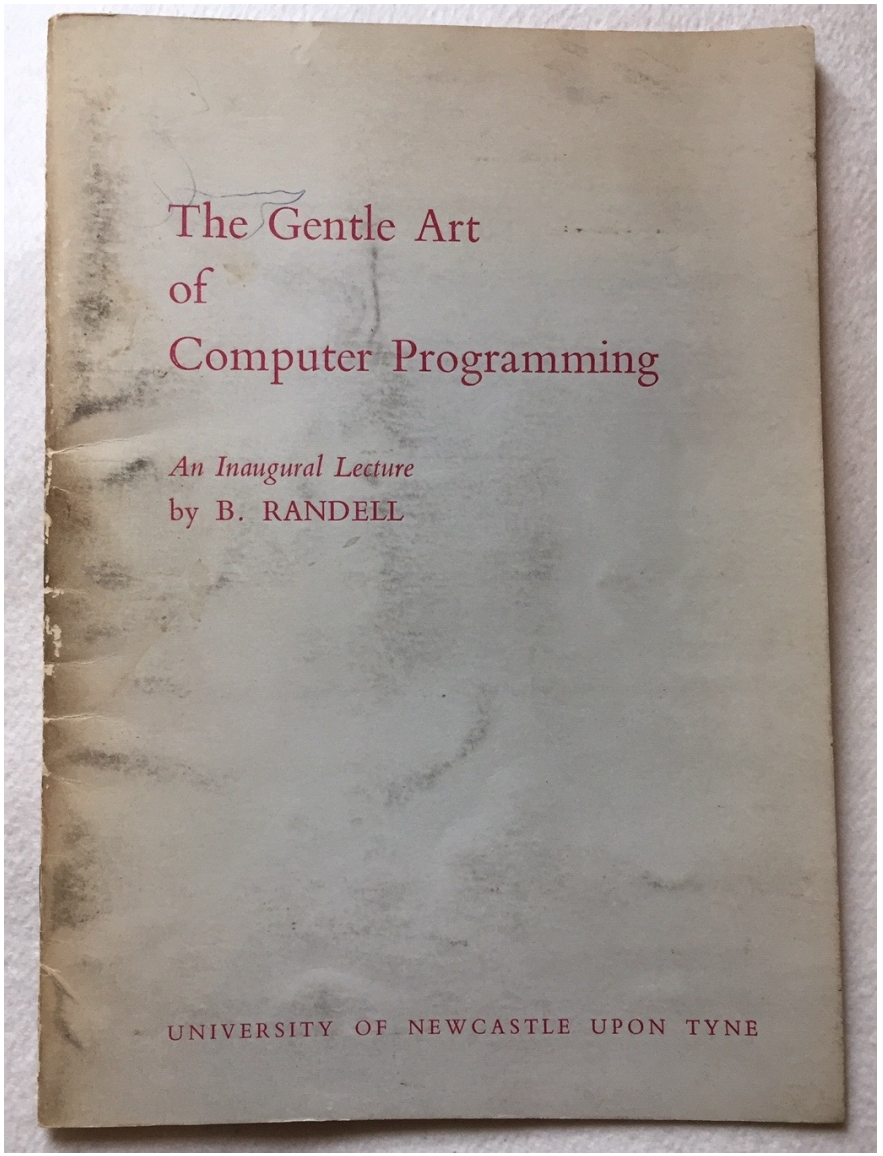
An Irish Origin of Modern Computers: Investigating the Work and Life of Percy Ludgate (1883-1922)

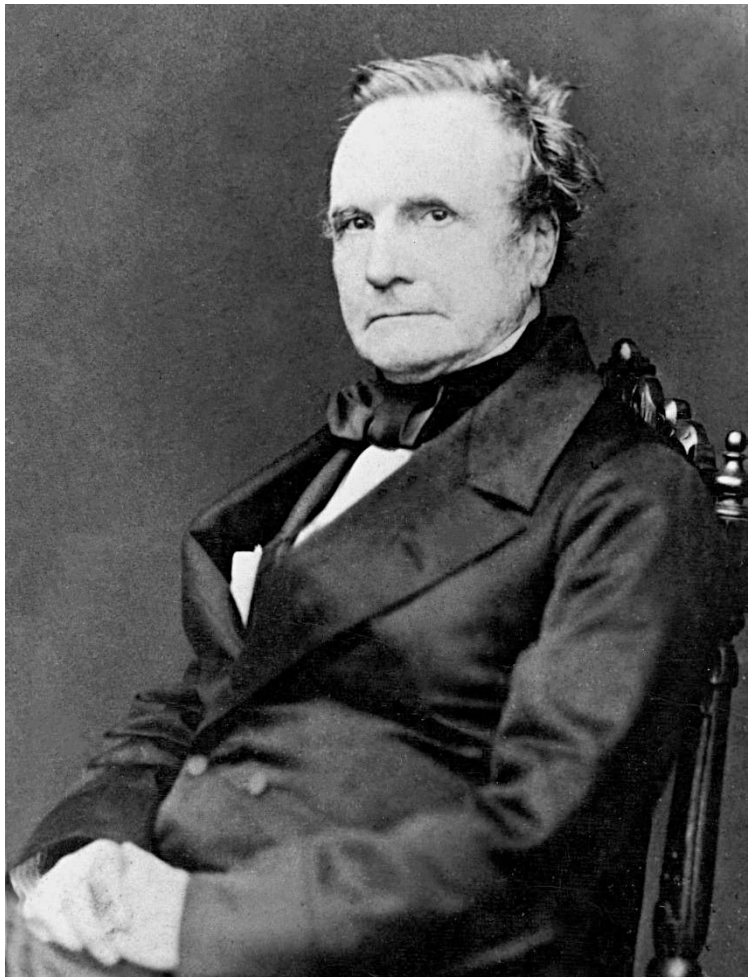
Brian Randell

Newcastle University

Percy Edwin Ludgate

The Beginning: I stumbled across Ludgate in 1970 shortly after I arrived at Newcastle University, while I was preparing my Inaugural Lecture and was looking for interesting things to say about Ada Lovelace and Charles Babbage.



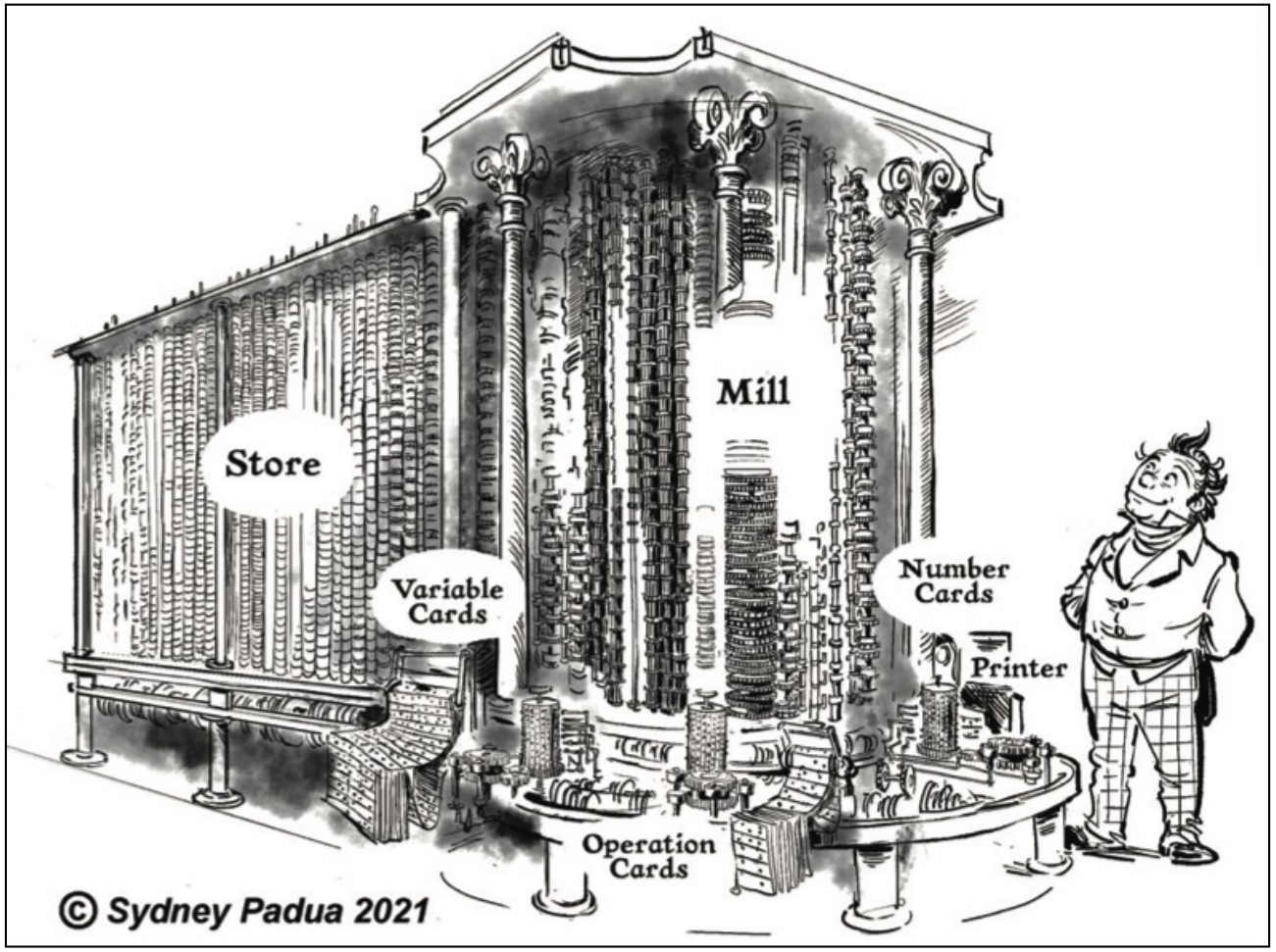


From Wikipedia - Public domain

Charles Babbage (1791-1871)

A famed brilliant mathematician, philosopher, inventor and mechanical engineer, who originated the concept of a programmable digital computer. He spent many years and a small fortune designing and trying (unsuccessfully) to construct machines for calculating and printing mathematical tables, and an **Analytical Machine** – a giant mechanical computer controlled by punched card programs, the forerunner of modern electronic computers.

Babbage's Analytical Engine – 1834



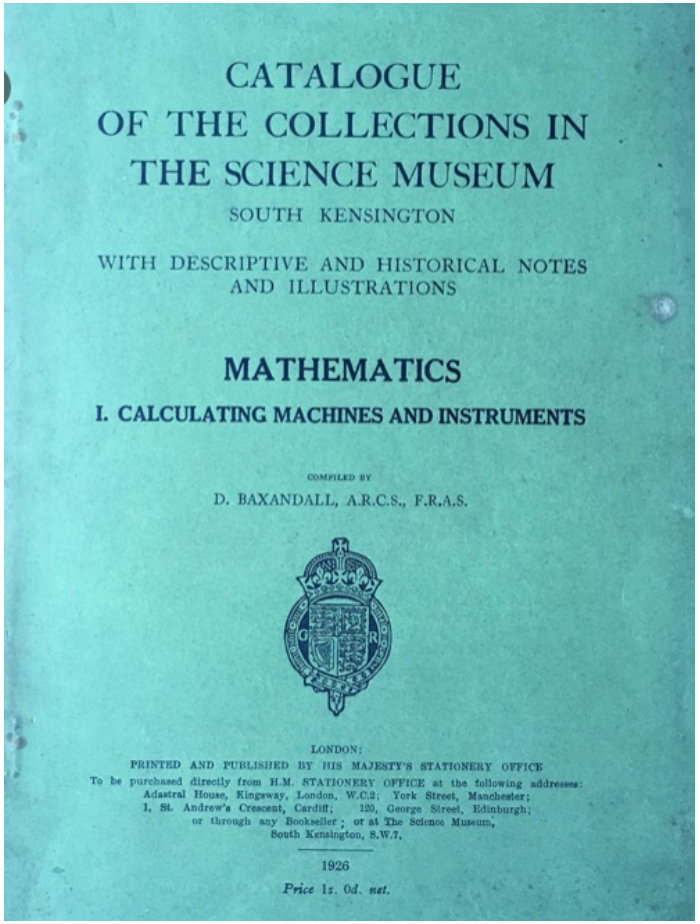
A monstrous machine, of which only a small fragment was ever built.

From: Wikipedia: Public domain

Ada Lovelace (1815-52)

"Sole daughter of my house and heart" – Lord Byron

Brought up by Lady Byron, who promoted her interest in mathematics, aiming to avoid Ada developing her father's notorious character. At the age of 18, when she was taken to a Babbage soirée, she became fascinated by his work on calculating machines and began to work with him. Famous for her translation and extensive annotation of an Italian description of the Analytical Engine – she went beyond Babbage in documenting the Engine's programming and conveying its potential. Died tragically early of uterine cancer aged 36. Now a veritable icon!


CATALOGUE
OF THE COLLECTIONS IN
THE SCIENCE MUSEUM
SOUTH KENSINGTON
WITH DESCRIPTIVE AND HISTORICAL NOTES
AND ILLUSTRATIONS
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I. CALCULATING MACHINES AND INSTRUMENTS
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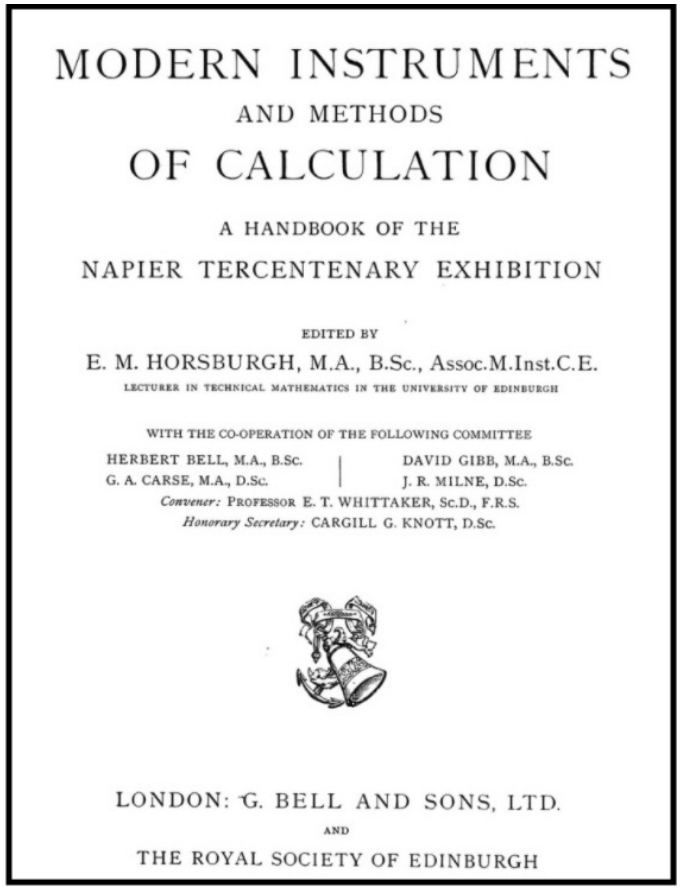
or through any Bookseller; or at The Science Museum,
South Kensington, S.W.7.
1926
Price 1*s.* 0*d. net.*

The 1926 Science Museum Catalogue

My search for something new to say about Ada Lovelace led me to the Museum's catalogue "*Calculating Machines and Instruments*", where I noticed it mentioned that a **Percy Ludgate** had designed a Difference Engine – a name that was not familiar to me.

Other difference engines were designed and made by Martin Wiberg (1863) in Sweden, G. B. Grant in the United States; others were designed by Léon Bollée in France, and Percy E. Ludgate in Ireland, which, however, were never constructed.



MODERN INSTRUMENTS
AND METHODS
OF CALCULATION

A HANDBOOK OF THE
NAPIER TERCENTENARY EXHIBITION

EDITED BY
E. M. HORSBURGH, M.A., B.Sc., Assoc.M.Inst.C.E.
LECTURER IN TECHNICAL MATHEMATICS IN THE UNIVERSITY OF EDINBURGH

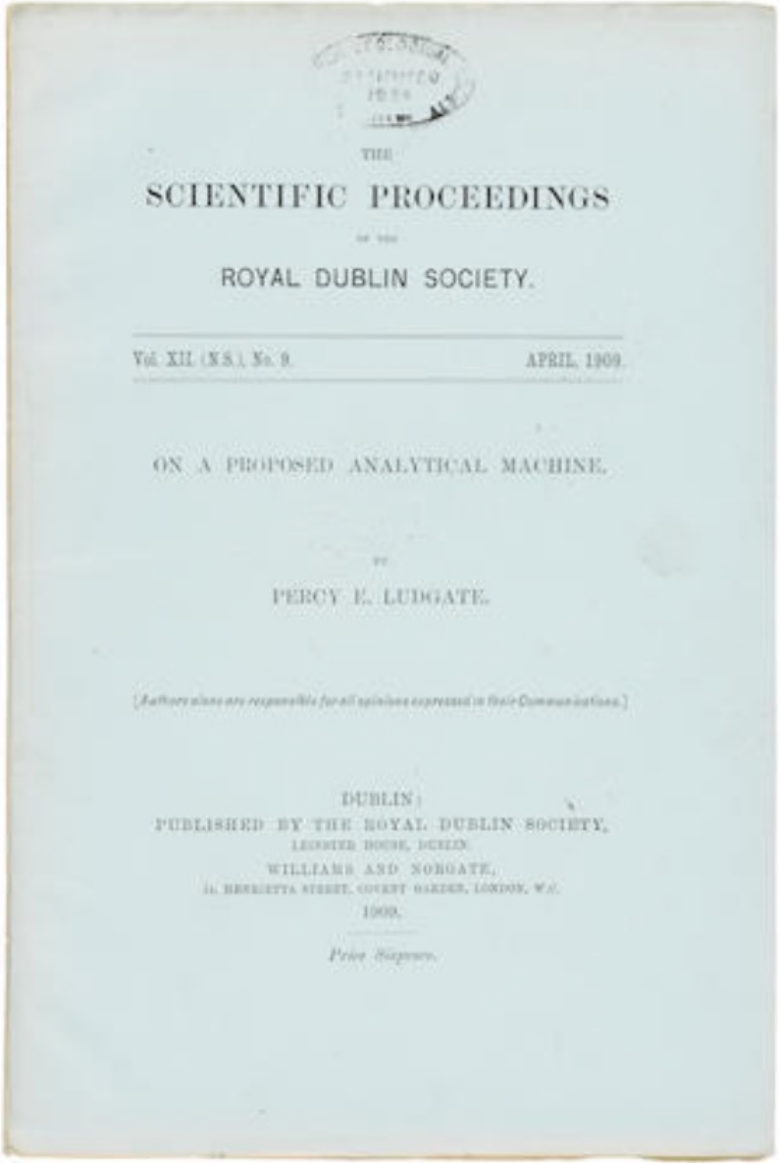
WITH THE CO-OPERATION OF THE FOLLOWING COMMITTEE
HERBERT BELL, M.A., B.Sc. | DAVID GIBB, M.A., B.Sc.
G. A. CARSE, M.A., D.Sc. | J. R. MILNE, D.Sc.
Convener: PROFESSOR E. T. WHITTAKER, Sc.D., F.R.S.
Honorary Secretary: CARGILL G. KNOTT, D.Sc.

LONDON: G. BELL AND SONS, LTD.
AND
THE ROYAL SOCIETY OF EDINBURGH

The 1914 Edinburgh Exhibition Handbook

Exploring further, I was led to the splendid *Handbook of the 1914 Napier Tercentenary Exhibition*, in which I found **Percy Ludgate** had a Chapter: "**Automatic Calculating Machines**" which ended with this startling claim:

I have myself designed an analytical machine, on different lines from Babbage's, to work with 192 variables of 20 figures each. A short account of it appeared in the *Scientific Proceedings, Royal Dublin Society*, April 1909. Complete descriptive drawings of the machine exist, as well as a description in manuscript, but I have not been able to take any steps to have the machine constructed.



THE

SCIENTIFIC PROCEEDINGS

OF THE

ROYAL DUBLIN SOCIETY.

Vol. XII. (N.S.) No. 9 APRIL, 1909.

ON A PROPOSED ANALYTICAL MACHINE.

BY

PERCY E. LUDGATE.

[Authors alone are responsible for all opinions expressed in their Communications.]

DUBLIN:
PUBLISHED BY THE ROYAL DUBLIN SOCIETY.
LEINSTER HOUSE, DUBLIN.
WILLIAMS AND NORGATE,
14, HENRIETTA STREET, COVENT GARDEN, LONDON, W.C.
1909.

Price Sixpence.

The Royal Dublin Society Paper:

PERCY E. LUDGATE:

ON A PROPOSED ANALYTICAL MACHINE (1909)

(Preprints of Ludgate's original paper cost sixpence in 1909 – this copy fetched $1000 at auction in 2015.)

The 1909 Paper's Opening Sentence

ON A PROPOSED ANALYTICAL MACHINE.

By PERCY E. LUDGATE.

(COMMUNICATED BY PROFESSOR A. W. CONWAY, M.A.)

[Read February 23. Ordered for Publication March 9. Published April 28, 1909.]

I purpose to give in this paper a short account of the result of about six years' work, undertaken by me with the object of designing machinery capable of performing calculations, however intricate or laborious, without the immediate guidance of the human intellect.

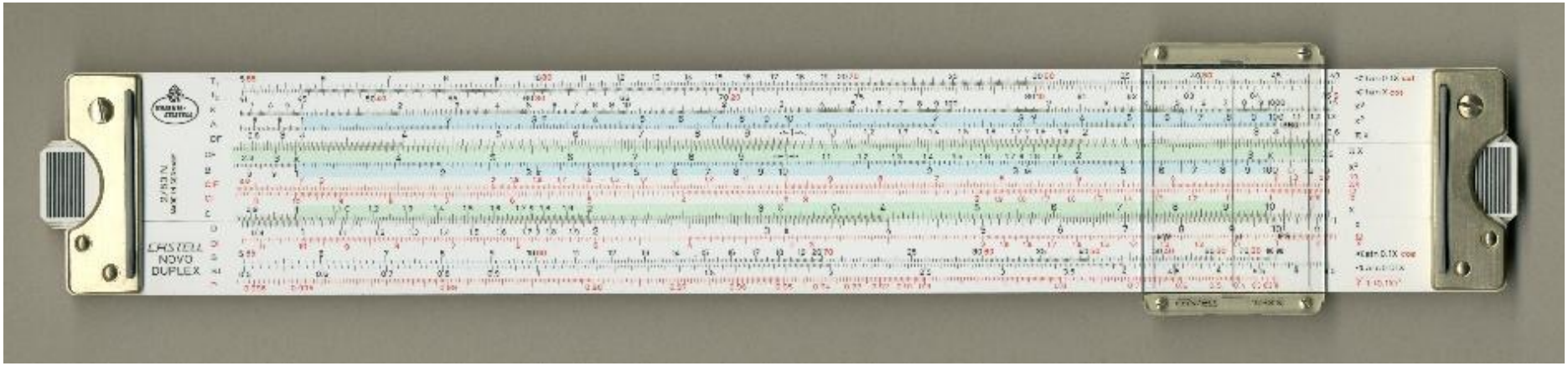
By 1909 . . .

- Calculating machines – first invented in the 17th century – were by now widely available to (rich) businesses and scientists. Few performed automatic multiplication.
- Adding machines (invented in the late 19th century) were coming into general use in well-equipped businesses and commerce.
- Punched card machines, invented for tabulating the 1890 U.S. census, had been used for many countries' national censuses, and were starting to be used for other large data processing tasks by a few large organisations.
- But the notion of an automatic, i.e. **programmable,** calculator had been largely forgotten.

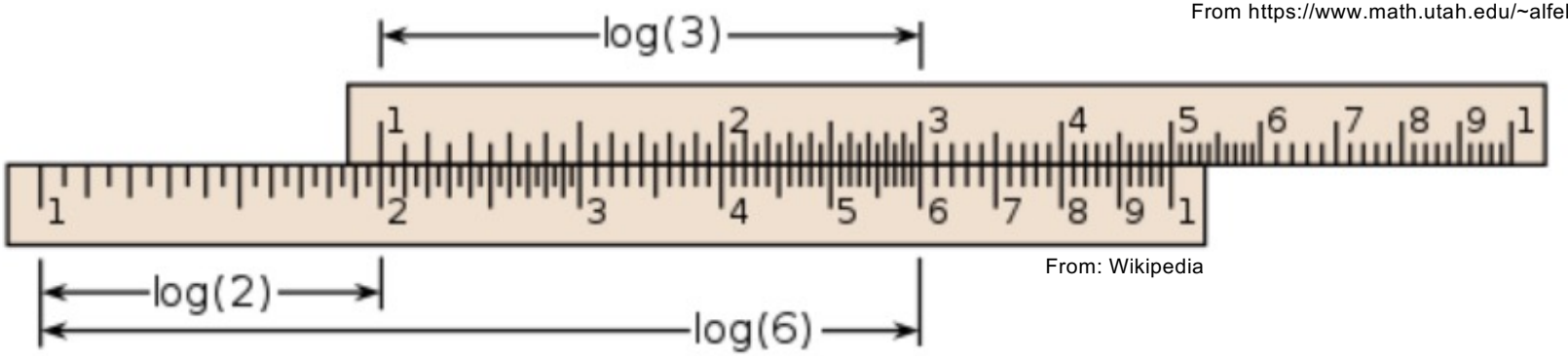
Ludgate's Program-Controlled Computer

- Ludgate credibly claims little prior knowledge of Babbage - the three main components (store, arithmetic unit, sequence controller) of his machine all show evidence of considerable ingenuity and originality.
- Each 20-digit signed decimal number was represented by a set of sliding rods in a shuttle; the set of 192 shuttles were arranged around two concentric cylindrical shuttle boxes.
- The planned arithmetic unit was based on what the 1909 review in *Nature* of Ludgate's paper delightfully termed "**Irish Logarithms**".
- Multiplication involved representing all the digits of the multiplicand, and a single digit (at a time) of the multiplier, as "logarithmic" index numbers; the multiplier index number was simultaneously added to each of the 20 multiplicand index numbers (by additive linear motion).
- The results were then converted back to give a set of two-digit decimal partial products, and added into the decimal accumulator (the "mill") to produce the overall result.

Slide Rules – once common, now forgotten



From https://www.math.utah.edu/~alfeld/sliderules/



From: Wikipedia

The slide rule was by this time a well-established device for performing multiplications and divisions, based on the use of continuous (ordinary!) logarithms, so analogue not digital, and accurate to just 2-3 decimal places.

“Irish Logarithms”

- Ludgate introduced a brand new concept, that he called an “Index”, to do multiplication based on a digital form of logarithm, now known as Irish Logarithms.
- The core of his machine did not just do additions; it did multiply-accumulate (MAC), i.e. multiply followed by add to any previous result in the Mill.
- For two (single-digit) operands Z_J and Z_K, Ludgate’s index numbers ensure $Z_{J*K} = Z_J + Z_K$.
- Some example indexes are:
  $Z_1 = 0$, $Z_2 = 1$, $Z_3 = 7$, $Z_4 = 2$, $Z_5 = 23$,
- **$Z_3 + Z_5 = 7 + 23 = 30 = Z_{15}$.**
- (Ludgate perhaps found his set of index numbers by ‘trial and error’, or by a systematic method that began with prime numbers and utilised ‘trial and error’.)

Ludgate's Tables

The example: $Z_3 + Z_5 = 7 + 23 = 30 = Z_{15}$

Decimal operand	Simple index	Ordinal number
0	50	9
1	0	0
2	1	1
3	7	4
4	2	2
5	23	7
6	8	5
7	33	8
8	3	3
9	14	6

Partial product	Compound index	Partial product	Compound index	Partial product	Compound index
1	0	15	30	36	16
2	1	16	4	40	26
3	7	18	15	42	41
4	2	20	25	45	37
5	23	21	40	48	11
6	8	24	10	49	66
7	33	25	46	54	22
8	3	27	21	56	36
9	14	28	35	63	47
10	24	30	31	64	6
12	9	32	5	72	17
14	34	35	56	81	28

(If you sort the simple indexes into order, and number them from zero, you get the "ordinals" – whose purpose was initially obscure.)

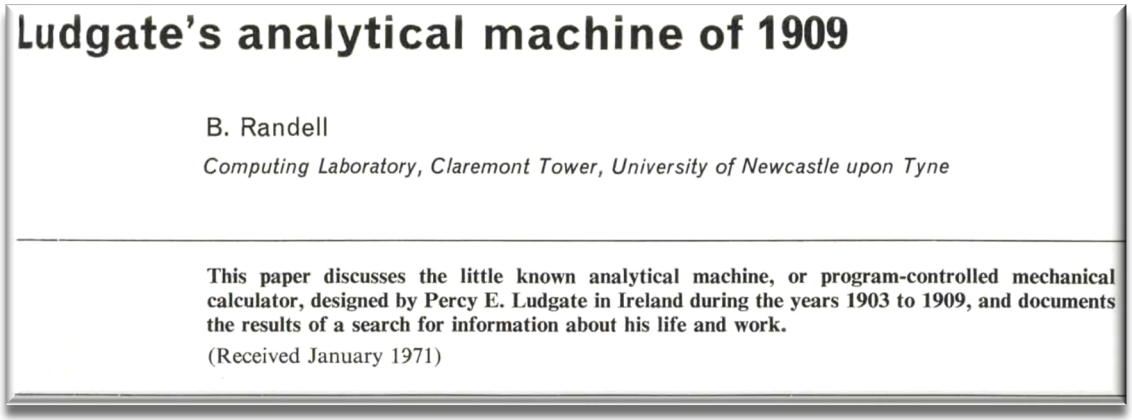
The Sequencing Mechanism

- The Analytical Machine was to be controlled from a keyboard, or by a “formula-paper” (a sheet or roll of perforated paper), on which each row of perforations defined a complete instruction – a definite improvement on Babbage. Operand values came from a “number-paper”, or a second keyboard.
- Each instruction specified the type of arithmetic operation to be performed, and identified two operands, i.e. the shuttles involved.
- Ludgate agreed with Babbage as to the fundamental importance of conditional branching – presumably to be done by skipping a specified number of rows, either forwards or backwards – e.g. at “a change in the value of a function or its approach to zero or infinity”.
- He made provision for built-in subroutines. The operation code for Division, for example, passed control temporarily to a sequence of instructions represented by perforations in a permanent ‘dividing cylinder’.
- Another cylinder provided a logarithm subroutine, and he mentioned that ”this system of cylinders ... may be indefinitely extended".

Results of my 1970 (Pre-Internet!) Investigation

- Just one relative of Percy Ludgate, his niece Violet, was found – in fact by the Royal Dublin Society Secretary, who called all the Ludgates in the Dublin Telephone Directories for me!
- Violet's family had lived near Percy Ludgate – she was 19 when he died – her memories were my main source of information.
- She provided the only known photograph of Ludgate.
- I tracked down just one colleague with recollections of Ludgate as an accountant, and learned he won praise for his work during WW1 for a committee controlling supplies of oats to the cavalry.
- I found a review of his 1909 paper in *Nature* by Prof. C.V. Boys.
- In 1914 Ludgate had stated: "Complete descriptive drawings of the machine exist, as well as a description in manuscript, but I have not been able to take any steps to have the machine constructed."
- But NONE of these drawings or manuscripts could be found!

Just Two Publications Resulted



Ludgate's analytical machine of 1909

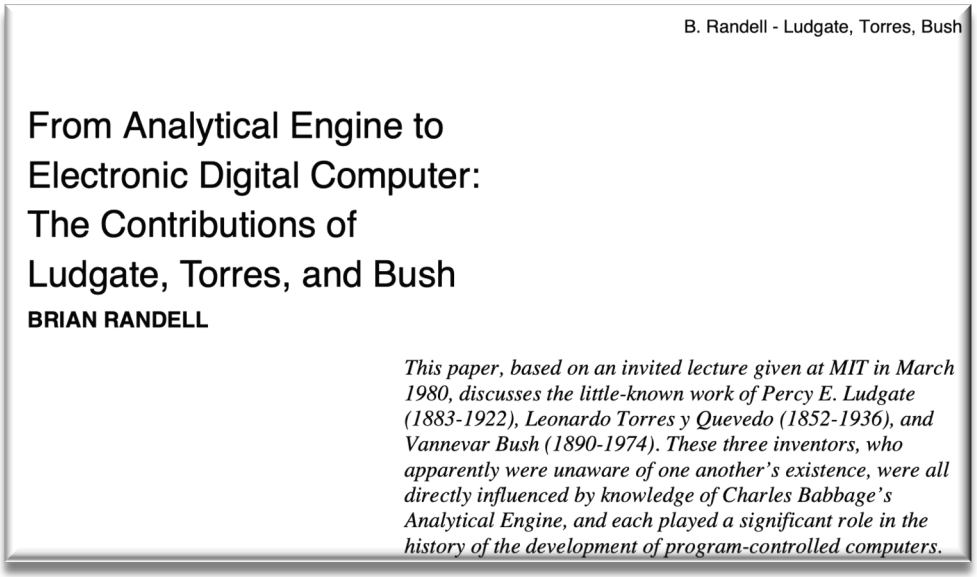
B. Randell

Computing Laboratory, Claremont Tower, University of Newcastle upon Tyne

This paper discusses the little known analytical machine, or program-controlled mechanical calculator, designed by Percy E. Ludgate in Ireland during the years 1903 to 1909, and documents the results of a search for information about his life and work.

(Received January 1971)

1971



B. Randell - Ludgate, Torres, Bush

From Analytical Engine to Electronic Digital Computer: The Contributions of Ludgate, Torres, and Bush

BRIAN RANDELL

This paper, based on an invited lecture given at MIT in March 1980, discusses the little-known work of Percy E. Ludgate (1883-1922), Leonardo Torres y Quevedo (1852-1936), and Vannevar Bush (1890-1974). These three inventors, who apparently were unaware of one another's existence, were all directly influenced by knowledge of Charles Babbage's Analytical Engine, and each played a significant role in the history of the development of program-controlled computers.

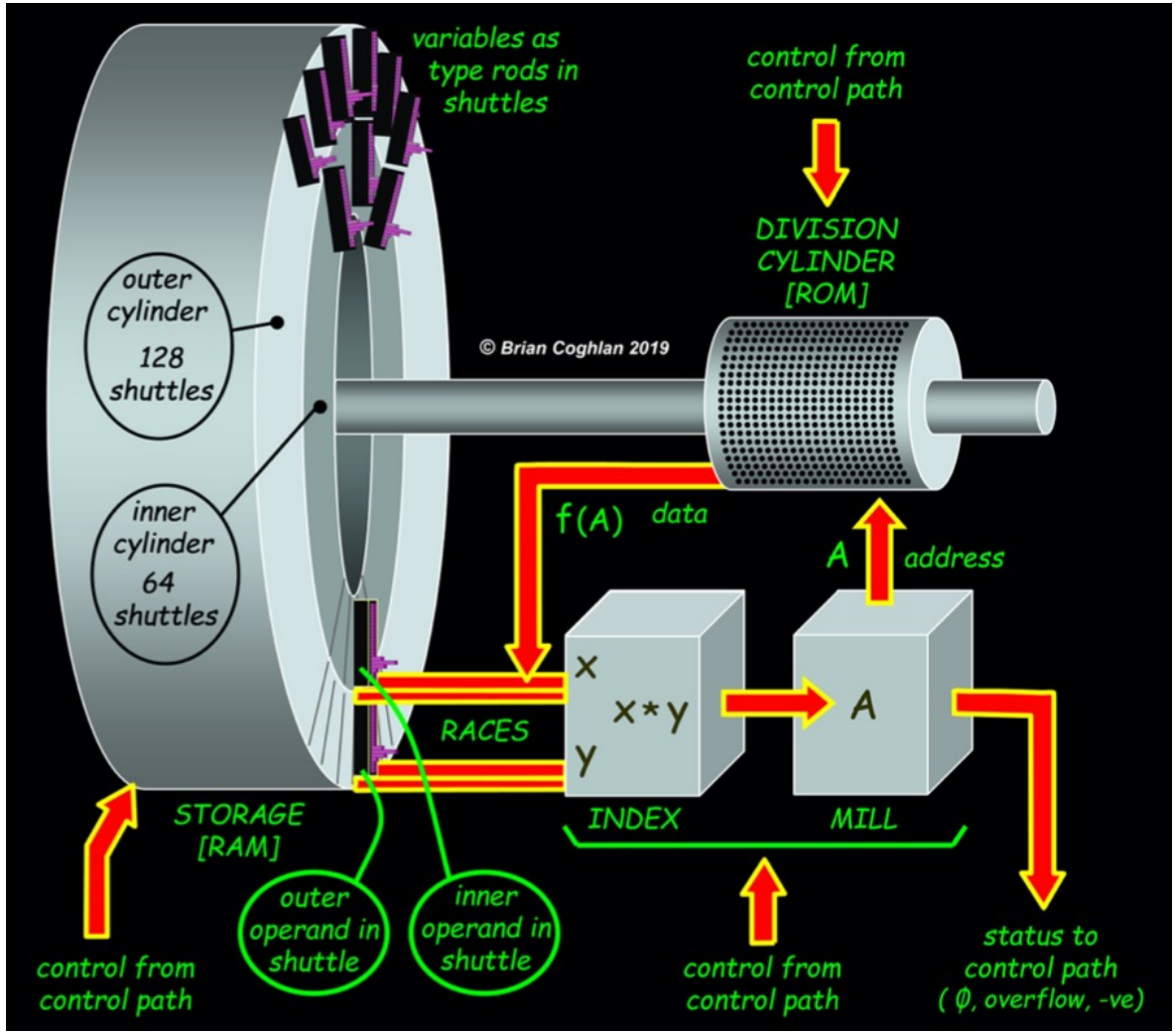
1982

My 1971 *Computer Journal* paper, and my 1982 paper in the *Annals of the History of Computing* revealed Ludgate and resurrected him from obscurity, **but no new information was found and revealed about Ludgate or his machine until . . .**

. . . 2017, When The Hunt Resumed

- I was contacted out of the blue by Dr. Brian Coghlan, curator of The John Gabriel Byrne Computer Science Collection of machines and documents in Trinity College Dublin.
- The Byrne Collection now holds copies (many original) of all the known literature and records relating to Ludgate. Its cataloguing had prompted Coghlan's attempt to investigate:
  - **Is there any chance that Ludgate's drawings and documents still exist and can be found?**
  - **Are any relatives (perhaps descended from his parents) alive or their possessions findable - and if so are there any documents, photos or memories of Percy Ludgate?**
- I soon found myself enmeshed in the team Brian Coghlan had assembled for his Ludgate investigation.
- This investigation's results to date are described in the January-March 2021 issue of the *IEEE Annals of the History of Computing* – and in Vol. 121C 2021 of the *Proceedings of the Royal Irish Academy*.

Ludgate's Machine 1909 – conjectural diagram



Here 'control path', 'data path', 'status', 'RAM', 'ROM', ' address', data', are modern terms, all other terms are from Ludgate's 1909 paper.

(A "Race" is "a groove or guide in which a ball bearing or roller bearing runs".)

This was intended to be a quite small machine, the size of a bar fridge.

Ludgate's Tables (again)

Decimal operand	Simple index	Ordinal number
0	50	9
1	0	0
2	1	1
3	7	4
4	2	2
5	23	7
6	8	5
7	33	8
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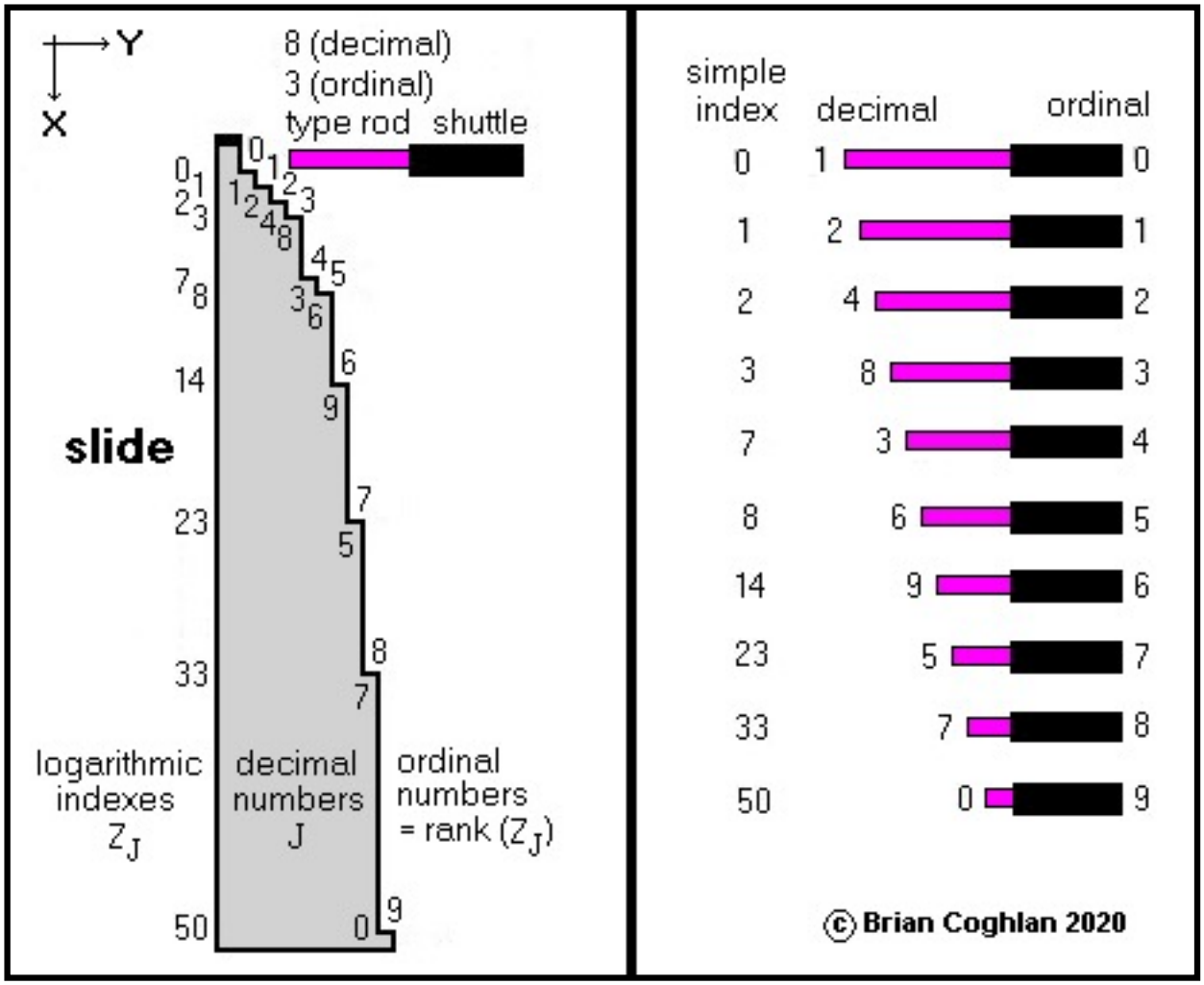
9	14	28	35	63	47
10	24	30	31	64	6
12	9	32	5	72	17
14	34	35	56	81	28

The right-hand table lists compound indexes representing the partial products. Thus, using the initial digits from the example in Ludgate 1909 (**8132 * 9247**):

$$Z_8 + Z_9 = 3 + 14 = 17 = Z_{72}$$

Logarithmic Slides and Rods



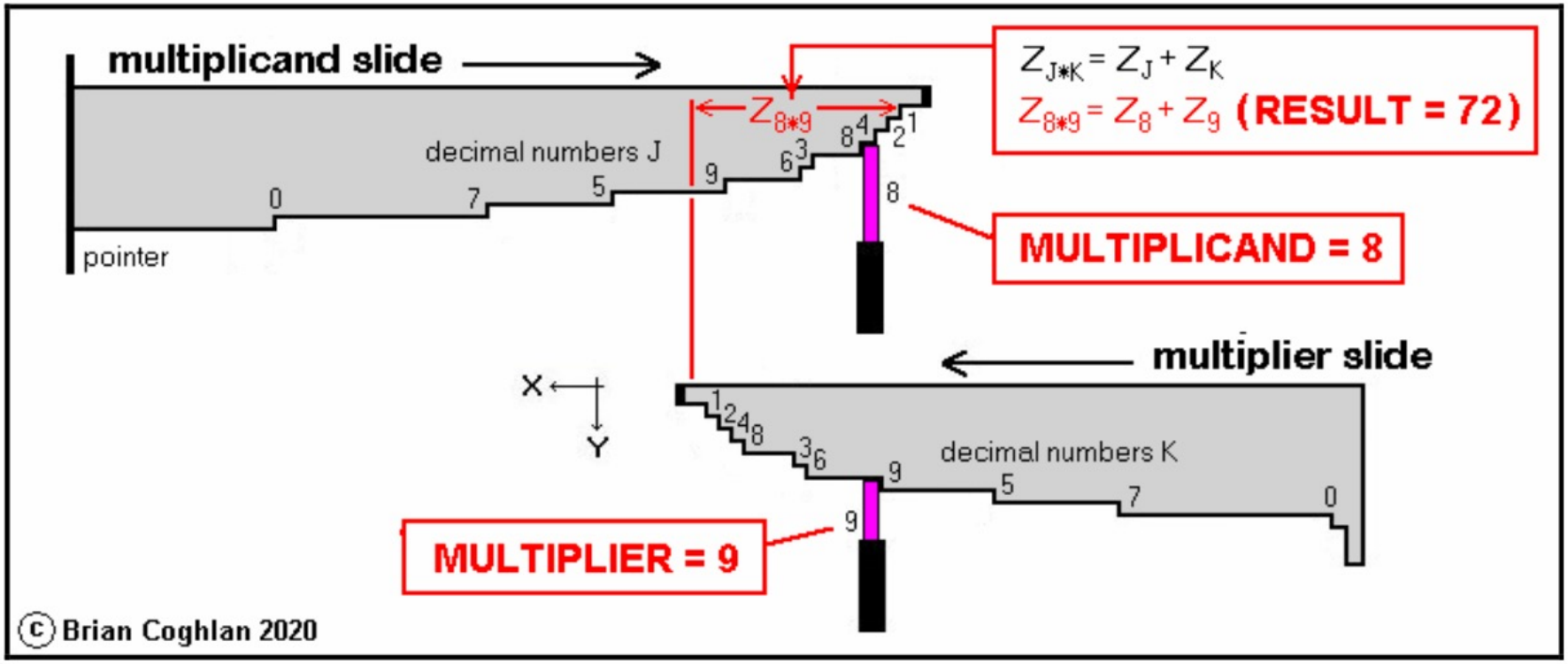
An Index Slide

Rod Protrusions

LHS: A “Slide” (presumed design) for converting ordinals representing decimal digits to “logarithms”.

RHS: A set of rods, whose protrusions represent the set of decimal digits. The extent of each protrusion matches a decimal digit’s ordinal value – thus they are ordered and engage conveniently with a set of ”steps” in the slide’s profile, whose positions reflect the value of their logarithms.

(Irish) Logarithmic Multiplication

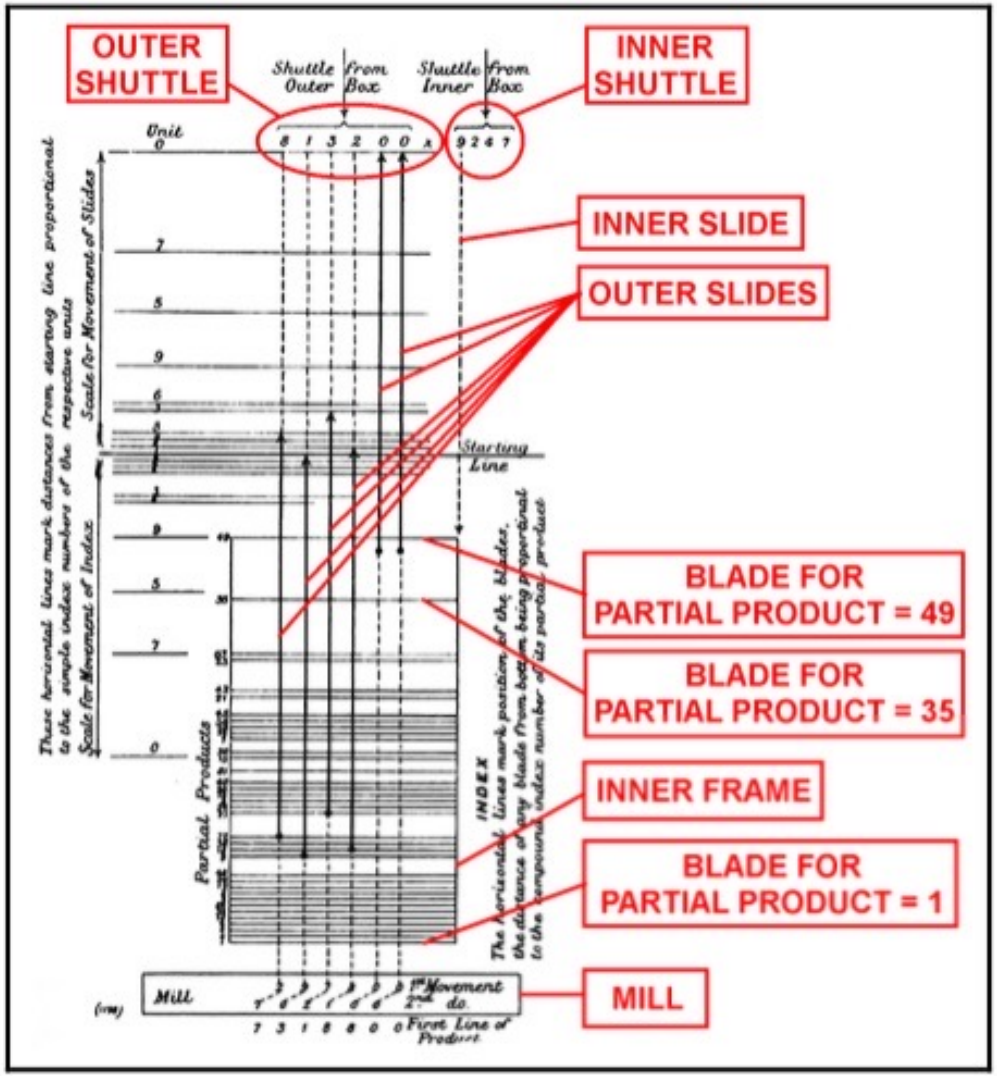


(It is not evident how the resulting product of two digits (the increased overlap of the two slides) is converted to a pair of decimal digits and transmitted to the “Mill”.)

A Drawing is Discovered!

- The chance of our finding Ludgate's drawings was remote, but the search was nevertheless intense and protracted. Family wills and papers were sought, libraries and archives (and the Internet) were scoured, and attempts made to find paperwork related to his career, to his submission of his 1909 Royal Dublin Society paper, and to his paper for the 1914 Napier Tercentenary Celebration.
- Just before Christmas 2019, prompted by our publicity campaign, an account of his work was discovered by Ralf Buelow (Heinz Nixdorf MuseumsForum) in the little-known magazine *The English Mechanic and World of Science* (Sept. 1909), which turned out to be derived from one in the equally obscure journal *Engineering* (August 1909).
- **Both included a drawing representing Ludgate's Index! This drawing surely must have been provided by Ludgate himself!**
- This additional information has facilitated detailed conjecturing concerning the design of the Index in particular.

The Drawing of the “Index”

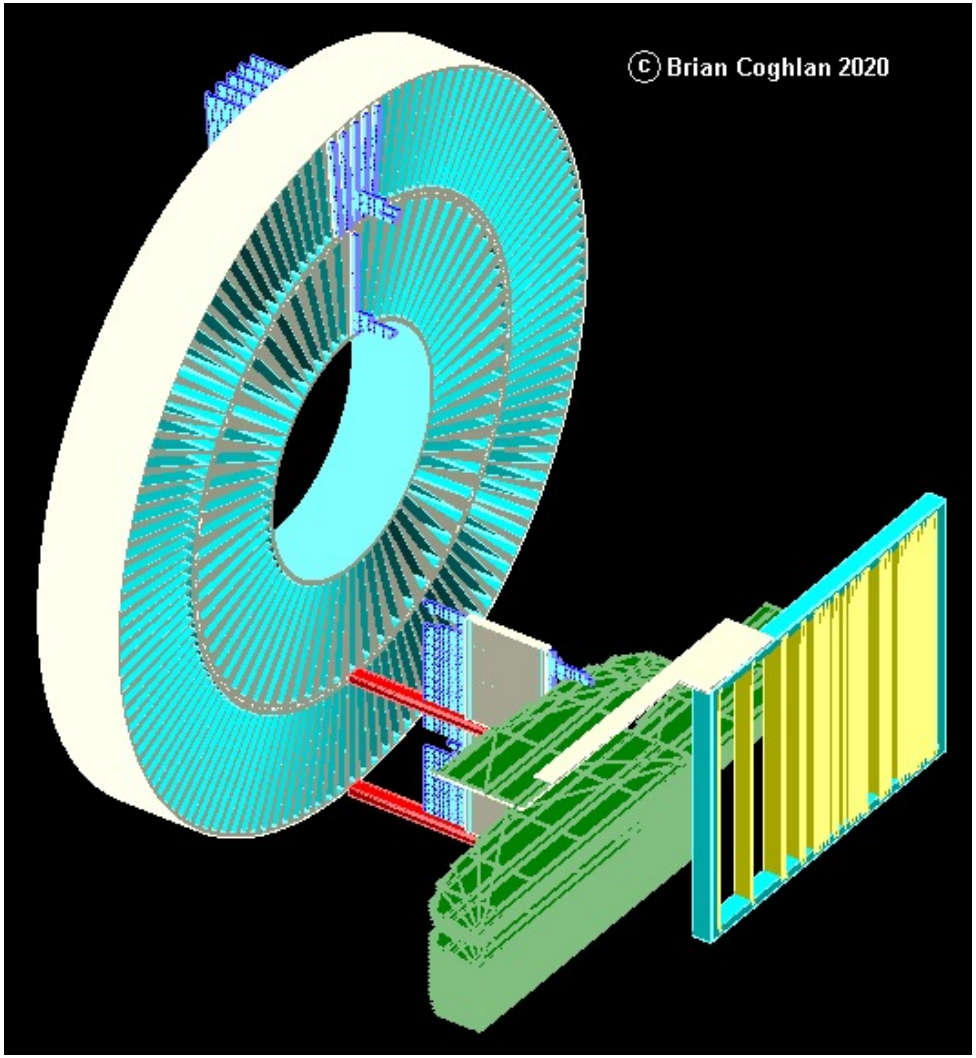


Annotated version of the Diagram in:

Anon. A Proposed Analytical Machine, *Engineering*, 20 Aug. 1909.

This portrays an Inner (Multiplier) slide and the set of Outer (Multiplicand) Index slides (both edge-on), positioned to show how the number 813,200 is multiplied by the first digit of 9247.

The Store and Index



An early 3D CAD rendition of a possible re-imagined Ludgate's Store and Index.

Three-quarter view, showing multiplicand and multiplier shuttles withdrawn from the Storage Cylinder (along "races") towards the Index. (These drawings actually show '813200' multiplied by '9', the first digit of '9247', the example portrayed in the 1909 drawing in *Engineering.)*

What we've added to our understanding

Base operation is **multiply-accumulate (MAC),** not addition

Multiply is done with **Irish Logarithms** by **INDEX**

Long multiply **starts at left digit** of multiplier

☆ Numbers must be **fixed point**

Multiply-accumulate result **units first, then tens** by **MILL**

☆ Timing implies **pipelining** tens carryadds

☆ Instruction set: **ADD, SUBTRACT, MULTIPLY, DIVIDE, STORE, CONDITIONAL BRANCH**

Two-operand addressing for LOAD and STORE

Fast for 1909: ADD/SUB 3 sec, MUL 10 sec, DIV 90 sec, LOG 120 sec

☆ Storage of 192 variables implies **(64 inner and 128 outer) shuttles** equi-spaced

☆ Hence storage size implies **binary storage addressing**

Numbers stored via **rod for sign & every digit** protruding 1-10 units

Data input/output via **perforated number-paper** (or upper keyboard)

Program input/output via **perforated formula-paper** (or lower keyboard), one instruction per row

☆ **Manual preemption**

Small size: estimated by Ludgate as 0.5m H x 0.7m L x 0.7m W

☆ denotes inferences that we have documented in detail

Ludgate's Analytical Machine – Some Still Unsolved Questions

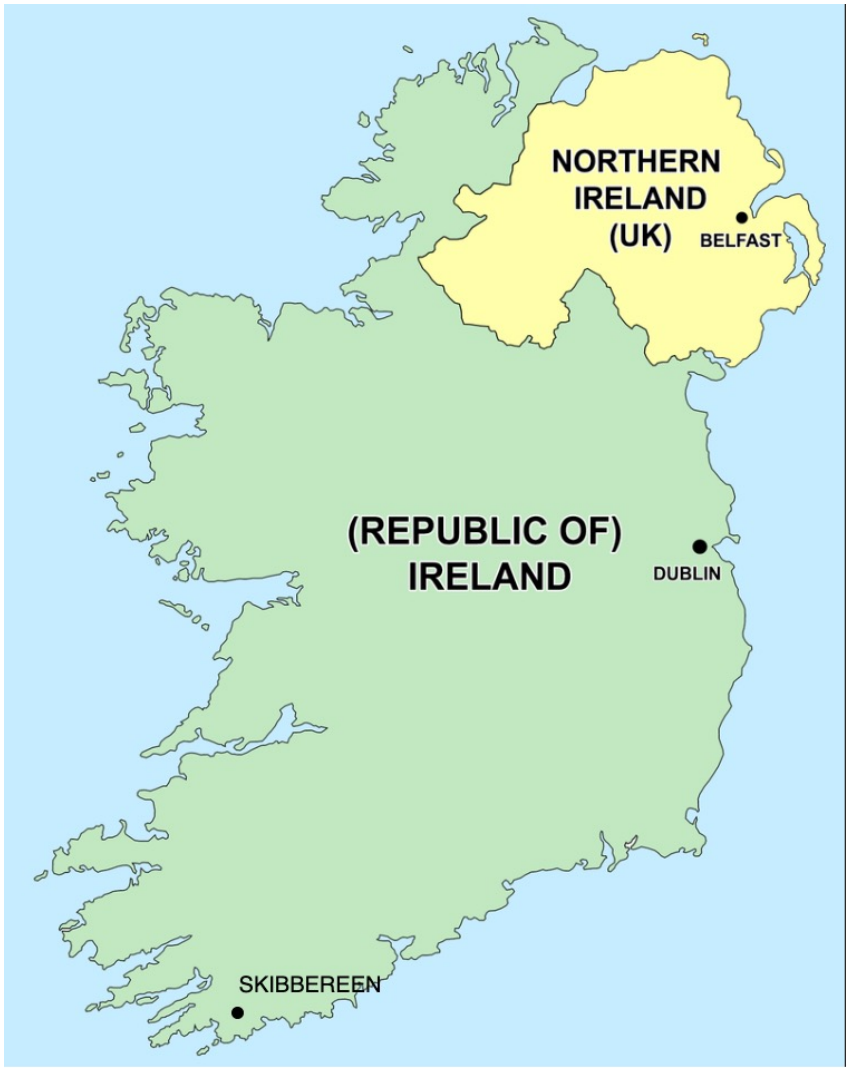
- How storage cylinders were rotated.
- How a shuttle was moved.
- How the Mill mechanism worked.
- Most of the internal timing.
- Almost everything about program control.
- Almost everything about input and output.

And of course, despite extensive searching, all the other drawings remain to be found!

Percy Ludgate's Ancestry and Early Life

- His ancestry has now been traced back to the mid-18th century, and some fifty relatives identified. No obvious motivations or influences have been discovered – his father was a Sergeant Musketry Instructor in the Militia. However, there remains hope of finding some descendants of the later generations, and hence the possibility of more information about Percy.
- We have established a number of further facts about his early life, e.g.
  - He attended St George's National School. At age 15 he was appointed a 'Boy Copyist' in the Irish Civil Service, a temporary post for boys aged 15-20 years old
  - In March 1903 Percy was the top Irish candidate in the Civil Service examinations for Assistant Clerkship. Six other Dublin candidates below him were appointed, but for some unknown reason he was not.
  - In October 1904 Percy Ludgate passed the Civil Service exams for Second-Division Clerkships in the Civil Service but failed the medical examination. His case was raised in the House of Commons, by Timothy Harrington MP, to no avail.
  - By 1911 he was a "commercial clerk" to a corn merchant.
  - He passed his Intermediate Accountancy Examinations in 1916, and his Finals (with Honours) in 1917.

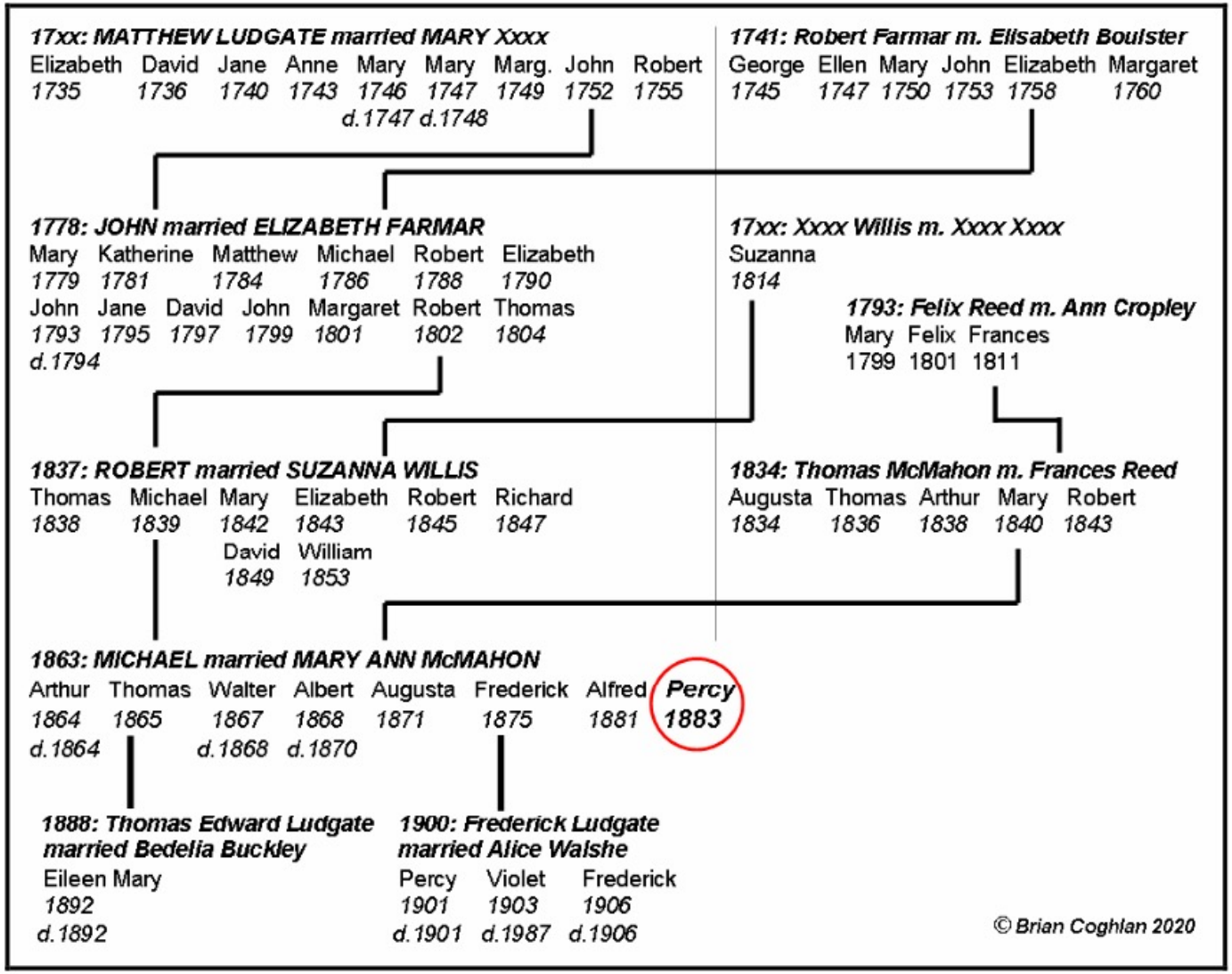
Skibbereen – Ludgate's Birthplace



Skibbereen High Street

Inside Skibbereen's Ludgate Digital Hub

Ludgate's Ancestry



Ludgate's Dublin Home from 1899 to 1922

30 Dargle Road, Drumcondra, Percy Ludgate's second home in Dublin.

Courtesy Michael Mongan

31 Dame St, Dublin

After some years as a commercial clerk to a corn merchant, Percy Ludgate worked (until his death in 1922, aged 39) as an accountant for Kevans & Son in the building with the yellow flag.

Courtesy Brian Coghlan

Finally, Our Other Surprising Discovery

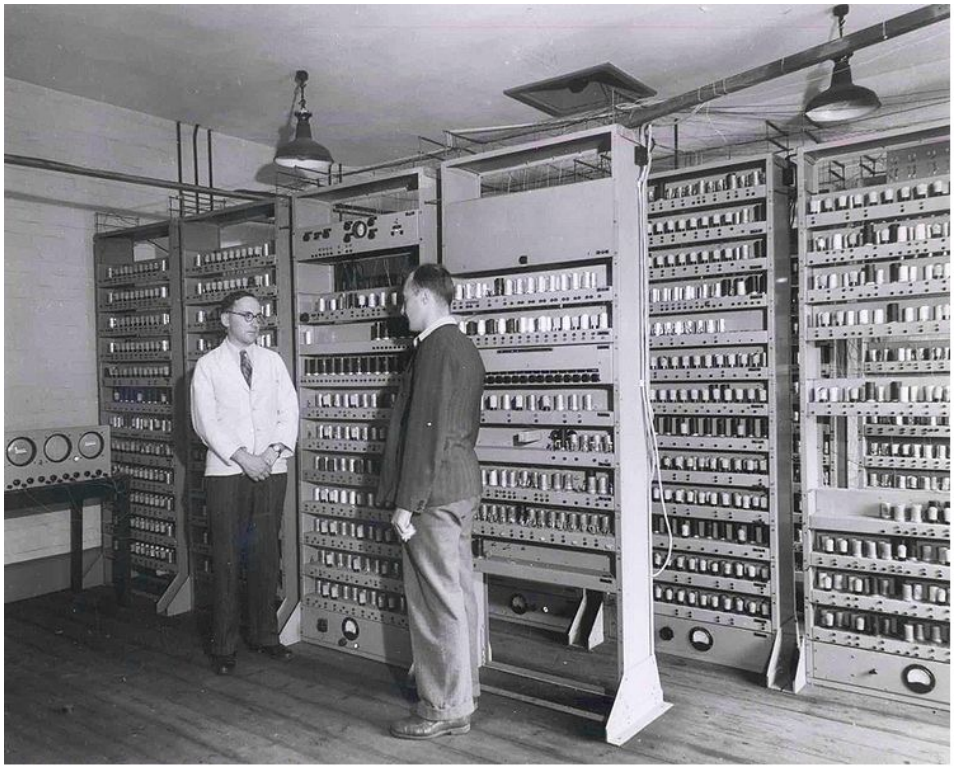
- Violet Ludgate – my only source of family information in 1970 about Percy Ludgate – had died, never having married, in 1987.
- By 1954 Percy Ludgate's parents and siblings had died, and until late 2018 it was thought that by 1987 there were no other descendants of his parents.
- The Ludgate grave lay unmarked in 2018; it could only be marked with permission from the owner, who was dead, or by close descendants, but there were none known.
- But then we discovered that someone else had been looking for information about Violet, in fact one of her descendants!
- Violet we learned had given birth to a daughter Barbara in 1935, who was adopted and renamed Anita, and brought up overseas. Anita had married and moved to America, and had numerous descendants there.
- One of Anita's daughters joined our project and contributed greatly!
- And Violet's grandchildren managed to obtain the necessary permissions and to arrange that the Ludgate grave have a suitable headstone at last!!

Thanks to Violet's Descendants

A Very Pleasing and Surprising "Result" of Our Investigation!

Courtesy Brian Coghlan

So it was to be another forty years . . .



. . . after Ludgate's paper before the world's first practical electronic programmable (i.e. general purpose) computers became operational – led by the EDSAC at Cambridge, in May 1949.

There are no known links back from these computers to the prior work of Ludgate, or that of the few further pioneers known to have subsequently designed (mechanical or electro-mechanical) computers, e.g. Torres Quevedo, Stibitz, and Zuse.

Our Annals Paper

IEEE Annals of the History of Computing, January-March 2021

Newcastle University

Acknowledgements

To my colleagues, who under Brian Coghlan's leadership, have conducted a far more intensive search for evidence than I managed during my original investigation.

To all the numerous individuals and organisations who have helped our very extensive search for further information about Ludgate and his work.

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To Dig Deeper:

https://www.scss.tcd.ie/SCSSTreasuresCatalog/ludgate/