin 1995). It attracted the attention of Ferranti who paid particular attention to the ACE at a June 1947 Open Day at the NPL (Lunt 1947).
- 143 On Wiener see (Conway and Siegelman 2005).
- 144 *News Review*, 11 Feb 1949.

- 145 The first publishable response at least; in a letter to Turing, W Ross Ashby had called it 'good radar but...pretty poor physiology' (TUR Add/2).
- 146 For a biography of Jefferson in Manchester see (Butler 2005); a longer but over-dutiful biography is (Schurr 1997).
- 147 Jefferson's tax return from 1945 shows income of £3500 and the majority of this was taxed at a rate of 50% (JEF/1/7/2). This may have been temporarily low; his surgical colleague Harry Platt was earning over £5000 a year pre-war (Butler 2005). In 1954 the Jeffersons lived at High Bank, Stenner Lane, Didsbury. (Manchester Literary and Philosophical Society 2018). The Lake District story is MMC/2/Jefferson/1/8.
- 148 The Oration was published in (Jefferson 1949a).
- 149 'petulant': (Brockbank 1965).
- 150 'draw the line at sonnets': *The Times*, 11 Jun 1949.
- 151 'wildly innocent': (ESHER 24 Jun 1949).
- 152 Newman's letter: *The Times* 14 Jun 1949. From this date the Vice-Chancellor's cuttings book starts to monitor coverage of the Manchester Computer (VCA/1).
- 153 'good brownie': (NewmanL/A3/2/23 Jul 1949).
- 154 *Illustrated London News* 25 Jun 1949; the 1949 BBC film clip was included in the computer50 celebration CD (Napper 1998). The date of 1948 sometimes attached to the clip is wrong.
- 155 'chaired': at any rate the seminar was organised under her aegis, and in the transcript it is Emmet who outlines the questions to be addressed (albeit unsuccessfully).
- 156 'strike-break': Blackett (Nye 2007).
- 157 'undogmatic' from Emmet DNB entry (O'Neill 2018). 'inure her': (Emmet 1996).
- 158 Whitehead photograph: (LP/17/6/4/1).
- 159 'civilise the scientists': (VCA/7/71). The scheme seems to have come to nothing.
- 160 Newman went for dinner at Emmet's house in the year they arrived (NewmanM/4/13/1 18 May 1948 and 12 Oct 1948). The following year she and Newman were sharing discussions on Brouwer's philosophy of consciousness (NEWMANM/2/7/7).
- 161 Polanyi's economics: (Nye 2011).
- 162 'Social Studies' p82 of (Emmet 1996); Mansfield Cooper, who was later to become Vice Chancellor, recalled that it was obvious that Polanyi had to be kept but that there was no chance he could persuade the University to create a new chair in Philosophy: (Wigner and Hodgkin 1977).
- 163 'Social Science' seminar: (Pullan 2007).
- 164 'a Higher obscurantist' cited in (Jha 1998). Emmet was probably the 'other philosopher' who is cited as warning the Vice Chancellor in (Wigner and Hodgkin 1977).
- 165 'the penumbra' (Emmet 1996).
- 166 'meat ration' (Emmet 1996).
- 167 'Blue Pilgrims: (LP/17/8/5). In retirement, Emmet left Manchester to move to Cambridge, partly to be near her aged mother, but also to move in with Richard Braithwaite and his wife Margaret with whom she shared an interest in philosophical thinking about religion (Emmet 1996). This was the same Braithwaite who had invited the undergraduate Turing to give a paper on mathematics and logic to the Cambridge University philosophy society.
- 168 'second attempt': a selection committee recommended leaving the chair unfilled but instead promoting Emmet to the post of Reader; it's unclear why the decision was reconsidered a year later (VCA 7/227). The outgoing Professor Ritchie, who rated Emmet very highly, was like Polanyi trained as a chemist and not as a philosopher.
- 169 'only woman' from (Pullan and Abendstern 2000). Violet Cane became the Professor of Statistics: in 1952 she had written, in collaboration with psychologist Richard Gregory, to Turing about the possibility of constructing a model electronic brain to study: (AMT/D/16). Emmet's house at 21 Yew Tree Lane, Northenden cost £500 in 1939: (LP/17/11/5) and (LP/17/6/4/1).
- 170 'violent attack'; 'un-tenured and mediocre' and Manchester's response to refugees in general: (Williams 2013). The technician was Martin Schmalz (Nye 2011).
- 171 Magda's application: (USC/4/1); Lyn's acquaintance: (NEWMANL/A/2/Pearson). On the other hand the Polanyis plural seem to have put the Blacketts up at one point in 1945 (Nye 2007), and the families holidayed together. By the late 1950s Magda and Michael were travelling together and Magda followed her husband's move to London and then the United States. Before the war the Polanyis were at 30 Sandleigh Avenue. In 1947–1950 Michael was living at 10 Gilbert Road in Hale and after that gave his address as the University.
- 172 Polanyi protest against Nazism: (Jha 1998); 'headhunted' is (Hush 2011).
- 173 Polanyi extended this belief to his students who recall notable freedom to choose what to work on (Calvin 1991).
- 174 'Blackett the great theoretical planner': Mansfield Cooper cited in (Wigner and Hodgkin 1977).
- 175 'rational scientific planning': (Agar 2016); 'banned as subversives': Polanyi's banning may have been by mistake: (Jha 1998; Nye 2007). Blackett's ban: (Nye 2011). Respect and affection: (Wigner and Hodgkin 1977).
- 176 Polanyi's notes are published in (Blum 2010); the prepared remarks also prompted a brief last-minute paper from the new Professor of Statistics, Maurice Bartlett, on the statistical nature of learning: (LP/17/6/6/14). Emmet is remembered by Margaret Boden as more sympathetic to Polanyi's position than to Turing's (Boden 2008b). Newman's surprise that he was expected to prepare for the seminar is Newman to Polanyi, 19 Sep 1949, MPP/B5/F6 in the Michael Polanyi Archive, University of Chicago.
- 177 The discussion was summarised in a typescript of unknown authorship which was published in (Blum 2010); Emmet's original copy is in (LP/17/6/6/14) which also contains the response by Meier. Emmet's copy appears identical to the copy owned by Wolfe Mays of which scans are available online. The author may have been Desmond Paul Henry, a junior member of the Philosophy Department (O'Hanrahan 2018). The ICI representative is described as 'HEWELL (?) (ICI Research)' and makes comments which suggest knowledge of electro-neurology and of epilepsy, subjects under investigation by Yule Bogue at ICI at the time. It's most likely the speaker was Dr LB (Ben) Wevill, an anaesthetist who was head of the medical department of ICI Pharmaceuticals (I'm grateful to George B Hill for this suggestion), or just conceivably a surgeon called Christopher Hewer who had worked with ICI in the 1940s developing trichlorethylene as an anaesthetic in London (Kennedy 1993). Also present was the London-based physiologist JZ Young whom Jefferson had recently consulted on his Lister Oration. Also contributing were a young Mathematics lecturer, Bernhard Neuman, and Maurice Bartlett. Wolfe Mays was a young philosophy lecturer, who preserved the transcription and later published a version of it (Mays 2000). Ferranti were not present, although they were also developing an EEG machine (Heaton 1950).
- 178 'Unimpressed': recollections of the then just-graduated and new member of the department, Desmond Henry in about 1998, as further recounted by JB Kennedy to Elaine O'Hanrahan in 2018. I'm grateful to the latter for passing this on. Piaget: (ATTE p604).
- 179 Turing had an earlier, restricted version of the Test in a 1948 manuscript (AMT/C/11) which was only narrowly circulated (Copeland 2004); this only conceived of telling the difference between a machine and a human when they played chess. The *Mind* paper was published as (Turing 1950); Wolfe Mays published his own response later (Mays 1952), revised much later as (Mays 2001).
- 180 Jefferson covered the idea of mechanical minds in the third of three public lectures in 1952; the note was taken by Michael Polanyi (Blum 2010).
- 181 *The Manchester Guardian* 7 Jul and 15 Nov 1951.
- 182 The five 1951 broadcasts: (Jones 2004).
- 183 The talk, *Intelligent Machines, a Heretical Theory* was published by Copeland (Copeland 2004), who says Turing gave this talk to The '51 Society. The typescripts are in AMT/B/20 and AMT/B/4. Neither typescript makes any reference to The '51 Society and both are undated; and I've been unable to find any reference to a suitable meeting in the apparently complete record of The '51 Society meetings held in the BBC Archives (at N8/62/1).
- 184 'little old ladies': (ATTE p526), though Max Newman recalls a slightly different version (Newman 1955) and it is not in the typed transcripts in KCC of Turing's talk.
- 185 More details of the Third Programme recording are in Proudfoot (Proudfoot 2015), which seems to be largely drawn from BBC archive material. 'trying to listen to': (ATTE p572). Lyn: (ESHER 13 Nov 1951).
- 186 (ESHER 13 Mar 1949).

- 187 Turing discussed *Le Rouge et Le Noir* with Nick Furbank (Turing 2015); *Finistère* and *The Cloven Pine* with Fred Clayton and *The Heart in Exile* and *Hemlock and After* with Robin Gandy (ATTE p613). 'Though they had little in common': (Furbank 1979) 'when he launched': (ESHER 13 Mar 1949). 'Without gifts': (ESHER 13 Nov 1957).
- 188 The Annual Report: (Anonymous 1955). The Lit & Phil's membership is online at (Anonymous 2018b). Hartree, Polanyi and Jefferson, but none of the women, each took a turn as President; Dorothy Emmet made it to Vice Chair of the Social Philosophy section in 1948. Turing is not listed in any of the Memoirs as a member but he is recorded in the Council Minutes of 12 Oct 1953 as being proposed as one by Michael Polanyi and Niel Pearson. I'm grateful to Kathryn Slater of the Lit & Phil for this information.
- 189 'The Luncheon Club': (Manchester Luncheon Club 1947).
- 190 The '51 society': (Coles and Smith 2006). *Manchester Guardian*, 12 Nov 1951.
- 191 'say nowt': (ESHER 12 Feb 1957). 100th meeting: (ESHER 19 Mar 1955).
- 192 'Atoms and whimsy': (Atkinson 2012).
- 193 The logbooks are at NAHC/MUC/2/C/6. There is a difference between these dates and when Ferranti Mark I is generally accepted to have arrived in February 1951. There is no logbook before April, and August is more compatible with Turing's November statement that 'we have had the machine for a few months' (TUR ADD/45).
- 194 The sodomy risk is recounted in Turner (Turner 2011).
- 195 'Lions and unicorns' (Conekin 2003).
- 196 'July 1950': (Duffy 1951). Ferranti told the Festival organisers on 30 Nov 1950 that they wouldn't supply a computer on the grounds of 'cost', although they did not have anything to show; Nimrod was designed in December 1950 (Stuart-Williams and Byrd 1951). 'gawk' and the Nimrod account is from the Australian John Bennett. Bennett was newly arrived at Ferranti as a programmer (Bennett 1994) and was the designer of the machine, which was built by Ferranti engineer Raymond Stuart-Williams (Smith 2014, Stuart-Williams 1951). Bennett may have been inspired by the Nimatron, an a electro-mechanical Nim machine at the 1940 New York World's Fair (Smith 2014), but the team would also have been aware of 'Bertie the Brain', a fully electronic noughts and crosses game shown in Toronto in 1950 by the team behind the computer project that was in the end replaced by FERUT. Smith suggests that Bertie has priority over Nimrod as the first known computer game. Turing at the Festival: (ATTE p562); he went with Cambridge friends Robin Gandy and Nick Furbank.
- 197 'ICI': Megaw received crystallography images from Charles William Bunn and his colleague Myra Bailey (Jackson 2008). Farid Ahmed: (Ahmed 2009).
- 198 Barlow and Jones cloth was based on a haemoglobin structure drawn by Max Perutz and was used in the South Bank's Regatta Restaurant (Jackson 2008).
- 199 ICI Trafford Park applied their expertise in scaling up production to an American-developed fermentation process in Trafford Park. (Quirke 2013; Kennedy 1993). On penicillin as the emblem of a New Elizabethan era, see (Bud 1998, 2007).
- 200 'largest ever': it had 3000 exhibits (Taylor 1951).
- 201 'Searchlights' from (Conekin 2003).
- 202 The Shrapnel article was in *The Manchester Guardian* of 4 May 1951 and has been edited here but the full text is online (Shrapnel 1951).
- 203 Fiore de Henriquez: (Marsh 2004). Her Festival piece, *The Skill of the British People*, was made of plaster and was probably destroyed afterwards.
- 204 Unlike Liverpool and many other cities Manchester held no independent Arts Festival. Perhaps relatedly, the Hyde mural, reproduced by (England 2015), is way too ugly to show here. Its painter, Harry Rutherford, was also an early BBC TV star from 1936, sketching variety acts as they performed. According to a Tameside Council history, the producer insisted he remain silent and would not allow a Lancashire accent on the air (Tameside Borough Council 2018).
- 205 'wirewoman' (Tootill 2009).
- 206 Ida Fitzgerald: (Lavington 1975). Pankhurst and pre-war women engineers: (Pursell 1993).
- 207 On a similar transition in the US: (Light 1999).
- 208 'Bedales' The Hartrees lived at 1 Didsbury Park, with five family bedrooms and rooms for two maids (Froese Fischer 2003); during the war they put up several academic families including the Blacketts.
- 209 'Chubby': (Froese Fischer 2003)
- 210 Hartree's biography is (Froese Fischer 2003).
- 211 Croarken in Hartree's group: (Lindsey 2010); Croarken's history: (Croarken 1993, 1990).
- 212 Two pianos: (Williams 2006).
- 213 Harold Jeffreys and psychoanalysis: (Forrester 2018).
- 214 Some time after moving in and naming all its seminar rooms after men, in 2016 the Manchester Mathematics department named two spaces in its Turing building after Phyllis Nicolson and Hanna Neumann. Neumann arrived in Manchester as a mathematics lecturer at UMIST in 1958, but her husband Bernhard had been a lecturer in the University since 1948: he attended Dorothy Emmet's 1949 seminar on the brain as a computer.
- 215 On the costs to the British of not valuing female computing labour: (Hicks 2017).
- 216 The files of Turing's secretary were rediscovered in 2017 and are now catalogued at NAHC/TUR_Add.
- 217 'not really' (ATTE p505 and p555). 'Shockable': (ATTE p 587). Popplewell's account was written in 1979: (ATTE p506) and (Campbell-Kelly 1980).
- 218 The programming manual was rewritten with contributions from Popplewell and Tony Brooker. Popplewell was giving coding courses in 1959: (NAHC/MUC/1/B/4). Popplewell is remembered in the 1960s by Mike Wyld (Lavington 2013), and as teaching users in Argentina how to use a new Ferranti Mercury in the 1960s (Impagliazzo 2006). Popplewell writing *exp* and *sin* routines is attested by Strachey (STRACHEY/C/3/4).
- 219 Popplewell was born in Stockport in October 1919. Simon Lavington recalls that she retired from the Computing Service in around 1965 when it was decoupled from the academic department. She married in September 1969.
- 220 Audrey Bates' First: (Lavington 2012). The second machine had been due to go to AWRE for £100,000 (Swann 1975). There is no direct evidence of national security need: FERUT was said to be needed for calculations for the St Lawrence Seaway (Swann 1975) and there was an existing domestic computer project which was failing, but the speed and size of the contract seems suggestive. Canada had no atomic weapons project but was pooling some cryptographic resources with the UK. The machine arrived in Toronto in April 1952; it was Calvin Gottlieb who head-hunted Bates to Toronto. The photograph of Bates is in (Pedwell 2017).
- 221 Popplewell is remembered by her step-family as visiting Canada in 1952, but transatlantic passenger records suggest she instead spent much of 1953 there.
- 222 This biographical information comes from (DTIC 1979): by 1979 she had changed her name to Audrey Clayton.
- 223 The equal pay dispute is remembered in (Berners-Lee 2011) and can usefully be read alongside (Hicks 2017).
- 224 Woods' memory is in (Berners-Lee 2011).
- 225 Worsley and Turing: (TUR/Add 13 and 92). On Worsley: (Campbell 2003).
226. On the lack of written information about sex: (Bullough 1994).
- 227 (Brewster 1913).
- 228 'Mashed potato': (ESHER 26 Feb 1950). Mahler: (Ledermann 2009b).
- 229 (ATTE p538). Hodges writes that some people were annoyed by this role-challenging. Mrs Clayton was presumably working-class; she came from a street of terraced houses, Mount Pleasant, a few minutes cycle away in Lacey Green.
- 230 Mary Lee Woods' memories (Berners-Lee 2011); John Bennett's: (Bennett 1994).
- 231 'tin hut': (Berners-Lee 2011). It was in fact a pre-fabricated Nursery School largely made of asbestos.
- 232 'Attractive young ladies': (Sumner 1994). Vera and Tony Brooker were one of the Ferranti marriages.
- 233 Staff common rooms: (Taylor 1983). Students' Union: (University of Manchester 2017).
- 234 Burgess: two of the losses were reported in (Burgess 1987) and a third in a Granada TV interview. I'm grateful to Andrew Biswell and Anna Edwards at the The International Anthony Burgess Foundation for this.
- 235 On the turn to Greek culture as a response to the Wilde trial see (Hall 2012).
- 236 'Exhibition catalogue': (Bronowski 1951).

- 237** *On Growth and Form* was circulating in art schools prior to Richard Hamilton's 1951 ICA exhibition (Jacobi 2014). The exhibition ran from 3 Jul to 1 Sep at ICA's first home in Dover St: (Moffat 2000, 2002) and (TGA 955.1.12.26). There was a book produced too, *Aspects of Form* (Whyte 1951) with chapters by Waddington and Grey Walter, which must have been discussed at the Ratio Club. The exhibition catalogue records photographs of various planktons but does not name the organisms used for glass models; some of the contemporary photographs appear to show a *Radiolaria*-like structure.
- 238** On D'Arcy Thompson's legacy: (Boden 2008a). In the 1930s, Thomson met pure mathematician Lederman in the St Andrew's University Library and, with the words 'Here is a good boy. Come along with me to my house and tell me all about it', got Lederman to write out the answer to his question about differential equations (Ledermann 2009a).
- 239** Dorothy Wrinch: (Senechal 2013).
- 240** The Theoretical Biology group (Senechal 2013) had at its centre, as well as Dorothy Wrinch: JD Bernal, who slept with his student Dorothy Hodgkin among many others; Joseph Needham, who would have a life-long relationship with his student Lu Gwei-djen; Dorothy Needham, who would share her house with both her husband Joseph and with Lu Gwei-djen; Hal Waddington, just going through a divorce, and Joseph Woodger who seems to have lived an entirely conventional family life in London. One of Joseph Woodger's four children was Mike Woodger who would become close platonic friend of Turing's in the post-war period after working with him at NPL.
- 241** 'You and I': Polanyi to Wrinch, 1948. Dorothy Wrinch Papers, Sophia Smith Collection, Smith College, Northampton, Mass.
- 242** Wrinch wrote to D'Arcy Thompson in 1931 that she had at last got her 'biological hypothesis. I am so thrilled. Without your wonderful book I should never have got it. Enclosed is first draft of cytology paper...I do think morphology is electrostatic, don't you?' (Senechal 2013). I've not been able to identify such a paper; at the time Wrinch did publish a number of papers on harmonics on spheroids which could lead to such a theory.
- 243** 'Best cryptanalyst': a personal remark about Joan Clarke by a senior GCHQ figure of the 2000s who gave me a lift after a talk in Cheltenham and whose name I have forgotten. The same figure said that his peers did not consider Turing should receive a retrospective pardon for breaking the law of a democratic state; (ATTE p245).
- 244** There had been some attempts to explore the mystery. The Fibonacci numbers are very closely related to the Golden Ratio, = 0.61803..., and there had been a few books, more number-mystical than mathematical, putting the Golden Ratio at the centre of a harmonious universe. D'Arcy Thomson is dismissive of Fibonacci structure, but his argument for this dismissal is hard to follow.
- 245** When combined with a mid-distance focus and facial expressions denoting passionate mental effort, discussing Fibonacci numbers is a surprisingly effective courtship strategy.
- 246** 'influential': The 1931 paper, as a text, had no impact on emerging computer engineering, though as the academic discipline of computer science emerged, it became necessary to retrofit Turing indirectly as the 'Father of Computer Science' through this work of mathematical logic (Daylight 2015). Through the 1951 paper Turing was a direct, but distant, founder of a mathematical biology that currently supports a handful of Professorships in the UK alone (Fox Keller 2002).
- 247** There is no definitive record of Turing's path to the Turing Instability. Gandy remembered being told that Turing wanted to 'defeat the argument from design' (ATTE p543), and Schrodinger's 1941 lecture *What Is Life* was well known to Turing. Hodges records that Polanyi had explicit objections to the principle of being able to explain embryonic form, and perhaps this goaded Turing into explicit mathematics just as Jefferson had goaded him about machine intelligence. More positively, Polanyi had more or less invented the systematic theory of reaction kinetics, and Polanyi's protégé Meredith Evans pushed his student Noel Hush and Turing together to talk kinetics (Hush 2011); but whatever influence the Manchester chemists had, it has left no formal acknowledgement. There were biologists involved too, outside of Manchester, notably the London neuroscientist John Zachary Young, who had known Turing at least since the 1949 seminar and had a series of discussions with him during 1949–1951; Young recalled Turing's 'frightening attention to everything one said' (ATTE p548). With the Ferranti Mark I on the way, it was Young whom Turing told that his theory was 'yielding to treatment' (AMT/K/1/78 8 Feb 1951), and Mike Woodger that he was hoping to make progress with the 'new machine' on 12 Feb 1951 (ATTE p551). Another source of ideas was the 'Ratio Club', the London-based group which Turing attended in 1950 and 1951 (Turing 2015). Highly interested in theoretical ideas, this was primarily a biological group, and of all the talks John Pringle's on 'Noise in the nervous system' may have been the closest to Turing's emerging thinking.
- 248** On the posthumous influence of the Turing Instability, see (Nanjundiah 2003). Both the 1952 paper and the substantial unpublished later material contain a much wider exploration of reaction-diffusion behaviour than the Turing Instability: see (Dawes 2016) and (Allaerts 2003).
- 249** Bonnet: (Bonnet 1754).
- 250** Memories of John Bennett in (Bennett 1996).
- 251** 'I doubt': (NEWMANM/4/5/1).
- 252** A more mathematical account of Turing's programme is in my (Swinton 2013).
- 253** Turing spoke at a Henley conference organised by the Nuffield Foundation (Anonymous 1952).
- 254** On the Prigogine seminar: (ATTE p586).
- 255** SEB: (TUR Add/38). Turing also talked 'on fir-cones' in Cambridge on 14 Nov 1951 (TUR Add/184).
- 256** Cannon on Lamarck: (Cannon 1959, 2017, 1960). Cannon on statistical genetics, especially Galton, is (Cannon 1958) cited in (Kraft 2000).
- 257** Wardlaw's memoir of his wife is (Wardlaw 1971).
- 258** On the development of biology in Manchester see (Wilson 2008).
- 259** 'A long time' is from Wardlaw's essays collected in (Wardlaw 1968). They include two papers written at the time of the collaboration: the one that Wardlaw had invited Turing to co-author with him as an account of the reaction-diffusion theory (Wardlaw 1953), and another that describes experimental support for the theory (Wardlaw 1954).
- 260** Botany memories of Turing from (Charlton and Cutter 1986). It's very unlikely that Turing did ever claim 'the existence of a central floret'. Turing was always well aware that the centre of the sunflower is developmentally the youngest and has no influence on the form already laid down in the rest of the plant.
- 261** Fox Keller (Fox Keller 2002) is perceptive on the biological reception and rejection of Turing's reaction-diffusion theories and the challenges to Theoretical Biology at the time.
- 262** Bernard Richard's account of his MSc: (Richards, 1998, 2013).
- 263** 'In a University Laboratory': *The Manchester Guardian*, 15 Mar 1955. The byline on the article is Williams, but the language is much closer to Bowden's, and the accompanying photograph is probably one commissioned by Ferranti and still held in the Ferranti archive. The article incorrectly says that the 1948 designs were intended only for 'lengthy calculations of an ordinary kind': other intended uses may have been invisible to Williams.
- 264** 'Ludicrous interpolation': Lord Halsbury in (Bowden 1953); Bowden's strategy and Blackett and PAYE: (Tweeddale 1993). Bowden lived in Bowdon (& grew sunflowers there): (Bowdon History Society 1999).
- 265** Commercial failure of the Atlas: (Gandy 2013). The 'half' machine was a full machine sold to Manchester University well below a commercial price.
- 266** Strachey's Jungian analysis: (Campbell-Kelly 1985).
- 267** The use of the Ferranti Mark I for music is described in (Copeland and Long 2017a).
- 268** 'Very bad': *The Manchester Guardian* 4 Jun 1952.
- 269** Dean of the Faculty of Music: (Kilburn and Piggott 1978).
- 270** Strachey's draughts as computer game: (Smith 2014).
- 271** Brief biographies of Christopher Strachey include (Campbell-Kelly 1985) and (Gaboury 2013). Not getting on with Kilburn: (Hendry 1990); (ATTE p557). Music on the Mark I: (Copeland and Long 2017b).
- 272** Prinz's recruitment to Ferranti was via Eric Grundy, head of the Instrument Department, on the recommendation of the Royal Military

- College of Science: (Gandy 2013). Other biographical statement about Prinz are from his daughter Dani Prinz.
- 273** Logical machines: (Mays and Prinz 1950). Prinz is photographed between the British General in charge of the Sector and Ludwig Erhard, the West German finance minister. The Federal Chancellor Adenauer was also present but declined to play (HNF 2015; Stuart-Williams and Byrd 1951).
- 274** Turing had earlier developed an algorithm — but not a program — for playing chess; Prinz’s work was quite independent and limited to endgame problems: (Copeland and Prinz 2017). ‘frivolities’: (Copeland and Prinz 2017). Bus timetabling: (NAHC/PRI/C).
- 275** John Turing’s memoir of his brother printed in the Second Edition of their mother’s biography (Turing 2012). John Turing was perhaps doubly ignorant: *Pansies* had had struggles with the censor over ‘obscene phraseology’ (Anonymous 2017) but though the title, a corruption of the French *Pensées*, consciously alluded to homosexuality, most of the subject matter is pretty standard DH Lawrence in the vigour of its heterosexuality.
- 276** (ATTE p496).
- 277** ‘big city scene’ from (Weeks and Porter 1998) as cited in Tebbutt (Tebbutt 2006).
- 278** ‘worst city’ *Sunday Pictorial* 25 May, 1 Jun and 8 Jun 1955, cited in ATTE p580. Drag shows at the Union pub were popular with American troops during the war. (Cook et al. 2007); ‘queer gender’ identities (Tebbutt 2006): it’s noticeable that Tebbutt’s principal reference for gay culture in Manchester is Hodges (Hodges 2014, 1983).
- 279** The Rembrandt and the Union: (Taylor, Evans, and Fraser 1996) p183 and (Cook et al. 2007) p155.
- 280** ‘Openly gay clubs’ from Whittle and Jones (1994) cited in (Taylor, Evans, and Fraser 1996) p183.
- 281** (ATTE p540). Hodges interviewed Arnold Murray around 1980 and the account in his book is primarily based on Murray’s memory. The encounter between Turing and Murray was remembered as being outside the Regal Cinema, now the Dancehouse, and half a mile south of a more widely-remembered cruising area around the Gaumont. Tebbutt (Tebbutt 2006) writes that the Trafford Bar, within the Gaumont Cinema at the corner of Oxford Street and Portland Street, was popular with gay men and that the adjacent urinal at the corner of Bridgewater Street and Oxford Street was popular for cottaging. Whittle (Whittle and Jones 1994) seems to be referring to the same cinema, but puts the meeting place in the Long Bar of the Odeon, a different cinema 100m further north. The Union Pub, that Hodges names, is five minutes’ walk east from this stretch of cinemas.
- 282** ‘small homosexual set’: (ATTE p499). This seems to have left no historical record.
- 283** A brief description of the University’s post-war mood is in (Rowley and Lees 2001); wartime licence is recorded for example in (Cook et al. 2007).
- 284** Personal memories as recounted to me. Reproof for Oxford Road affection: (Pullan and Abendstern 2000).
- 285** ‘Gielgud’ in (Pullan and Abendstern 2000). Gielgud appeared in court on 22 Oct 1953. When he next appeared in public it was in Liverpool at the premiere of a new play. Thanks in part to his co-star Sybil Thorndike, he received a standing ovation, and the play came to Manchester two weeks later without incident. Although Gielgud’s film career was undamaged by the affair, he was personally affected and briefly suffered a nervous breakdown.
- 286** (Pullan and Abendstern 2000). Anthony Burgess’ pre-war observation on homosexuality in student life was that he only felt its ‘full blast in the thespian form’ (p201) and that ‘how the homosexuals got on we did not know. There did not seem to be many of them about’ (Burgess 1987).
- 287** Turing and Murray’s meeting: (ATTE p565) from Arnold Murray’s memories of a quarter of a century earlier. ‘real good stuff’ is Turing’s description of his fictional counterpart Alec Pryce’s achievement.
- 288** The arrest and trial were reported in the local *Alderley and Wilmslow Advertiser* on 29 Feb and 4 Apr 1952.
- 289** Stringent condition: (ATTE p582).
- 290** Shortly after the event Turing wrote that he had estimated the chances of getting into trouble with the law at about 10:1 against: (AMT/D/14a Feb 1952). Hodges rightly emphasises the difference between the tolerance of King’s and the intolerance of Manchester, but I’ve been unable to find any evidence on my more local speculation one way or the other. US-driven security tightening and increasing prosecutions after 1951: (Hyde 1970).
- 291** ‘father-figure’ and the account that follows (ATTE p584) is from an interview Hodges had with Max Newman.
- 292** Cited in passive voice in (ATTE p594).
- 293** Special number on homosexuality: (Glover, Mannheim, and Miller 1958).
- 294** From start to finish, the *News of the World* had a contemptible element, but you have to admire the occasional headline (ATTE p597). The Northern edition of the *NotW* is not archived anywhere except by News International, who did not make a copy available to Hodges.
- 295** Hodges has clarified that he was referring to the overall social climate at the time rather than any specific comment of Jefferson or Polanyi.
- 296** Alexander: (ATTE p594).
- 297** In 1952, England and Wales saw over 600 men found guilty for ‘gross indecency’, with 65% being sent to prison. Probation was ordered in most of the remaining cases (HMSO 1956). ‘Gross indecency’ more or less meant consensual sexual activity between men, whether in public or private. Dermot Turing (Turing 2015) is strong on the medico-legal background to Turing’s case. Class status and the trial: ATTE.
- 298** The specific drugs administered to Turing were probably two different oestrogens, first oestrone by mouth, and later oestradiol benzoate injected under the skin as an oily depot. This latter drug was most likely obtained as Dimenforman from the Dutch company Organon, who may have used the urine of pregnant women as a source. These were the drugs used in the only British publication on male libido suppression at the time. This came from a Bristol hospital (Golla and Sessions Hodge 1949) and was presented as a more desirable alternative to physical castration in cases where a sexual criminal continued to be a social nuisance. Similar treatment was also in use at the Portman Clinic in London, and in the rest of Europe. There are no published reports of experience with the treatment in Manchester; though in the late 1950s the Medical Faculty of the University were offering a course in ‘homosexuality and other perversions’ (Pullan and Abendstern 2000).
- 299** The Wolfenden Report was published in 1957 (HMSO 1957). The submissions, mainly dating from 1954 and 1955, are preserved in the National Archives and were published with a commentary by Lewis (Lewis 2016). The Report is primarily remembered as enabling the 1967 Act which decriminalised male homosexuality, but it was also concerned with (female) prostitution, for which the streets of Manchester had been, for some, notorious. In 1930, AJP Taylor asked himself ‘where were the prostitutes who my father said used to line Oxford Street? In all my walks in the city I identified only one...maybe she, like me, just liked walking and was not a prostitute at all’. The Methodist preacher Bill Gowland, who came to the Albert Hall in 1948, though, had no difficulty and spent his Saturday evenings in Piccadilly Gardens ‘conversing with prostitutes’ (Connolly 2013).
- 300** Gertrude Jefferson was an assistant psychiatrist at the MRI: *The Manchester Guardian* 13 Feb 1961.
- 301** In London, similar referrals were being made to a psychiatrist, Dr Mary Woodward, who gave almost all of her patients psychotherapy alone, though a handful were also treated ‘with the hormone method’. (Woodward 1958) cited in (Turing 2015).
- 302** (ATTE p595): 17 Apr 1952 to Philip Hall.
- 303** ‘I’m growing breasts’ recounted by Norman Routledge to Hodges; ‘attractive nurse’ Turing to Nick Furbank (AMT/F). The evidence for clinical depression is weak: there are no medical records, and depression is not a word used by Turing’s emotionally close friend Robin Gandy. Noel Hush did explicitly use the word depression, but though Hush worked productively with Turing he was not an intimate and this memory was recorded long afterwards, and in particular after Hodges’ book had been published (Hush 2011). Moreover Turing was productive and engaged with colleagues throughout the period of his probation.
- 304** Hodges interviewed Franz Greenbaum’s wife Hilla, and reports that Greenbaum was not considered as very respectable in the Manchester intellectual community because of his Jungian leanings (ATTE p611). Some

- say that Lyn Newman prompted Turing to see Greenbaum (Turing 2015), others that it was Ruthi, wife of mathematician Walter Lederman (Ledermann 2009b), but it could also have been a referral via the probation service. Greenbaum was also an NHS psychiatrist at Salford Royal Hospital but the Hall letter (Note 387) suggests his was not the court-ordered referral.
- 305** 'I have had a dream': (AMT/F 10 Dec 1953 to PN Furbank). Greenbaum was also an NHS psychiatrist at Salford Royal Hospital but a letter from Turing to Philip Hall suggests the court-ordered referral was not to Greenbaum.
- 306** The conversation between Blackett and Stopford is (ATTE p586) and probably a memory of Newman's. Turing's new contract was confirmed at the beginning of 1953 (ATTE p612). Jefferson gave his talk at the Lit & Phil on 5 Apr 1954 (Jefferson 1954). 'Pigling Bland': (ESHER 13 Dec 1948). Lit & Phil election: the co-sponsor was Niel Pearson of The '51 Society (Lit & Phil Council Minutes for 12 Oct 1953). I thank Kathryn Slater of the Lit & Phil for this information.
- 307** 'Turing lies with men': (AMT/D/14a Feb 1952 to Norman Routledge).
- 308** The significance of the Kjell affair is unclear, and the facts likely to remain mysterious unless made sense of from the Norwegian end or with the release of files from the Security Service. This account is from ATTE (p609, p617); see especially note 8.21 which refers to a loss of a list of names and addresses from within Turing's morphogenesis papers at the time held at AWRE. I believe Hodges is referring here to Nick Hoskin, who was generous with me in discussing the morphogenesis papers he had helped to publish after Turing's death.
- 309** The Webbs: (ATTE p586).
- 310** Turing with the Greenbaums: (ATTE p612); 'avoided him' is an unsourced statement (ATTE p585), perhaps from Dai Edwards.
- 311** Turing agreed to give a talk to the student mathematical society on 15 Jan 1954 and probably stayed with the Newmans afterwards (TUR Add/136).
- 312** 'the news' (ESHER 18 Jul 1954).
- 313** Hodges has long made a strong and clear case for pre-meditation (Hodges 2016b); Copeland has suggested accident on slimmer but not dismissable grounds (Copeland 2017b).
- 314** In 2012 I was delighted to take part in a mass science experiment based in Manchester called Turing's Sunflowers (Swinton, Ochu, and The MSI Turing's Sunflower Consortium 2016).
- 315** Alan Turing Way: (Kelner 2014).
- 316** The cipher text is IEKYF ROMSI ADXUO KVKZC GUBJ and Hughes has said it encodes 'Founder of Computer Science': (Wyke and Cocks 2004). A small amount of support came from Manchester City Council but the majority came from individuals.
- 317** Bowdon *does* have a blue plaque for children's writer Alison Uttley, who additionally gets a second plaque just near Turing in the University as she was also an early female physics undergraduate there.
- 318** Aphorism 95 of Book I of Bacon's 1620 work *The New Organon, or True Directions Concerning the Interpretation of Nature: Empirici, formicae more, congerunt tantum, et utuntur: rationales, araneorum more, telas ex se conficiunt: apis vero ratio media est, quae materiam ex floribus horti et agri elicit sed tamen eam propria facultate vertit et digerit*.
- 319** Though both plaques are in essence correct, their brevity means they can mislead in more ways than ignoring each other. The Baby was the first running demonstration of a practical computer memory, but is not universally considered the 'first stored-program computer'. Many computer scientists, most notably the local department, might challenge the idea that Turing is a 'creator' of their discipline. And calling Kilburn a graduate of Manchester is artfully accurate, but his first degree was from Cambridge. His PhD was from Manchester, while Williams's BSc was from Manchester and his DPhil from Oxford.
- 320** Turing and Newman do have roles, albeit supporting ones, in the historical webpages compiled to support the 50th celebrations by Brian Napper (Napper 1998).
- 321** Newman was careful, when interviewed in the 1970s, to distinguish what he thought his part contribution to the Colossus had been, but despite his modesty a sense of pride is present. (Newman 1976).
- 322** 'Colossus': (NAHC/MUC/7/18).
- 323** The engineers are still prominent in (Lavington 2012) although Lavington has recently expanded on the role of Newman's mathematicians, especially Jack Good, in the initial design and even naming of the Baby. I'm grateful to Lavington for sharing this from his forthcoming book.
- 324** Williams generous with credit: (Edwards 2010). Kilburn's 'Where I've got the knowledge from, I've no idea' is transcribed in (Bowker and Giordano 1993); Williams 'when we arrived' is from (Williams 1976) as cited in (Copeland 2011b). Kilburn's irritability when asked about the source of the idea of the computer is cited in (Copeland and Long 2017b).
- 325** 'It was as electrical engineers' (Copeland 2017a).
- 326** Williams and Kilburn split the income on all of the memory patents, which Kilburn was sensitively keen to explain as Williams' generosity. Kilburn's also wrote that Williams had 'handed over his patents to the University allowing it to freely determine how the benefits should be distributed' (Kilburn and Piggott 1978). Lavington's notes of a conversation with Kilburn, available at NAHC/MUC/9/44, suggest that there were substantial sums involved in the patent income, through arrangements which were confidential and are still unclear, and it's a speculation that some defensiveness about these arrangements may have emerged as prickliness about credit allocation.
- 327** Lavington (2012) places the ray tracing work as occurring in Autumn 1949. He suggests the application was probably to lens design for spy plane photography.
- 328** 'The calculations': (Turing 1953).
- 329** 'all night': (ATTE p515).
- 330** Addressing numerical computation: (Napper 2010, 1998).
- 331** Newman's and Blackett's response to the use for atomic weapons calculations were recalled by Newman to Hodges, who recalled this orally to me.
- 332** Hodges suggested some of these dichotomies — without merely simplifying to them — in a talk I saw in Manchester in 2004 which was profoundly influential in the writing of this book. His account of them is at (Hodges 2003). Hodges also points out a further tension arising from a perception in TRE staff like Kilburn, who were not indoctrinated into the Enigma secret, that wartime Bletchley Park had been a waste of time in comparison with the triumph of radar.
- 333** 'ideas men': recalled by Hilton in (Copeland 2017a).
- 334** 'Engineering research must not be allowed to degenerate into mathematics', typescript for a talk by Williams to the National Physical Laboratory on 5 May 1965 (NAHC/MUC/1).
- 335** 'no time for Turing': (Tootill 2009). At the time Tootill was puzzled by the coldness and he only speculated about this as the motivation in hindsight. Tootill remembers Turing as pleasant and was invited to his house, though he did not know of Turing's sexuality until after his death. 'Broadminded': (Brooker 2010).
- 336** In 1948 Turing was paid £1350/year as a Reader and Kilburn £800 as a Lecturer: (NAHC/MUC/2); Kilburn was made a Reader in 1955: (NAHC/MUC/7/1). Kilburn's Ferranti consultancy rose from £200/year in 1951 to £500/year in 1959: (NAHC/MUC/5).
- 337** 'jagged rift': and the mathematician/engineer divide more generally (Sumner 2012).
- 338** (Brooker 2010).
- 339** 'machines more than programs': (Campbell-Kelly, 1980).
- 340** 'IBM replacement': In 1956 The Board of Trade were acknowledging the view that the US Univac was faster than any British computer for business purposes, and an IBM machine for scientific ones (NAHC/MUC/1/B/1). On Wythenshawe developing large computing centres: (Martin 2013).
- 341** 'Industrial estates': Ferranti later moved some computer production to a subsidiary at Gem Mill in Chadderton. Though Gem Mill is now demolished, and the subsidiary American owned, it still manufactures semiconductors nearby under the name Diodes Zetec.
- 342** The 'set back by decades' story is second-hand personal information. The computer scientists believed (incorrectly) that Turing had an indifference to programming convenience. Lack of Turing's representation in the Kilburn building: (Sumner 2013).
- 343** Here are those lines: Turing constructed a pair of coupled nonlinear partial differential equations in a two-dimensional plane. These described the concentrations of two reacting and diffusing chemicals. With the ratio of diffusion constants as a bifurcation parameter, the system can move from having a globally stable spatially constant state to a variety of

patterned solutions. Linearisation of the equation at the spatially constant state yields a dispersion relation, between the wave-number of Fourier modes and their growth-rate, which allows analysis of the emergent pattern. Turing's contribution was not so much this analysis, but the construction of a model that could yield an instability when analysed this way.

- 344** The colonial worldview of this analogy is based on one that Turing might have possessed as the son of an Indian Civil Servant (cf (Agar 2003)), but greatly exaggerated for effect. Turing mainly used the language of 'growth' and 'poison' but in his own private notes he did once describe a related system he was looking at as 'cannibals and missionaries': it is the missionaries who are the poison here.
- 345** He didn't, and never used the bicycle bit of the analogy at all: I did. In the talks I started giving in the 1990s, and in print in 2003 (Swinton 2003), I never said that Turing had said anything about bicycles, but it has turned out too good an image not to attach to Turing's name instead of mine (Leppänen 2004; Woolley 2014; Yong 2010; Leppänen et al. 2003; Huw Jones, McWilliam, and Purvis 2011). I am pleased to find my invention thought in good company with Turing's 'comical but brilliantly apt analogies' (Newman 1955), even if a leading textbook (Maini et al. 2016) doesn't credit me. But there is no copyright in a joke analogy and I can be grateful some of these authors at least included unchanged my disclaimer about its imperialist nature.

One of Turing's major followers into mathematical biology, Meinhardt (2013), while sharing my admiration for the 1952 paper, disagrees that Turing consciously used what I call a bicycle mechanism to create an instability at all. He might be right, but this doesn't account for how Turing could have stumbled upon a specific numerical example with exactly this property.

- 346** Turing had also been thinking about a system extended in space, such as the problem of chain reactions between barrels of gunpowder on a grid. It was this that made Jack Good suspect Turing had had some indoctrination into the atomic bomb program. Berestykic (2013) suggests the possibility that Turing was aware of Hodgkin-Huxley's reaction-diffusion models for nerve propagation coming out of Cambridge, of

which the first was submitted five months after Turing's was. This is quite possible, though neither paper mentions the other while Turing was perfectly happy to cite the contemporary biologist Waddington.

- 347** The first entry by Turing in the logbooks is on 4 Sep 1951 (NAHC/MUC/2C6). As far as I know, no one has tried to check Turing's calculations in Table 1 of his paper; the fact that only some of them were done by computer suggests he may have had hand-calculations completed as a way of checking. By 'Manchester university computer' Turing *might* not have been referring to the Ferranti Mark I owned by the University from 1951 but the University-built machine which had been disassembled in June 1950, and was even harder to program, though this is unlikely given his comment to JZ Young in February 1951 that the model was yielding to treatment but that he hoped to do more when the new computer arrived. Either way it was a remarkable feat: a solution of a nonlinear partial differential equation with minimal development time and in tiny memory.
- 348** For more mathematical details see (Swinton 2013) and references in (Swinton, Ochu, and The MSI Turing's Sunflower Consortium 2016).

Figure Notes

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 Figure 3. Raphael Tuck 'Oilette' series c1905 held in KCC.
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 Figure 36. ©Graham Floyd.
 Figure 37. ©*Illustrated London News*, 25 Jun 1949.
 Figure 38. ©The University of Manchester; (MUC/9/62). Lavington dates this to 1952. Norway: (MUC/9/85).
 Figure 39. JS.
 Figure 40. JS. Based on (University of Manchester 1926) with the 1951 building added. The offices of the Pure Mathematics Professor were on the top floor of the 1872 main building, but their location there is speculative. The applied mathematics Professor,

- Goldstein, and his (human) computer were on the ground floor of the Christie Building, not marked (VCA/7/318). The Philosophy Seminar room was planned in 1926 on the ground floor of the Arts Building. I'm grateful to Martin Dodge for supplying a plan of this building.
- Figure 41.** ©HU; reproduced in (Wainwright 2011).
- Figure 42.** ©The University of Manchester; provided to me by Martin Dodge.
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- Figure 44.** ©HU; MSI 1996/10/6/15.
- Figure 45.** ©HU.
- Figure 46.** ©KCC; TUR/C.
- Figure 47.** (Nicholas and Hellier, 1947). Relative rainfall from (British Association, 1962).
- Figure 48.** JS.
- Figure 49.** JS. The Hollymeade plaque was organised by Andrew Crompton, a University of Manchester lecturer in architecture.
- Figure 50.** ©KCC; the letter was sold at auction in 2016 but its location is unknown.
- Figure 51.** ©Ken Howarth; heritagephotoarchive.co.uk.
- Figure 52.** ©HU.
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- Figure 54.** Freud Museum London.
- Figure 55.** ©KCC; AMT C/27.
- Figure 56.** ©HU; NAHC/MUC/5/64
- Figure 57.** ©HU; LP/17/2. Whitehead: (Emmet 1996); Whitehead's daughter Jessie is on the left.
- Figure 58.** Crown ©; TNA BW 150/1. Walter also co-published studies of the EEGs of delinquent youth with R Sessions-Hodge, the second author on Golla's chemical castration paper.
- Figure 59.** TNA WORK 25/75/B3/D4. Much more detail on the tortoises and the British cybernetics activity they sprang from is in (Boden 2008b).
- Figure 60.** ©The British Society of Neurological Surgeons; Hunterian Museum.
- Figure 61.** The seats of the faculties is from Alberto Magnus's *Philosophia naturalis* in (Jefferson 1949b).
- Jefferson and Emmet are known to have discussed Descartes (LP 19/9/1).
- Figure 62.** JS.
- Figure 63.** ©HU; LP 17/2.
- Figure 64.** JS. Wittgenstein said, probably unreliably, that when in Manchester he had considered discussing philosophy with Alexander but decided 'no good would come of it' (Emmet 1967, Mitchison 1979, Drury 2003).
- Figure 65.** ©HU; ancestry.co.uk.
- Figure 66.** JS.
- Figure 67.** ©HU; LP/17/6/6/14.
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- Figure 70.** ©HU; around 1934.
- Figure 71.** ©Getty.
- Figure 72.** ©HU; *Discovery*, March 1951.
- Figure 73.** ©Getty.
- Figure 74.** ©HU; From *Applications of Ferranti Computers*, January 1957, MOSI 1996.10/6/15/4; the Ferranti marketing article this is drawn from is signed by Ahmed's supervisor, DJC Cruickshank, who did not work on the Manchester machines (Ahmed 2009).
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- Figure 78.** ©HU; Midwinter Pottery: (Jenkins 1997); Festival Pattern Group: (Jackson 2008). The plate is from the collection of the late Professor Dorothy Trump. On the atomic bomb underneath Festival imagery: (Jolivet 2014).
- Figure 79.** ©Antonia Cunliffe Davis. Terylene was developed, under the noses of a much larger research effort by both ICI and foreign companies, by a small group in the Calico Printers' Association, now St James' Building (Kennedy 1993). Cunliffe's childcare advice is at NEWMANL/A/2/Cunliffe.
- Figure 80.** ©Antonia Cunliffe Davis
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- Figure 85.** ©HU.
- Figure 86.** ©HU; MSI Ferranti archive. The knitting shot was used in Ferranti's December 1952 brochure. Neither operator is named. Although knitting was a common private skill for men, Joan Clarke recalled that Turing was unusual in being happy to knit in front of his junior staff during air-raids at Bletchley Park (Clarke 1993).
- Figure 87.** ©Kleboe/Picture Post/Getty; Picture Post 26 Feb 1955.
- Figure 88.** ©Cambridge University Press (Jeffreys and Swirles 1999).
- Figure 89.** ©ancestry.co.uk; Sydney Morning Herald, 2 Aug 1959.
- Figure 90.** Portrait ©Nicolson family; Differential analyser ©British Council. Radioactive basement: (Todd 2008). Computer history mythology for some time wrongly had it that the figure on the top left was atom spy Klaus Fuchs (Lindsey 2010) although Fuchs did recruit Howlett (Howlett 1979) to the numerical computing group at Harwell's atomic bomb program. Howlett recalls that when he joined the group 'consisted of about eight young people, mostly girls'.
- Figure 91.** ©University of Toronto Archives.
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- Figure 97.** (HMSO 1951).
- Figure 98.** ©HU; reconstruction by Museo Reina Sofía, Madrid.
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- Figure 100.** JS.
- Figure 101.** (Church 1904). Sunflower patterns as investigated by Manchester: (Swinton, Ochu, and The MSI Turing's Sunflower Consortium 2016).
- Figure 102.** ©KCC; AMT/K3/5.
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- Figure 104.** ©KCC; TUR/C.
- Figure 105.** Cannon was wrong and Darwinism was right: (Cook et al. 2012).
- Figure 106.** Plate 1 of (Haeckel 1914); *Circogonia icosohedra* is redrawn from the type report in (Haeckel 1887) and no taxonomic databases has further reports on it.
- Figure 107.** NAHC PRINZ/A.
- Figure 108.** ©Camphill Village Trust; STRACHEY.
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- Figure 111.** JS.
- Figure 112.** ©Hodges; (Hodges 1983).
- Figure 113.** ©HU. This was one of a dozen films showing at the Regal in December 1952: it is pure speculation that this poster for this film was visible to Turing on the unknown day of the meeting.
- Figure 114.** (Manchester City News, 1938); Martin Dodge.
- Figure 115.** JS.
- Figure 116.** ©Elsevier.
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- Figure 121.** JS.
- Figure 122.** JS.
- Figure 123.** ©KCC; TUR/C.
- Figure 124.** Bonnet: (Bonnet 1754).

References

- Adams, JF. 1985. 'Maxwell Herman Alexander Newman. 7 February 1897–22 February 1984', *Biographical Memoirs of Fellows of the Royal Society*, 31:436-52.
- Agar, J. 2003. *The Government Machine: A Revolutionary History of the Computer* (MIT Press). 2016. 'Britain's Oppenheimer?', STS Observatory 25 Feb. www.blogs.ucl.ac.uk/sts-observatory/2016/02/25/britains-oppenheimer.
- Ahmed, FR. 2009. 'For the love of computers in the 1950s', *Canadian National Committee for Crystallography Newsletter*, 1.
- Ahmed, FR, and Cruickshank, DWJ. 1953. 'Crystallographic calculations on the Manchester University electronic digital computer (Mark II)', *Acta Crystallographica*, 6:765-69.
- Allaerts, W. 2003. 'Fifty years after Alan M Turing. An extraordinary theory of morphogenesis', *Belgian Journal of Zoology*, 133:3-14.
- Anderson, DP. 2004. 'Was the Manchester Baby conceived at Bletchley Park?' *Alan Mathison Turing 2004: A celebration of his life and achievements*, University of Manchester. British Computer Society. 2007a. 'Frederic Calland Williams: The Manchester Baby's Chief Engineer', *IEEE Annals of the History of Computing*:90-102. 2007b. 'Max Newman: Topologist, Codebreaker, and Pioneer of Computing', *IEEE Annals of the History of Computing*:76-81. 2007c. 'Patrick Blackett: Physicist, Radical, and Chief Architect of the Manchester Computing Phenomenon', *IEEE Annals of the History of Computing*:82-85. 2009a. 'Biographies: Tom Kilburn: A Pioneer of Computer Design', *IEEE Annals of the History of Computing*, 31:82-86. 2009b. 'The contribution of MHA Newman and his mathematicians to the creation of the Manchester 'Baby'', *BSHM Bulletin: Journal of the British Society for the History of Mathematics*, 24:27-39. 2010. 'Contested Histories: De-mythologising the early history of modern British computing' in A Tatnall (ed.), *History of Computing: Learning from the Past*. (Springer). 2013a. 'Max Newman: Forgotten Man of Early British Computing', *Communications of the ACM*, 56:29-29. 2013b. 'Patrick Blackett: Providing 'White Heat' to the British Computing Revolution', *Communications of the ACM*, 56.
- Anonymous. 'Biological conference at Henley-On-Thames 21st-23rd March 1952'. Nuffield Foundation. 1955. 'Annual Report of Council', *Memoirs and Proceedings of the Manchester Literary and Philosophical Society*, 97. 1962. *Manchester and Its Region* (Manchester University Press). 1995. *Our blitz: red skies over Manchester, a wartime facsimile* (Aurora). 2017. 'DH Lawrence work shows censor battle', BBC News. www.bbc.co.uk/news/uk-england-nottinghamshire-34647492. 2018a. 'Ferranti'. www.gracesguide.co.uk/Ferranti. 2018b. 'Lit and Phil Card Index'. www.cardindex.manlitphil.ac.uk.
- Atkinson, H. 2012. *The Festival of Britain: a land and its people* (IB Tauris).
- Bennett, JM. 1994. 'Autobiographical Snippets' in JM Bennett (ed.), *Computing in Australia: The development of a profession* (Hale and Iremonger).
- Bennett, JM. 1996. 'Ferranti recollections (1950–1965)', *IEEE Annals of the History of Computing*, 18.
- Berdichevsky, C. 2006. 'The Beginning of Computer Science in Argentina: Clementina 1961–1966.' in J Impagliazzo (ed.), *History of Computing and Education 2* (Springer)
- Berestykic, H. 2013. 'Alan Turing and Reaction-Diffusion Equations' in SB Cooper and others (eds.), *Alan Turing: His Work and Impact* (Elsevier).
- Berners-Lee, ML. 2001. "Mary Lee Berners-Lee, an interview." Interview by J Abbate. IEEE History Center. 2011. "Conway and Mary Lee Berners-Lee: Voices of Science." Interview by T Lean. An Oral History of British Science, The British Library.
- Bird, K, and Sherwin, M. 2006. *American Prometheus: the triumph and tragedy of J. Robert Oppenheimer* (Knopf).
- Blum, PR. 2010. 'Michael Polanyi: Can the Mind be represented by a Machine?', *Polanyiana*, 19:35-60.
- Boden, MA. 2008a. 'D'Arcy Thompson: A grandfather of A-Life' in P Husbands (ed.), *The Mechanical Mind in History* (MIT Press). 2008b. *Mind as Machine: A History of Cognitive Science* (Clarendon Press).
- Bonnet, C. 1754. *Recherches sur l'usage des feuilles dans les plantes* (Luzac).
- Bowden, RV. 1953. *Faster Than Thought: A Symposium on Digital Computing Machines* (Pitman).
- Bowdon History Society. 1999. *Bowdon and Dunham Massey* (Tempus).
- Bowker, G, and Giordano, R. 1993. 'Interview with Tom Kilburn', *IEEE Annals of the History of Computing*, 15:17-32.
- Brewster, ET. 1913. *A Guide To Living Things* (Doubleday, Page).
- British Association, 1962. *Manchester and its region* (British Association for the Advancement of Science)
- Brockbank, W. 1965. *The honorary medical staff of the Manchester Royal Infirmary, 1830–1948* (Manchester University Press).
- Brooker, T. 2010. "Tony Brooker interviewed by Thomas Lean." An Oral History of British Science, British Library.
- Bud, R. 1998. 'Penicillin and the new Elizabethans', *The British Journal for the History of Science*, 31:305-33. 2007. *Penicillin: Triumph and Tragedy* (Oxford University Press).
- Bullough, VL. 1994. *Science in the Bedroom: A History of Sex Research* (Basic Books).
- Burgess, A. 1987. *Little Wilson and Big God* (Heinemann).
- Butler, S. 2005. 'Academic Medicine in Manchester: the careers of Geoffrey Jefferson, Harry Platt and John Stopford 1914-1939', *Bulletin of the John Rylands University Library of Manchester*, 87:133-54.
- Calvin, M. 1991. 'Memories of Michael Polanyi in Manchester', *Tradition and Discovery*, 18:40-42.
- Campbell-Kelly, M. 1980. 'Programming the Mark I: Early Programming Activity at the University of Manchester', *IEEE Annals of the History of Computing*, 2:130-68. 1985. 'Christopher Strachey, 1916-1975: A Biographical Note', *IEEE Annals of the History of Computing*, 7:19-42.
- Campbell, SM. 2003. 'Beatrice Helen Worsley: Canada's female computer pioneer', *IEEE Annals of the History of Computing*, 25:51-62.
- Cannon, HG. 1958. *The Evolution of Living Things* (Manchester University Press). 1959. *Lamarck and Modern Genetics* (Manchester University Press). 1960. 'The myth of the inheritance of acquired characters', *New Scientist*:798. 2017. 'An essay on evolution and modern genetics', *Zoological Journal of the Linnean Society*, 43:1-17.
- Charlton, WA, and Cutter, EG. 1986. *135 Years of Botany at Manchester* (University of Manchester).
- Church, AH. 1904. *On the Relation of Phyllotaxis to Mechanical Laws* (Williams and Norgate).
- City Treasurer's Department. 1946. *The City's Finances: a pictorial summary* (Manchester Corporation).
- Clarke, J. 1993. 'Letters from Joan Clarke to Professor Tropp, published by Kerry Howard of Bletchley Park Research'.
- Coles, J, and Smith, D. 2006. 'The Fifty-One Society: A case study of BBC radio and the education of adults', *Studies in the Education of Adults*.
- Conekin, B. 2003. *The autobiography of a nation: The 1951 Festival of Britain* (Manchester University Press).
- Connolly, A. 2013. "'He saw the city and wept': the Manchester and Salford Methodist mission 1910-60' in J Wolff and others (eds.), *Culture in Manchester: institutions and urban change since 1850* (Manchester University Press).
- Conway, F, and Siegelman, J. 2005. *Dark Hero of the Information Age: In search of Norbert Wiener, the Father of Cybernetics* (Basic Books).
- Cook, LM, Grant, BS, Saccheri, IJ, and Mallet, J. 2012. 'Selective bird predation on the peppered moth: the last experiment of Michael Majerus', *Biology Letters*.
- Cook, M, Mills, R, Trumbach, R, and Cocks, H. 2007. *A gay history of Britain* (Greenwood World).
- Copeland, BJ (ed.). 2004. *The Essential Turing* (Oxford University Press). 2005. *Alan Turing's Automatic Computing Engine* (Oxford University Press). 2011a. 'The Manchester computer: A revised history. Part 1: The memory', *IEEE Annals of the History of Computing*, 33:4-21. 2011b. 'The Manchester computer: A revised history. Part 2: The Baby computer', *IEEE Annals of the History of Computing*, 33:22-37. 2012. *Turing: Pioneer of the Information Age* (Oxford University Press). 2017a. 'Baby' in BJ Copeland and others (eds.), *The Turing Guide* (Oxford University Press). 2017b. 'Life and work' in BJ Copeland and others (eds.), *The Turing Guide* (Oxford University Press). 2017c. 'Tunny: Hitler's biggest fish' in BJ Copeland and others (eds.), *The Turing Guide* (Oxford University Press).
- Copeland, BJ, and Long, J. 2017a. 'Computer Music' in BJ Copeland and others (eds.), *The*

- Turing Guide (Oxford University Press). 2017b. 'Turing and the History of Computer Music' in J Floyd and others (eds.), *Philosophical Explorations of the Legacy of Alan Turing* (Springer).
- Copeland, BJ, and Prinz, D. 2017. 'Computer chess: the first moments' in BJ Copeland and others (eds.), *The Turing Guide* (Oxford University Press).
- Cranwick, LMDC. 2008. 'Busting out of crystallography's Sisyphian prison', *Acta crystallographica A*, 64:65-87.
- Croarken, M. 1990. *Early Scientific Computing in Britain* (Oxford University Press). 1993. 'The Beginnings of the Manchester Computer Phenomenon: People and Influences', *IEEE Annals of the History of Computing*, 15:9-16.
- Dawes, JHP. 2016. 'After 1952: The later development of Alan Turing's ideas on the mathematics of pattern formation', *Historia Mathematica*, 43:49-64.
- Daylight, EG. 2015. 'Towards a Historical Notion of "Turing—the Father of Computer Science"', *History and Philosophy of Logic*, 36:205-28.
- Desmarais, RJ. 2010. 'Science, Scientific Intellectuals and British Culture in The Early Atomic Age, 1945–1956: A Case Study of George Orwell, Jacob Bronowski, JG Crowther and PMS Blackett', PhD thesis, Imperial College London.
- Dodge, M. 2018. 'Healthier modern cities: cleaning the air', *The Modernist*.
- Drury, MOC. 2003. *The Danger of Words and Writings on Wittgenstein* (Thoemmes Continuum).
- DTIC. 1979. *ADA083756: An Assessment of the Influence of Emerging Social and Economic Trends on the People and Management of the Coast Guard. Volume II.* (Defense Technical Information Center).
- Duffy, WN. 1951. 'Ferranti Ltd & The Festival of Britain', *The Ferranti Journal*, 9.
- Duxbury-Neumann, S. 2017. *What have the Germans ever done for us? A history of the German population of Great Britain* (Amberley).
- Edwards, APJ. 1994. 'Ben Lockspeiser', *Biographical Memoirs of Fellows of the Royal Society*, 39:246-61.
- Edwards, D. 2010. "National Life Stories: An Oral History of British Science." Interview by T Lean. British Library.
- Emmet, DM. 1967. "Alexander, Samuel" *The Encyclopaedia of Philosophy*. Macmillan. 1996. *Philosophers and Friends: Reminiscences of Seventy Years in Philosophy* (Macmillan).
- England, G. 2015. 'Harry Rutherford's Festival of Britain Mural'. www.hydedaily.blogspot.co.uk/2015/01/harry-rutherfords-festival-of-britain.html.
- Erskine, R. 1986. 'GC and CS Mobilizes "Men of the Professor Type"', *Cryptologia*, 10:50-59.
- Flowers, FA. 1999. *Portraits of Wittgenstein* (Thoemmes).
- Floyd, J. 2017. 'Turing on "Common Sense": Cambridge Resonances' in J Floyd and others (eds.), *Philosophical Explorations of the Legacy of Alan Turing* (Springer).
- Forrester, J. 2018. *Freud in Cambridge* (Cambridge University Press).
- Fox Keller, E. 2002. *Making Sense of Life* (Harvard University Press).
- Freud, S. 2002. *Unser Herz zeigt nach dem Süden: Reisebriefe 1895–1923* (Aufbau-Verlag).
- Froese Fischer, C. 2003. *Douglas Rayner Hartree* (World Scientific).
- Furbank, PN. 1979. *EM Forster: A life* (Secker and Warburg).
- Gaboury, J. 2013. 'A Queer History of Computing: Part Three | Rhizome'. www.rhizome.org/editorial/2013/apr/9/queer-history-computing-part-three.
- Gandy, A. 2013. *The Early Computer Industry - Limitations of Scale and Scope* (Palgrave Macmillan).
- Gardiner, M. 1988. *A Scatter of Memories* (Free Association Books).
- Glover, E, Mannheim, H, and Miller, E. 1958. 'Special Number on Homosexuality', *The British Journal of Delinquency*, 9.
- Goldstein, L. 1999. 'Wittgenstein's PhD Viva: A Re-creation', *Philosophy*, 74 499-513.
- Golla, FL, and Sessions Hodge, R. 1949. 'Hormone treatment of the sexual offender', *The Lancet*, 11 Jun.
- Good, IJ. 1982. 'A Report on TH Flowers's Lectures on Colossus', *Annals of the History of Computing*, 4:55-59. 2006. 'From Hut 8 to the Newmanry' in BJ Copeland (ed.), *Colossus* (Oxford University Press).
- Goodeve, P. 2011. 'Nimrod'. www.goodeveca.net/nimrod.
- Grattan-Guinness, I. 2012. 'On Mathematicians Who Liked Logic: The Case of Max Newman'. In BS Cooper and others (eds.), *How the World Computes*. Springer.
- Gwyer, RGB. 1949. 'Editorial', *The Ferranti Journal*, 7. 1950. 'Personal Notes', *The Ferranti Journal*, 8.
- Haeckel, E. 1887. *Zoology, Volume XVIII: Report on the Radiolaria collected by HMS Challenger* (HMSO). 1914. *Kunstformen der Natur* (Bibliographisches Institut Leipzig).
- Hall, LA. 2012. *Sex, Gender and Social Change in Britain since 1880* (Macmillan).
- Heaton, W. 1950. 'The Ferranti Electroencephalograph: what it is and what it does', *The Ferranti Journal*, 8.
- Hendry, J. 1990. *Innovating for Failure: Government Policy and the Early British Computer Industry* (MIT Press).
- Hicks, M. 2017. *Programmed Inequality: How Britain Discarded Women Technologists and Lost its Edge in Computing* (MIT Press).
- Hill, GB. 2016. *Alderley Park discovered* (Carnegie Publishing).
- Hill, R, and Shuttleworth, N. 2003. *Manchester Marathons, 1908–2002* (Ron Hill Running Enterprises).
- HMSO. 1951. *Exhibition of Science, Festival of Britain South Kensington. 1957 Report of the Committee on Homosexual Offences and Prostitution*.
- HNF. 2015. 'Das Elektronengehirn kommt'. www.blog.hnf.de/das-elektronengehirn-kommt.
- Hobsbawm, EJ. 2002. *Interesting Times: A Twentieth-Century Life* (Allen Lane).
- Hodges, A. 1983. *Alan Turing: The Enigma* (Hutchinson). 2003. 'Website: Alan Turing Home Page'. www.www.turing.org.uk. 2014. *Alan Turing: The Enigma* (Vintage). 2016a. 'Alan Garner and Alan Turing: On the Road' in E Wagner (ed.), *First Light* (Random House). 2016b. "University of Oxford Strachey Lecture: The Once and Future Turing".
- Hoffmann, B. 1984. "The Princeton Mathematics Community in the 1930s. Transcript Number 20." Interview by A Tucker. Princeton University.
- Howarth, K. 1982. "The 'Birth' of the Computer: Tom Kilburn interview at the North West Sound Archive."
- Howarth, TEB. 1978. *Cambridge Between Two Wars* (Collins).
- Howlett, J. 1979. 'Computing at Harwell'. www.chilton-computing.org.uk/acl/literature/reports/p009.htm. 1993. 'Differential Analysers'. www.chilton-computing.org.uk/acl/associates/permanent/howlett/croaken.htm. 1996. 'Foreword', *Advances in Computational Mathematics*, 6.
- Hush, N. 2011. "Professor Noel Hush, theoretical chemist." Interview by R Williams. Australian Academy of Science
- Huw Jones, D, McWilliam, R, and Purvis, A. 2011. 'Design of Self-Assembling, Self-Repairing 3D Irregular Cellular Automata' in A Salcido (ed.), *Cellular Automata* (InTech).
- Hyde, HM. 1970. *The Other Love* (Heinemann).
- Jackson, L. 2008. *From Atoms to Patterns: Crystal Structure Designs from the 1951 Festival of Britain*. (Richard Dennis).
- Jacobi, C. 2014. 'Kind of cold war feeling' in C Jolivette (ed.), *British Art in the Nuclear Age* (Routledge).
- Jefferson, G. 1949a. 'The Mind of Mechanical Man', *British Medical Journal*, 1:1105-10. 1949b. 'Rene Descartes on the Localisation of the Soul', *Irish Journal of Medical Science*, 285. 1954. 'The Search For The Mechanisms Involved in Thinking and Talking', *Memoirs and Proceedings of the Manchester Literary and Philosophical Society*, 95:69-84.
- Jeffreys H and Swirles B. 1999. *Methods of Mathematical Physics*. (Cambridge University Press)
- Jenkins, S. 1997. *Midwinter Pottery: A Revolution in British Tableware* (Richard Dennis).
- Jha, SR. 1998. 'On the Duties of Intellectuals to Truth: The Life and Work of Chemist-Philosopher Michael Polanyi', *Science in Context*, 11.
- Jolivette, C. 2014. 'Representations of Atomic Power at the Festival of Britain' in C Jolivette (ed.), *Representations of Atomic Power at the Festival of Britain* (Routledge).

- Jones, A. 2004. 'Five 1951 BBC Broadcasts on Automatic Calculating Machines', *IEEE Annals of the History of Computing*, 26:3-15.
- Kellermann, EW. 2010. *A Physicists Labour in War & Peace* (Stamford House).
- Kelner, S. 2014. 'Manchester was ahead of the pack in honouring Alan Turing', *The Independent*, 28 Nov.
- Kennedy, C. 1993. *ICI: The Company That Changed Our Lives* (SAGE Publications Ltd). 2nd edition.
- Kermode, F. 1997. *Not Entitled* (Flamingo).
- Kidd, A, and Wyke, T. 2016. *Manchester: Making the Modern City* (Liverpool University Press).
- Kidd, AJ. 2006. *Manchester: a history* (Carnegie Publishing). 4th edition.
- Kilburn, T, and Piggott, L. 1978. 'Frederic Calland Williams', *Biographical Memoirs of Fellows of the Royal Society*, 24:583-604.
- Knight, NR. 1999. *Altrincham to Manchester before Metrolink* (Foxline).
- Kraft, A. 2000. 'Building Manchester biology 1851–1963: National agendas, provincial strategies', PhD thesis, University of Manchester.
- Lavington, SH. 1975. *A history of Manchester computers* (NCC Publications). 2006. 'In the Footsteps of Colossus: A Description of Oedipus', *IEEE Annals of the History of Computing*, 28:44-55. 2012. *Alan Turing and his contemporaries: building the world's first computers* (BCS). 2013. 'Audio Interview: David Howarth and Mike Wylde'. www.chilton-computing.org.uk/acl/technology/atlas50th/p009.htm.
- Ledermann, W. 2009a. 'Ledermann on D'Arcy Thompson'. www-history.mcs.st-andrews.ac.uk/Extras/Ledermann_DArcy_Thompson.html#Thompson_DArcy. 2009b. 'Manchester: 1946–62'. www-history.mcs.st-and.ac.uk/Ledermann/Ch8.html.
- Leppänen, T. 2004. 'Computational studies of pattern formation in Turing systems', Helsinki University of Technology.
- Leppanen, T, Karttunen, M, Kaski, K, and Barrio, RA. 2003. 'Dimensionality effects in Turing pattern formation', *International Journal of Modern Physics B*, 17:5541-53.
- Lewis, B. 2016. *Wolfenden's Witnesses, Homosexuality in Postwar Britain* (Springer).
- Light, JS. 1999. 'When computers were women', *Technology and Culture* 40(3):455-483.
- Lindsey, C. 2010. 'The Hartree Differential Analyser', *Computer Resurrection*.
- Lovell, B. 1975. 'Patrick Maynard Stuart Blackett, Baron Blackett, of Chelsea', *Biographical Memoirs of Fellows of the Royal Society*, 21:1-115. 1988. 'Blackett in War and Peace', *The Journal of the Operational Research Society*, 39:221-33. 1990. *Astronomer by Chance* (Macmillan).
- Lunt, TJ. 1947. 'Open Day at the National Physical Laboratory', *The Ferranti Journal*, 5.
- Manchester Chamber of Commerce. 1931. *Handbook 1931–1932* (Manchester Chamber of Commerce).
- Manchester City News. 1938. A Pictorial and Descriptive Guide to Manchester.
- Manchester Corporation. 1974. *Water for the Millions: Manchester Corporation Waterworks 1847–1974* (Manchester Corporation)
- Manchester Literary and Philosophical Society. 2018. 'Lit and Phil Card Index'. www.cardindex.manlitphil.ac.uk.
- Manchester Luncheon Club. 1947. *Silver Jubilee Commemorative volume* (Privately printed).
- Marsh, J. 2004. *Art & Androgyny: The Life of Sculptor Fiore de Henriquez* (Elliott & Thompson).
- Martin, CD. 1995. 'ENIAC: The Press Conference That Shook the World', *IEEE Technology and Society Magazine*, December.
- Martin, I. 2013. 'Private Places in Public Space: Commerce, Community and Computers in Wythenshawe's Civic Centre'. <https://postwarmcr.wordpress.com/2013/04/27/95>.
- Mays, W. 1952. 'Can Machines Think?', *Philosophy*:148-62. 2000. 'Turing and Polanyi on Minds and Machines', *Appraisal*, 3. 2001. 'My Reply to Turing: Fiftieth Anniversary', *Journal of the British Society for Phenomenology*, 32:4-23.
- Mays, W, and Prinz, DG. 1950. 'A Relay Machine for the Demonstration of Symbolic Logic', *Nature*, 165:197–98.
- McGregor Ross, H. 2005. 'Finding the Necessity for Invention', *Computer Resurrection*.
- McGuinness, B. 1988. *Wittgenstein: A Life. Volume 1: Young Ludwig, 1889–1921*, (Duckworth). (ed.).
2008. *Wittgenstein in Cambridge: Letters and Documents 1911–1951* (Blackwell).
- Meinhardt, H. 2013. 'Traveling waves and oscillations out of phase: an almost forgotten part of Turing's paper' in SB Cooper and others (eds.), *Alan Turing: His Work and Impact* (Elsevier).
- Metropolitan Vickers. 1946. 'Now for reconstruction'. *The British Trade Journal and Export World*.
- Mitchison, N. 1979. *You May Well Ask* (Flamingo).
- Moffat, I. 2000. 'A Horror of Abstract Thought': Postwar Britain and Hamilton's 1951 "Growth and Form" Exhibition', *October*, 94. 2002. 'The Independent Group's encounters with logical positivism and searches for unity in the 1951 Growth and Form Exhibition', PhD thesis, MIT.
- Monk, R. 2012. *Inside The Centre: The Life of J. Robert Oppenheimer* (Random House).
- Moran, J. 2006. 'Milk bars, Starbucks and the uses of literacy', *Cultural Studies*, 20:552–73.
- Mosley, S. 2004. 'Public Perceptions of Smoke Pollution in Victorian Manchester.' in EM Dupuis (ed.), *Smoke and Mirrors: The Politics and Culture of Air Pollution* (New York University Press.). 2013. 'Clearing the Skies: Air Pollution Problems in Post-war Manchester'. <https://postwarmcr.wordpress.com/2013/04/27/clearing-the-skies-air-pollution-problems-in-post-war-manchester>.
- Murray, J. 1975. 'A personal contribution to the bombe story', *NSA Technical Journal*, 20:41–6.
- Nanjundiah, V. 2003. 'Alan Turing and "The Chemical basis of Morphogenesis"' in T Sekimura (ed.), *Morphogenesis and Pattern Formation in Biological Systems* (Springer-Verlag).
- Napper, B. 1998. '50th Anniversary of the Manchester Baby computer'. www.curation.cs.manchester.ac.uk/computer50/www.computer50.org.
- Newman, MHA. 1955. 'Alan Mathison Turing', *Biographical Memoirs of Fellows of the Royal Society*, 1:253-66. 1976. 'Pioneers of Computing 15.' Interview by CR Evans. Science Museum.
- Newman, W. 2002. 'Married to a Mathematician: Lyn Newman's Life in Letters', *The Eagle*: 2-7. 2006. 'Max Newman: Mathematician, Codebreaker and Computer Pioneer' in BJ Copeland (ed.), *Colossus* (Oxford University Press).
- Nicholas, R, and Hellier MJ 1947. *An Advisory Plan* (South Lancashire and North Cheshire Advisory Planning Committee).
- Nye, MJ. 2004. *Blackett: Physics, War, and Politics in the Twentieth Century* (Harvard University Press). 2007. 'Manchester friends at odds: Michael Polanyi, P. M. S. Blackett and the scientist as political speaker' in JV Pickstone (ed.), *The History of Science and Technology in the North West/Manchester Region History Review* (Carnegie Publishing). 2011. *Michael Polanyi and His Generation: Origins of the Social Construction of Science* (University of Chicago Press).
- O'Hanrahan, E. 2018. "Philosophy at Manchester and Alan Turing". Unpublished notes.
- O'Neill, O. 2018. "Emmet, Dorothy Mary (1904–2000)" *Dictionary of National Biography* (Oxford University Press).
- Parkinson-Bailey, JJ. 2000. *Manchester: An Architectural History* (Manchester University Press).
- Partridge, F. 1981. *Love in Bloomsbury* (IN Tauris). 2001. *Ups and Downs* (Weidenfeld & Nicolson).
- Peck, J, and Ward, K. 2002. *City of revolution: Restructuring Manchester* (Manchester University Press).
- Peierls, RE. 1985. *Bird of Passage: Recollections of a Physicist* (Princeton University Press).
- Perkins, C, and Dodge, M. 2012. 'Mapping the Imagined Future: The Roles of Visual Representation in the 1945 City of Manchester Plan', *Bulletin of the John Rylands University Library of Manchester*, 89.
- Proudfoot, D. 2015. "What Turing Himself Said About the Imitation Game" *IEEE Spectrum*.
- Pullan, B. 2007. *A Portrait of The University of Manchester* (Third Millennium).
- Pullan, B, and Abendstern, M. 2000. *A History of the University of Manchester, 1951–73* (Manchester University Press).
- Pursell, C. 1993. "'Am I a Lady or an Engineer?'" The Origins of the Women's Engineering Society in Britain, 1918–1940', *Technology and Culture*, 34.
- Quirke, V. 2013. 'The Material Culture of British Pharmaceutical Laboratories in the Golden Age of Drug Discovery (c. 1935–75)', *The International Journal for the History of Engineering & Technology* 79:280-99.
- Read, D. 1964. *The English Provinces* (Edward Arnold).
- Reader, WJ. 1975. *Imperial Chemical Industries: A History. Volume II 1926–1952*. (Oxford University Press).

- Rigby, C. 1948. *John Barbirolli: A Biographical Sketch* (Sherratt).
- Rowley, EE, and Lees, C. 2001. *The University of Manchester at War 1939–1946* (Development & Alumni Office, Manchester University).
- Rowlinson, F. 1947. *Contribution to Victory* (Metropolitan Vickers).
- Salveson, P. 1996. 'Loving Comrades: Lancashire's Links to Walt Whitman', *Quarterly Review*, 14:57-84.
- Sargant Florence, P. 1968. 'The Cambridge Heretics 1909–1932' in AJ Ayer (ed.), *The Humanist Outlook* (Pemberton).
- Savage, M, and Wolff, J. 2015. 'Manchester: City of Culture' in J Wolff and others (eds.), *Culture in Manchester* (Manchester University Press).
- Schofield, J. 2017. *Illusion and Change: Manchester* (MCR Books).
- Schurr, PH. 1997. *So That Was Life: A Biography of Sir Geoffrey Jefferson* (Royal Society of Medicine Press).
- Schuster, A. 1900. 'The new physical laboratory', *Manchester Guardian*, 29 June.
- Schweber, SS. 2012. *Nuclear Forces: The Making of the Physicist Hans Bethe* (Harvard University Press).
- Scott, D, and Bent, C. 1984. *Borrowed Time: A Social History of Salford Harriers. 1884–1984* (Salford Harriers).
- Senechal, M. 2013. *I died for beauty: Dorothy Wrinch and the cultures of science* (Oxford University Press).
- Sessions-Hodge, R. 1950. 'The Treatment of the Sexual Offender with Discussion of a Method of Treatment by Gland Extracts', *Actes du Ile Congrès international de criminologie*, 306-317.
- Shapely, P. 2016. 'Post-war housing in Manchester: making the same mistakes?' in R Brook and others (eds.), *Making Post-War Manchester: Visions of an Unmade City* (Modernist Society).
- Shapley, O. 1996. *Broadcasting a Life* (Scarlet Press).
- Shrapnel, N. 1951. 'Britain as it might be', *The Guardian*, 4 May (republished 2015).
- Smith, A. 2014. 'The Priesthood At Play: Computer Games In The 1950s'. <https://videogamehistorian.wordpress.com/tag/nimrod>.
- Spalding, F. 2002. *Stevie Smith: A Biography* (Sutton).
- Sterrett, SG. 2006. *Wittgenstein Flies a Kite: A Story of Models of Wings and Models of the World* (Pi Press).
- Streat, R. 1987. *Lancashire and Whitehall: The Diary of Sir Raymond Streat* (Manchester University Press).
- Stuart-Williams, R, and Byrd, DJP. 1951. 'Das Fliegende Gehirn or "A Bird Grows Wings"', *The Ferranti Journal*, 9:104.
- Stuart-Williams, RS. 1951. 'Ferranti Nimrod Computer', *Electronic Engineering*.
- Sumner, F. 1994. 'Memories of the Manchester Mark 1', *Computer Resurrection*.
- Sumner, J. 2012. 'Turing today', *Notes and Records of the Royal Society*, 66:295-300. 2013. 'Walls of resonance: Institutional history and the buildings of the University of Manchester', *Studies in History and Philosophy of Science Part A*, 44:700-15. 2014. 'Defiance to compliance: Visions of the computer in postwar Britain', *History and Technology*, 30:309-33.
2016. 'Science, technology and medicine' in A Kidd and others (eds.), *Manchester: Making the Modern City* (Liverpool University Press).
- Swann, BB. 1975. 'An informal history of the Ferranti computer department'. www.chilton-computing.org.uk/acl/pdfs/swann.htm.
- Swinton, J. 2003. 'Watching the daisies grow: Turing and Fibonacci phyllotaxis' in CA Teuscher (ed.), *Alan Turing: Life and Legacy of a Great Thinker* (Springer).
2013. 'Turing, morphogenesis, and Fibonacci phyllotaxis: Life in Pictures' in SB Cooper and others (eds.), *Alan Turing: His Work and Impact* (Elsevier).
- Swinton, J, Ochu, E, and The MSI Turing's Sunflower Consortium. 2016. 'Novel Fibonacci and non-Fibonacci structure in the sunflower: results of a citizen science experiment', *Royal Society Open Science*, 3:160091-91.
- Tameside Borough Council. 2018. 'Blue Plaque: Harry Rutherford'. <https://www.tameside.gov.uk/blueplaque/harryrutherford>.
- Taylor, AJP. 1957. 'The World's Cities (1): Manchester', *Encounter*.
1983. *A Personal History* (Atheneum).
- Taylor, B. 1951. *The Official Book of The Festival of Britain (Advance programme)* (HMSO).
- Taylor, I, Evans, K, and Fraser, P. 1996. *A Tale of Two Cities: Global change, Local Feeling and Everday Life in the North of England* (Routledge).
- Textile Recorder Annual (1954) (Harlequin Press).
- Tebbutt, C. 2006. 'Beyond the Village', MA thesis, University of Manchester.
- Teulon Porter, N. 1962. 'As I seem to Remember'. Cambridge University Library.
- The Manchester Joint Research Council. 1954. *Industry and Science* (Manchester University Press).
- The Pauling Blog. 2013. 'Dorothy Wrinch'. <https://paulingblog.wordpress.com/tag/dorothy-wrinch>.
- Thomas, D. 2003. *Around Manchester in the 50s & 60s* (Manchester Evening News).
- Thomas, T. 2017. 'Recollections of "Magnetic drum" storage for the Mark I'. www.curation.cs.manchester.ac.uk/digital60/www.digital60.org/about/biographies/tommythomas/manchester_drums.html.
- Timmins. 1998. *Made in Lancashire: A History of Regional Industrialisation* (Manchester University Press).
- Todd, N. 2008. "Historical And Radio-Archaeological Perspectives On The Use Of Radioactive Substances By Ernest Rutherford." (University of Manchester).
- Tootill, G. 2009. "National Life Stories: An Oral History of British Science." Interview by T Lean. British Library.
- Turing, AM. 1950. 'Computing Machinery and Intelligence', *Mind*, 59:433-60.
1953. 'Some Calculations of the Riemann Zeta Function', *Proceedings of the London Mathematical Society*, S3-3.
- Turing, D. 2015. *Prof: Alan Turing Decoded* (The History Press).
- Turing, SS. 1959. *Alan M. Turing* (W. Heffer).
2012. *Alan M. Turing* (Cambridge University Press). Second edition.
- Turner, B. 2011. *Beacon for change: how the 1951 Festival of Britain helped to shape a new age* (Aurum).
- Tweeddale, G. 1993. 'A Manchester computer pioneer: Ferranti in retrospect', *IEEE Annals of the History of Computing*.
- University of Manchester. 1926. *The Victoria University of Manchester: a short historical and descriptive account* (Manchester University Press).
2017. 'The old Students' Union'. www.manchester.ac.uk/discover/history-heritage/history/buildings/students-union.
- University of Manchester Department of Computer Science. 1998. *The Computer That Changed The World, CD-ROM* (Europress)
- von Tunzelmann, A. 2014. 'The Imitation Game: inventing a new slander to insult Alan Turing', *The Guardian*, 20 Nov.
- Wainwright, M. 2001. *Looking Back: The University of Manchester* (Manchester University Press).
- Wardlaw, CW. 1953. 'A commentary on Turing's diffusion-reaction theory of morphogenesis', *New Phytologist*, 52:40-47.
1954. 'Evidence relating to the diffusion-reaction theory of morphogenesis', *New Phytologist*, 54:3949.
1968. *Essays on Form in Plants* (Manchester University Press).
1971. *A quiet talent: Jessie Wardlaw, 1903–1971* (Privately published).
- Weeks, J, and Porter, K. 1998. *Between the acts: lives of homosexual men 1885–1967* (Rivers Oram).
- Whittle, S, and Jones, A. 1994. *Consuming Differences: the collaboration of the gay body with the cultural state* (Arena).
- Whyte, LL. 1951. *Aspects of Form: A Symposium on Form in Nature and Art* (Lund Humphries).
- Wigner, EP, and Hodgkin, RA. 1977. 'Michael Polanyi', *Biographical Memoirs of Fellows of the Royal Society*, 23:437-45.
- Wilkes, MV. 1968. 'Computers Then and Now', *Journal of the ACM*, 15:1-7.
- Wilkes, MV, and Kahn, HJ. 2003. 'Tom Kilburn CBE FEng. 11 August 1921–17 January 2001',

Biographical Memoirs of Fellows of the Royal Society, 49:283-97.

Williams, B. 2013. *Jews and other Foreigners* (Manchester University Press).

Williams, FC. 1976. "Pioneers of Computing 7." Interview by CR Evans. Science Museum.

Williams, MR. 1997. *A History of Computing Technology* (Wiley).

Williams, RM. 2006. 'Bertha Swirles Jeffreys (1903–1999)' in G Williams and others (eds.), *Out of the Shadows: Contributions of Twentieth-Century women to physics* (Cambridge University Press).

Wilson, D. 2008. *Reconfiguring biological sciences in the late twentieth century: a study of the University of Manchester* (Faculty of Life Sciences, University of Manchester).

Wilson, JF. 2000. *Ferranti: A History* (Manchester University Press).

Woodward, M. 1958. 'The Diagnosis and Treatment of the Sexual Offender', *British Journal of Delinquency*, 9:44-59.

Woolf, V. 1978. *A Reflection of the Other Person: The Letters of Virginia Woolf 1929–1931* (Hogarth Press).

Woolley, TE. 2014. 'Mighty morphogenesis' in S Parc (ed.), *50 Visions of Mathematics* (Oxford University Press).

Wyke, T, and Cocks, H. 2004. *Public Sculpture of Greater Manchester* (Liverpool University Press).

Wyke, T, Robson, B, and Dodge, M. 2018. *Manchester: Mapping the City* (Birlinn).

Yong, E. 2010. 'Spots plus spots equals maze: how animals create living patterns', *National Geographic* 7 Sep.

Zichichi, A. 2016. *A Lesson for the Future of Our Science* (World Scientific).