OXFORD

ALAN TURING'S ELECTRONIC BRAIN

The struggle to Build the ACE, the World's Fastest Computer

B. JACK COPELAND

Alan Turing's Electronic Brain

This page intentionally left blank

Alan Turing's Electronic Brain

The Struggle to Build the ACE, the World's Fastest Computer

B. Jack Copeland and others



OXFORD

UNIVERSITY PRESS

Great Clarendon Street, Oxford 0x2 6DP

Oxford University Press is a department of the University of Oxford. It furthers the University's objective of excellence in research, scholarship, and education by publishing worldwide in

Oxford New York

Auckland Cape Town Dar es Salaam Hong Kong Karachi Kuala Lumpur Madrid Melbourne Mexico City Nairobi New Delhi Shanghai Taipei Toronto

With offices in

Argentina Austria Brazil Chile Czech Republic France Greece Guatemala Hungary Italy Japan Poland Portugal Singapore South Korea Switzerland Thailand Turkey Ukraine Vietnam

Oxford is a registered trade mark of Oxford University Press in the UK and in certain other countries

> Published in the United States by Oxford University Press Inc., New York

> > © Oxford University Press 2005

The moral rights of the author have been asserted Database right Oxford University Press (maker)

First published in hardback as Alan Turing's Automatic Computing Engine 2005

First published in paperback in 2012

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, without the prior permission in writing of Oxford University Press, or as expressly permitted by law, or under terms agreed with the appropriate reprographics rights organization. Enquiries concerning reproduction outside the scope of the above should be sent to the Rights Department, Oxford University Press, at the address above

You must not circulate this book in any other binding or cover and you must impose this same condition on any acquirer

> British Library Cataloguing in Publication Data Data available

Library of Congress Cataloging in Publication Data Data available

Typeset by Newgen Imaging Systems (P) Ltd., Chennai, India Printed in Great Britain on acid-free paper by Biddles Ltd., King's Lynn, Norfolk

> ISBN 978-0-19-856593-2 (Hbk) ISBN 978-0-19-960915-4 (Pbk)

> > 24681097531

This is only a foretaste of what is to come, and only the shadow of what is going to be. We have to have some experience with the machine before we really know its capabilities ... I do not see why it should not enter any one of the fields normally covered by the human intellect, and eventually compete on equal terms.

> Alan Turing (Quoted in *The Times*, 11 June 1949: 'The Mechanical Brain')

This page intentionally left blank

Foreword

Donald W. Davies

It was on May 10 1950 that the Pilot Model of the Automatic Computing Engine (ACE) ran its first program. This lit the lamps along the top of the control desk, one at a time, at a rate that could be controlled by the input keys. It was a great event for those who had been building the machine, simple though the program was. That small beginning culminated in the National Physical Laboratory's commercial computing service and led on to several ranges of computers.

The Second World War saw scientific research projects of a size and complexity that reached new levels. Underlying much of the work were complex mathematical models, and the only way to get working solutions was to use numerical mathematics on a large scale. In the Tube Alloys project, for example, which became the UK part of the Manhattan Project to make a fission bomb, we had to determine the critical size of a shape of enriched uranium and then estimate mathematically what would happen when it exploded. For this problem we used about a dozen 'computers'—young men and women equipped with hand calculators (such as the Brunsviga). These human computers were 'programmed' by physicists like myself. The same story, with different physics and different mathematics, was repeated in many centres across the United Kingdom.

In meetings which began in 1943 it was decided that a centre of excellence would be formed, as soon as possible after the war ended, in order to develop numerical mathematics for peaceful applications of complex mathematical models. This centre became the Mathematics Division of the National Physical Laboratory. The Division began life in 1945 under its first superintendent, J. R. Womersley.

At the same time the idea was born of building a large, fast, programmed digital computer which the new Division could use to exploit its numerical expertise. The ENIAC electronic calculator had illuminated the way forward, and there were two other major influences on this plan. One was the extraordinary paper written by Alan Turing in 1936, where, in the course of resolving a fundamental problem in mathematical logic, Turing had described the design of a computer that could calculate anything capable of being calculated by means of an algorithm. Turing's design was, to an extent, idealized, but it became the basis for all the following work on programmed computation. The second major influence was the ultrasecret work on codebreaking machines at Bletchley Park, in particular the 'Colossus'. A large, fast electronic machine, Colossus was not itself a general-purpose programmed computer, but it demonstrated the technology needed to convert Turing's ideas of 1936 into reality.

Putting all these things together, it is not surprising that in the NPL Mathematics Division a computer project soon began, with Turing at its head, and involving two of the builders of Colossus. Turing rapidly wrote his report 'Proposed Electronic Calculator', which set out a detailed design study for the ACE. This brilliant report covered all aspects of the computer, from the physics of the 'delay lines' that formed its memory to the principles of programming. Alan Turing is celebrated as a genius, both for his mathematical work in 1936 and later, and for his codebreaking skill, exemplified by the now famous 'Bombe', the machine used to break the German Enigma code. Turing's brilliance showed again in the design of the ACE. The Pilot Model of the ACE could calculate faster than any computer of its generation and many of the next generation too.

Turing was joined in 1946 by Jim Wilkinson, who would later become a world expert in matrix inversion, eigenvalue calculations, and related numerical processes. (His breakthroughs in these areas were only possible with a fast computer—the Pilot ACE—on which to test his work.) Then Mike Woodger joined, followed by Gerald Alway, myself, Betty Curtis, Henry Norton, and others. Turing's innovative design was a brilliant start. Moreover, we had the mathematicians who were to make the ACE into a great working machine, expertise from Colossus, the major electronic digital project of the Second World War, and the resources of the National Physical Laboratory to fund and build the computer.

But then followed an unfortunate part of the story—delays that cost us two years. The chance to be the builders of the first stored-program computer escaped us. Several things rescued us from the log-jam. A key figure was Harry Huskey, who joined us in 1947 after working on the ENIAC. Huskey got things done and without him another year would have been lost. He proposed to build a small-scale version of the ACE, called the Test Assembly, to test the electronics and construction. I'm not sure how much Turing approved of this particular effort! The next important development was the recruiting of two expert electronic engineers from EMI, Edward (Ted) Newman and David (Tubsy) Clayden. Clayden's chapter 'Circuit Design of the Pilot ACE and the Big ACE' (Chapter 19) describes the revolutionary style of logic device they brought with them, employing what was called 'current-steering'. When Huskey left us to return to the United States his Test Assembly was partly built. A battle ensued between those who had been designing it and Newman, for whom its style of circuits, based on the ENIAC precedent, was anathema. In the end Huskey's design work was largely abandoned, but not entirely so, for we kept to the logical design of the Test Assembly in building the Pilot Model ACE.

Once the Pilot Model was working reliably, the whole machine was moved across the NPL site from Bushy House, where it had been constructed, into a new room where it became a working computing service. The machine was running again a very short time after the move, a tribute to its sound engineering. Not only was it the fastest computer of its day (and the hardest to program!) but with 1000 electronic valves it was by far the most compact. The Pilot Model ACE enabled Mathematics Division to make great advances in numerical analysis, and provided industry with the first commercial electronic computing service.

The main honours for the design and construction of the Pilot Model ACE are shared by Alan M. Turing, James H. Wilkinson, and Edward A. Newman, aided by a sharp nudge from Harry D. Huskey, who really started the Pilot Model idea rolling.