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Brian Coghlan, Brian Randell, Ralf Buelow

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***Index Terms* — Percy Ludgate, Konrad Zuse, Z3 Patent, IBM, Couffignal**

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Authors

Brian Coghlan is a retired Senior Lecturer with the School of Computer Science and Statistics, Trinity College Dublin, The University of Dublin, Ireland. He is curator of The John Gabriel Byrne Computer Science Collection. Contact him at <coghlan@tcd.ie>.

Brian Randell is an Emeritus Professor of Computing Science, and Senior Research Investigator, in the School of Computing, Newcastle University, U.K. His book *The Origins of Digital Computers: Selected Papers* was first published in 1973, by Springer Verlag. Contact him at <Brian.Randell@ncl.ac.uk>.

Ralf Buelow is a former museum curator and a free-lance historian of technology and science journalist. He is based in Berlin and works for the Heinz Nixdorf MuseumsForum, Paderborn, Germany. Contact him <at ralf.buelow@t-online.de>.

How Percy Ludgate's 1909 paper (and IBM) helped thwart Konrad Zuse's Computer Patent in 1960

Brian Coghlan, Trinity College, D02 X9W9, Dublin, Ireland, Brian Randell, Newcastle University, NE4 5TG, Newcastle upon Tyne, U.K., Ralf Buelow, Heinz Nixdorf MuseumsForum, 33102, Paderborn, Germany

Abstract:
This investigation discusses how Percy Ludgate's paper from 1909, which details his design for a mechanical computer called the "Analytical Machine", was utilized by a German patent attorney in 1960 to prevent the approval of Konrad Zuse's computer patent, just in time, as the patent (first applied for on 16th June 1941) was about to be granted. This narrative is then followed by analyses of, and discovery of proof of, the role of IBM in preventing Zuse from getting what would have been the premier patent on the concept of a programmable computer, and then by an exploration of how information about Ludgate's 1909 paper was found by (or for) the opposing German patent attorney.

There were only two mechanical designs published for a programmable computer well before the electronic computer era, Charles Babbage's "Analytical Engine", details of which were published by Ada Lovelace in 1843 [3], [33], and Percy Ludgate's "Analytical Machine", published by Ludgate in 1909 [15], [16], [34], [35], [55]. Subsequently, from c.1914 Leonardo Torres y Quevedo and his successors began electromechanical designs and from c.1937 electronic designs began [43], then from c.1949 fully electronic modern computers and their billions of successors started to emerge. A third mechanical design dates from the dawn of the electronic computer era in 1936, namely Konrad Zuse's "V1", later renamed "Z1" [61] – his subsequent designs, and particularly the Z3 (1941), which features large in this account, were electromechanical.

Until recently it appeared that Babbage and Ludgate had no influence on modern computers, since as far as was generally known there was no record in the literature concerning modern electronic computers that specifically stated inheritance from either of their machines. Hence Babbage and Ludgate's importance has been seen as primarily historical. However, in 2022 one of the authors, Ralf Buelow of the Heinz Nixdorf MuseumsForum, outlined in [12] [1] how Percy Ludgate's 1909 paper design for a mechanical computer was used in 1960 by a German patent attorney to thwart Konrad Zuse's computer patent just as it was about to be granted, and how Zuse thereafter alleged that the attorney had been helped by IBM.

The present paper describes a detailed investigation we have made of these matters. For technical details of the design of the Z3 machine, and of the claims in Zuse's patent application, we refer the reader to the excellent accounts by Raúl Rojas [46], [47], [48]. Our paper thus is largely based on translations of the relevant sections of the principal documentary evidence we have found relating to this patent dispute, including that related to IBM's involvement in the successful effort to prevent Zuse obtaining what might have become the primary patent of the concept of a programmable computer. We may now say that Ludgate, whose work hitherto had seemed merely of historical interest, in fact may well have had some influence on the way in which the international computer industry developed, even though his work was unknown to the designers of the first electronic computers.

Zuse's patent litigation

All of the Zuse patent litigation documentation, and to date almost all of the literature about it, is in the German language. The microfilm images of the litigation documents are published online by the Konrad Zuse Internet Archive [30], [31] and scanned images by the Deutsches Museum [21]. The most extensive literature about the litigation is the excellent German-language account given by Hartmut Petzold's chapter "Die Mühlen des Patentamts" ("The Mills of the Patent Office") [41] [2] in Rojas' very illuminating book "*Die Rechenmaschinen von Konrad Zuse*" [45]. For ease of comparison by future scholars, for the principal original German-language litigation documents mentioned in this paper we have prepared a set of online supporting documents in which the original German texts are shown side-by-side (for 2-page view) with very careful translations to English [56]; these translations are the source of the great majority of the quotations in the present text.

Konrad Zuse applied for many patents on his computing inventions[3]. It must be stressed that this Section concentrates entirely on Zuse's efforts in relation to just one of these applications, his attempt to obtain a patent for

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[1] English translation (2023) of [12] available at [56].
[2] English translation (2023) of [41] available at [56].
[3] Coghlan, B., Buelow, R., Randell, B., "Konrad Zuse's Computer Patents", available at [56].

the concept of a programmable digital computer based on his Z3 computer [60]. It expands on Petzold's account, specifically enlarging on those elements that relate to Percy Ludgate's 1909 paper on his Analytical Machine. Zuse himself, in his autobiography, gave this account of his patenting efforts:

> *'I had filed a few patent applications before and during the war, such as the one in 1936 for mechanical switching techniques with a mechanical store - for which I was later given a patent, albeit only after these designs were no longer of any value. I filed my first patents for the program control and arithmetic units in 1937. They were rejected due to insufficient disclosure. During a simultaneous filing in the United States, Babbage was cited against me - as already mentioned. In mid-1941, when Z3 had taken concrete form, I filed a patent for it. The patent was later recorded under file number Z391, and it was probably my most important patent. Only in late 1952 was it made public with fifty-one claims. The examiners had - eleven years after filing - no problems whatsoever with the patent eligibility. None of the computer manufacturers who are important today filed petitions against the patent, only Triumph, which however was later backed by IBM. With admirable attention to detail, a whole host of objections were collected - clearly a great contribution to the history of computing. Yet the innovation and progressiveness of my invention still could not be doubted. Only in mid-1967, that is, twenty-six years after filing the patent, was a final decision made by the German Patent Office. It said in effect that a patent-worthy invention did not exist: "The innovation and progressiveness of the object concerned in the main application are not doubted. Yet a patent cannot be granted due to insufficient inventive merit." Not only I, but also the Telefunken Company was deeply disappointed. I had a patent contract with them, and their patent department had worked on my case. I was also pained to learn that the deciding appellate court had not allowed the appeal to reach the Bundesgerichtshof, Germany's Federal Court.'*
> *[61, pp.109-110]* [4]

Zuse first registered the principle of the Z3 under the title "*Calculating device*" with the Reich Patent Office on 16th June 1941, when it was given the file number Z26476 IXb/42m. Only one drawing of the Z3 survived the Second World War, the machine itself being destroyed in a bombing raid. Zuse escaped from Berlin, bringing his only surviving machine, his Z4, with him to Bavaria. Probably due to World War II, the application was not processed to a conclusion. After World War II the German Patent Office was reorganised, and hence from November 1951 Konrad Zuse revived his attempt to obtain this patent, which was renumbered Z391, but to Zuse's very evident frustration this application then followed a difficult and tortuous trajectory, as is briefly outlined below.

The Triumph-Werke company in Nuremberg opposed this patent throughout. They produced motorcycles, typewriters and accounting machines [18], [38]. The patent attorneys working for Triumph-Werke collected older patents that Zuse's claims conflicted with, so causing rejection of these claims[5]. Zuse then amended his patent application and resubmitted it in 1958, having reformulated the claims as follows:

> *'In contrast, the invention is characterised by the combination of the following features, some of which are known per se, as mentioned above:*
> *I. At least one memory unit for storing the numbers in specific memory cells,*
> *II. at least one arithmetic unit,*
> *III. a planning unit for controlling operational sequences in accordance with a predetermined program, which cooperates with a device suitable for the output of character combinations in such a way that the program, developed in accordance with operational and transmission processes, runs successively as an ordered sequence of individual commands encoded in the form of numbers or the like.*
> *IV. and at least one selecting unit for decoding the set instructions and initiating the associated arithmetic operations and transmissions by connecting the called memory cells to setting or result elements of the arithmetic unit, such a selecting unit containing more active elements on the output side than there are setting elements on the input side.'*

---

4 The German edition of Zuse's biography refers on page 98 line 10 to "*Bundespatentgericht*". In the English edition [61], on page 109 lines 26-27, this is translated in error to "*German Patent Office*" as above, whereas it should be "*Federal Patent Court*".

5 [56, letter of 29th November 1957, pp.422-423].

[56, letter of 8th May 1958, p.430]

Note that item IV above specified encoded instructions, highlighted in the description as a point of demarcation from Babbage, which for Zuse became a focus of the subsequent litigation, as will become evident below.

In 1959, the examiners of the Munich-based Patent Office voted to approve Konrad Zuse's application, despite the objections that had been made to it, and wrote to Zuse's patent attorney stating:

> *'The patent specifications cited by the opponent thus relate to individual parts of the calculating machine which is the subject-matter of the present application, none of these patent specifications describe a machine which contains all of these parts in such a combination as is indicated by the new main claim filed on 13 May 1958. Furthermore, in none of the machines and devices described in the above-mentioned patent specifications are the commands given in the form of numbers, so that there is also no command encoding or command decoding and no selection mechanism for the alternate connection of individual machine parts to each other.'*
> *[56, letter of 30th July 1959, p.219]*

The Patent Office declared that they could not find in the works of Babbage, Louis Couffignal[6], Torres y Quevedo or George Stibitz any program-controlled calculating machine whose construction and mode of operation corresponded to Zuse's claims, and therefore they intended to grant the patent (although as can be seen below, later the Patent Office changed its judgement regarding the French computer pioneer Couffignal's work):

> *'Through the work of Ch. and H.P.Babbage, the idea of the program control of calculating machines by means of punched cards, such as those used for the control of looms, has become known in principle, and special circuits and devices have also been developed by L. Couffignal for the automatic solution of certain arithmetic operations, but precise information on the constructive solution of this problem, as it is to be solved by the program-controlled calculating machine forming the subject of the present application, is not contained in any of the literature. Also, in the solution derived from the work of Torres y Quevedo (Bulletin de la société d'encouragement pour l'industrie nationale) as well as that from the report by G.R.Stibitz on the Bell Complex Number Computer (Bull.American.Mathem.Soc.) there is no program-controlled calculating machine to be found whose construction and mode of operation are identical with the machines forming the subject-matter of the present application.*
>
> *The patent specifications and literature cited therefore do not prevent the present application from being patented. […]*
>
> *It is therefore intended to grant the requested patent on the basis of the documents submitted'*
> *[56, letter of 30th July 1959, pp.220-221]*

The importance of this letter cannot be overstated, and in January 1960 Konrad Zuse's computer patent was about to be granted. However, on the 12th of January 1960, the Patent Office received a new objection by the company Triumph-Werke, sent the day before, that constituted somewhat of a bombshell. The trajectory of the patent litigation then sharply reversed. Triumph-Werke had engaged a new patent attorney, Dr.Gerhard B. Hagen who in the first mention of Ludgate thus far referred to his 1909 paper, giving a precise reference and a ten page explanation of it, in a letter (Fig.1) to the Patent Office starting:

> *'<u>In reply to the decision of 30.7./11.9.1959.</u>*
> *The applicant filed new patent claims 1 - 5 by petition of 12.5.1958, which the examining office initially considered to be allowable. In this opinion, however, these claims are not patentable, since claim 1 is identically anticipated and claims 2-5 are not inventive, both deficiencies being based on the literature of P.E. Ludgate "On a proposed analytical machine", published in the journal "Scientific Proceedings Royal Dublin Society", 1909, Volume XII, Issue IX, Pages 77-91 which had not yet been taken into account in the previous examination procedure.'*
> *[56, letter of 11th January 1960, p.206]*

[6] Louis Pierre Couffignal proposed an electromechanical computer in 1938 [43], and later headed the digital computing laboratory of the Institut Blaise-Pascal. He visited Aiken and von Neumann in 1946, and on 20 May 1947 visited Zuse in Bavaria [7].

Hagen also mentioned Charles Babbage [3], [33], Couffignal [19] and Claude Shannon [49]:

> *'The most significant objection in the examination procedure so far was the description of the computing system by Ch. Babbage […] Ludgate's publication shows that although he was not familiar with Babbage's calculating machine when he planned his device, he used the same basic principle […] Such an arithmetic unit was the subject of an earlier application, the applicant's Application Z 23 624 IX/42m and is in itself an arithmetic unit similar to the structure of the French patent of Couffignal 819 695 […] Couffignal's arithmetic unit, which works in binary form, is not only capable of multiplication and division, but also of extracting roots […] This arithmetic unit plays the role of the mechanism, which is called "mill" by Babbage and also by Ludgate […] Both Babbage and Ludgate used storage mechanisms as an essential part of their calculating machines […] Likewise, in Babbage's and Ludgate's machines, the arithmetic unit and the memory unit were interconnected by a program unit […] The use of selection pyramids is shown in the aforementioned French patent specification of Couffignal […] they are also dealt with in the paper of Shannon'.*
> *[56, letter of 11th January 1960, pp.208, 209, 211, 212, 214]*

But Hagen principally focussed on Ludgate's paper, ending after ten pages of closely worded objections with:

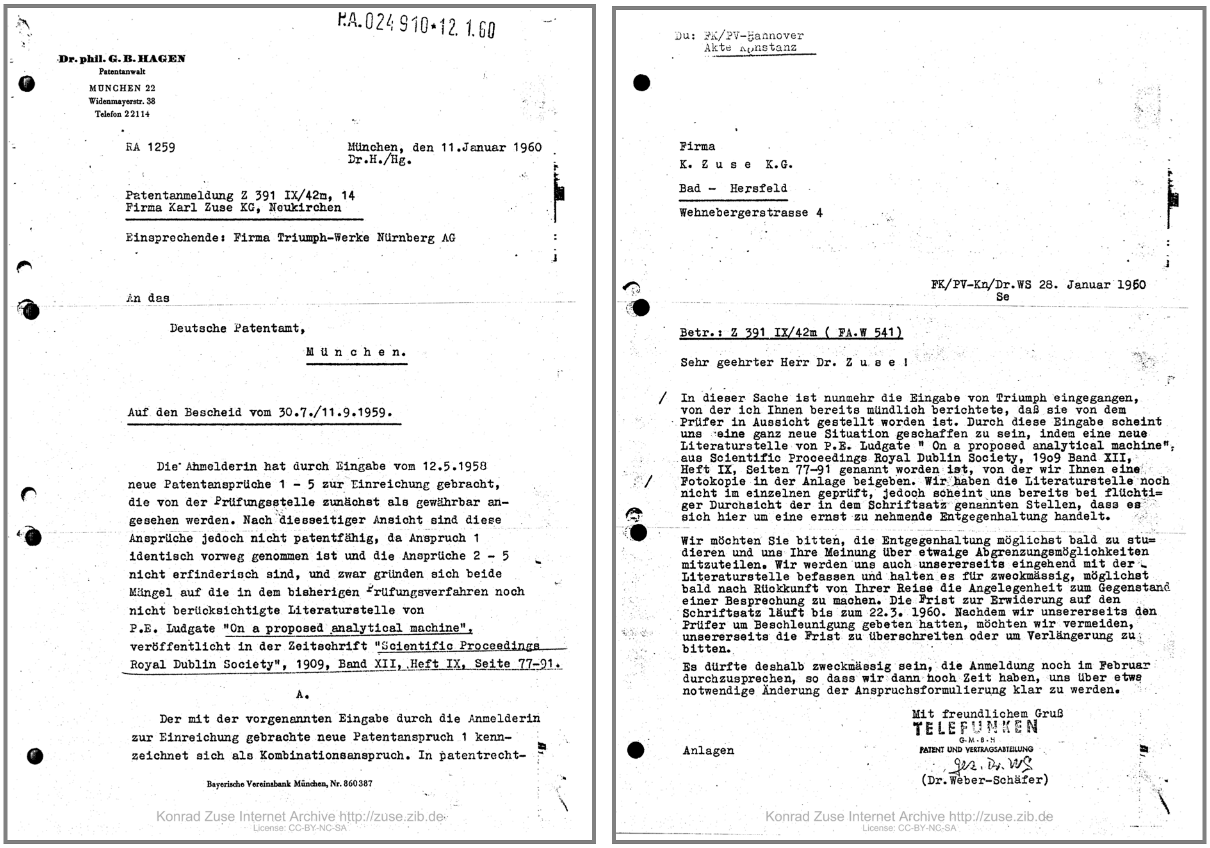
> *'According to this view, the new claim 2 is also completely anticipated by the Ludgate publication.*
>
> *Claim 3 emphasises the use of binary code for the layout; here, too, no protectable disclosure can be seen, since coded punched tape control is based precisely on the derivation of the control processes from yes-no circuits.*
>
> *Claim 4 says no more than what is shown in Swiss patent specification 181 926 with respect to the punched tape control, applied to a telegraph system. There, too, selection of circuits and selection of letters and numerical values take place.*
>
> *The new claim 5 refers to the use of selection pyramids. The use of selection pyramids is shown in the aforementioned French patent specification of Couffignal […] they are also dealt with in the paper of Shannon, published in the journal "Transaction of American Institute of Electrical Engineers", 1938, page 713, volume 57.*
>
> *With respect to the other claims still maintained, […] since the subclaims cannot form a further development of the idea characterized in the current claim 1, they cannot serve as a basis for a possible restriction of claim 1, which is not to be regarded as eligible for protection.*
>
> *For these reasons, in our view, the application should be rejected in its entirety.'*
> *[56, letter of 11th January 1960, pp.213-215]*

Whether Zuse knew of their work was unimportant; the decisive factor was that someone had had the ideas before him. Telefunken's patent attorney Dr.-Ing. Max Weber-Schäfer, acting for Zuse,[7] sent him a worried letter (Fig.1) on the 28th of January 1960, stating that he believed that "*a whole new situation has been created*", as it was "*an objection to be taken seriously*":

> *'Betr.: Z 391 IX/42m (FA.W. 541)*
> *Dear Dr. Z u s e !*
> *In this matter, the petition from Triumph has now been received, which I have already reported to you orally that the examiner had promised. Through this input it seems to us that a whole new situation has been created, because of a new reference to P.E. Ludgate "On a proposed analytical machine", from Scientific Proceedings Royal Dublin Society, 1909, Volume XII, Issue IX, pages 77-91, of which we enclose a photocopy for you. We have not yet examined the reference in detail, but after a cursory glance at the sources named in the brief, it seems to us that this is an objection to be taken seriously.*

7 Telefunken supported Zuse's attempt to patent the principles of his Z3 computer.

We would like to ask you to study the objection as soon as possible and let us know what you think about the possibilities of limitation. For our part, we will also take a close look at the literature and consider it expedient for us to discuss the matter as soon as possible after your return from your trip. The deadline for replying to the pleading is 22.3.1960. On our part, having asked the examiner to speed things up, we would like to avoid exceeding the deadline or asking for an extension.'
[56, letter of 28th January 1960, p.439]



RA.024910•12.1.60

Dr. phil. G. B. HAGEN
Patentanwalt
MÜNCHEN 22
Widenmayerstr. 38
Telefon 22114

RA 1259

München, den 11.Januar 1960
Dr.H./Hg.

Patentanmeldung Z 391 IX/42m, 14
Firma Karl Zuse KG, Neukirchen

Einsprechende: Firma Triumph-Werke Nürnberg AG

An das

Deutsche Patentamt,

München.

Auf den Bescheid vom 30.7./11.9.1959.

Die Ahmelderin hat durch Eingabe vom 12.5.1958 neue Patentansprüche 1 - 5 zur Einreichung gebracht, die von der Prüfungsstelle zunächst als gewährbar angesehen werden. Nach diesseitiger Ansicht sind diese Ansprüche jedoch nicht patentfähig, da Anspruch 1 identisch vorweg genommen ist und die Ansprüche 2 - 5 nicht erfinderisch sind, und zwar gründen sich beide Mängel auf die in dem bisherigen Prüfungsverfahren noch nicht berücksichtigte Literaturstelle von P.E. Ludgate "On a proposed analytical machine", veröffentlicht in der Zeitschrift "Scientific Proceedings Royal Dublin Society", 1909, Band XII, Heft IX, Seite 77-91.

A.

Der mit der vorgenannten Eingabe durch die Anmelderin zur Einreichung gebrachte neue Patentanspruch 1 kennzeichnet sich als Kombinationsanspruch. In patentrecht-

Bayerische Vereinsbank München, Nr. 860387

Du: FK/PV-Hannover
Akte Konstanz

Firma
K. Z u s e K.G.
Bad - Hersfeld
Wehnebergerstrasse 4

FK/PV-Kn/Dr.WS 28. Januar 1960
Se

Betr.: Z 391 IX/42m (FA.W 541)

Sehr geehrter Herr Dr. Z u s e !

In dieser Sache ist nunmehr die Eingabe von Triumph eingegangen, von der ich Ihnen bereits mündlich berichtete, daß sie von dem Prüfer in Aussicht gestellt worden ist. Durch diese Eingabe scheint uns eine ganz neue Situation geschaffen zu sein, indem eine neue Literaturstelle von P.E. Ludgate " On a proposed analytical machine", aus Scientific Proceedings Royal Dublin Society, 19o9 Band XII, Heft IX, Seiten 77-91 genannt worden ist, von der wir Ihnen eine Fotokopie in der Anlage beigeben. Wir haben die Literaturstelle noch nicht im einzelnen geprüft, jedoch scheint uns bereits bei flüchtiger Durchsicht der in dem Schriftsatz genannten Stellen, dass es sich hier um eine ernst zu nehmende Entgegenhaltung handelt.

Wir möchten Sie bitten, die Entgegenhaltung möglichst bald zu studieren und uns Ihre Meinung über etwaige Abgrenzungsmöglichkeiten mitzuteilen. Wir werden uns auch unsererseits eingehend mit der Literaturstelle befassen und halten es für zweckmässig, möglichst bald nach Rückkunft von Ihrer Reise die Angelegenheit zum Gegenstand einer Besprechung zu machen. Die Frist zur Erwiderung auf den Schriftsatz läuft bis zum 22.3. 1960. Nachdem wir unsererseits den Prüfer um Beschleunigung gebeten hatten, möchten wir vermeiden, unsererseits die Frist zu überschreiten oder um Verlängerung zu bitten.

Es dürfte deshalb zweckmässig sein, die Anmeldung noch im Februar durchzusprechen, so dass wir dann noch Zeit haben, uns über etwa notwendige Änderung der Anspruchsformulierung klar zu werden.

Mit freundlichem Gruß
TELEFUNKEN
G.M.B.H
PATENT UND VERTRAGSABTEILUNG
gez. Dr. WS
(Dr. Weber-Schäfer)

Anlagen

Figure 1: left: Page 1 of Hagen's letter to the Munich Patent Office of 11th January 1960 citing Ludgate.
right: Weber-Schäfer's letter to Zuse of 28th January 1960, referring to Hagen's letter of 11th January 1960.
Courtesy of the Konrad Zuse Internet Archive [30]

Because Weber-Schäfer had attached a copy of Ludgate's paper, Zuse was able to study it and draft a rebuttal, (Fig.2). Zuse concentrated on the perforated paper which carried the program of Ludgate's machine. Zuse saw no counterpart to this in his patent application. He categorically ruled out a "Vercodungssystem" (coding system) as being prior art by Ludgate, writing:

'It corresponds to a wrong interpretation of the writing of LUDGATE and is the product of the imagination of the opposing party.'
[56, letter of 2nd March 1960, p.442]

Zuse may have made an error, as Ludgate's 1909 paper does not specify the format of instructions, only stating:

'Each row of perforations across the formula-paper directs the machine in some definite step in the process of calculation—such as, for instance, a complete multiplication, including the selection of the numbers to be multiplied together.'
[35, p.80], 28th April 1909

On 29th March 1960, Weber-Schäfer drafted a new patent application[8] aimed at countering Hagen's now-revised objections, and in hindsight this might be considered the beginning of the end.

In 1961, Hagen filed a further objection against Zuse's now-revised patent application, based on Louis Couffignal's 1938 doctoral thesis [19]. Triumph-Werke's objections were successful. In a preliminary letter from the Patent Office to Telefunken patent attorney Dr.-Ing. Benno Johannesson (acting for Zuse) on 15th November 1961 and a confirmation on 20th September 1962, the Munich Patent Office issued a final refusal to patent Zuse's concept.

> *'Thus, claim 1 cannot be granted either in the version of 28 April 1960, or in an amended version which is limited to a device for transferring numbers from the arithmetic unit to the memory and vice versa.*
>
> *In this situation, the requested patent is likely to be refused.'*
> *[56, letter of 15th November 1961, p.169]*
>
> *'After proper publication and examination of the objection, the request for this patent to be granted*
> *"Program-controlled calculating machine"*
> *failed.'*
> *[56, letter of 20th September 1962, p.152]*

In reaction, in 1962 Konrad Zuse took the case one step further by having his attorney appeal to the then newly established Federal Patent Court, which was also based in Munich, this time more specifically:

> *'This construction principle, […], is based on the idea underlying the invention of using an instruction code encoded in yes-no value combinations in program-controlled calculating machines.*
>
> *In none of the previous publications relating to program-controlled calculating machines - these are the works of Babbage, Ludgate and Couffignal - is this idea explicitly stated.'*
> *[56, letter of 19th December 1962, p.140]*

Subsequently Zuse eventually reformulated the patent specification, stating in its introduction:

> *'However, nothing more can be learned from this proposal about the technical means for program control than from the older works of Babbage and Ludgate.'*
> *[56, letter of 22nd June 1964, p.98]*

The Federal Patent Court, after considering Zuse's complaint, rejected his appeal on the 14th August 1967. Their judgement stated:

> *'The general concept of claim 1 corresponds to the literature cited on program-controlled calculating machines by Couffignal (Dissertation 1938), Babbage and Ludgate in the objection.*
> *[…]*
> *The appeal is admissible, but could not succeed.*
>
> 1. *In the preamble of the patent claims, the application refers to program-controlled calculating machines with a memory, an arithmetic unit and a program unit which executes the operation and transport commands on a program carrier. According to the second paragraph of the new introduction to the description of 22 June 1964, it is based on the task of developing measures for the construction of such machines, which have only been described so far, but not implemented.*
> 2. *A task which is itself inventive is obviously not present. […] Consistent with this, the applicant, in defending the subject-matter of the application, did not rely on the status of the task, but on the means identified in the claim, with which it intends to solve the task.*
> 3. *According to claim 1 of the main application, in accordance with the applicant's submissions, general protection is sought for the concept of the programmable feature of the machine described in the preamble, consisting of controllable switch groups which contain more output*

8 [56, letter of 29th March 1960, pp.443-449].

control lines than input control lines, i.e. that is constructed according to a so-called Christmas-tree circuit (e.g. German patent specification 554 888).

[…]

The novelty and progressiveness of the subject-matter claimed in the main application cannot be doubted. However, for lack of inventive value, no patent can be granted.'

[56, letter of 14th August 1967, p.5, pp.7-9]

With this acceptance of the relevance of the prior work by Couffignal, Babbage and Ludgate, and the expressive phrase, "*for lack of inventive value, no patent can be granted*" the Patent Court ended the Zuse patent proceedings, in which Zuse's computer patent application was refused twice, in 1962 by the Patent Office and in 1967 by the Patent Court, and in which Percy Ludgate's 1909 paper played a crucial role at the most critical time, just as the patent was about to be granted in January 1960.

Zuse subsequently wrote some pithy comments on German patent law:

'It must be considered a failure of our patent law that a patent application can take so long that the general application of the inventive idea, at the time quite amazing, has since become quite usual. […] In the early days of computer development, on the other hand, there was great confusion about patent protection for computers and all that went with them. I can indeed count myself – without wishing to be melodramatic about it – among the victims of this confusion.'

[61, pp.111-112]

One can but speculate as to what would have been the consequences, on Zuse's career, and indeed the global computer industry, should the German Patent Court have ruled in Zuse's favour and granted his patent. The concluding paragraph of Hartmut Petzold's "The Mills of the Patent Office" simply states:

'It is hardly possible to answer the question of what the granting of the patent in 1967 would have meant. At that time, not only the opposing party had recognised the "outstanding achievement of being the first to realise a programmatic calculating machine in practice"; in the end, however, it was solely a matter of the legally recognized "inventive strength". The financial consequences depended on its recognition. The assumption that the entire international computer industry had to pay Zuse license fees does not seem very realistic. It must also remain open whether the granting of the patent would have given Zuse KG relief in its difficult financial situation and prolonged its period of independence. In 1994, Zuse characterised the rejected patent succinctly: "All computers would have been covered under this fallen patent." He said nothing about the consequences expected at the time from a granting of the patent.'

[41, p.107][9]

Zuse might be considered quite unlucky to have started so early in 1936 yet failed 31 years later in 1967. On the other side of the coin, Ludgate and Couffignal (and, as detailed below, IBM) may also now be considered a European counterpart to the American Atanasoff and Honeywell in their (in hindsight worthy) roles in thwarting or invalidating fundamental European and American patents which might have led to the costs of computers being significantly inflated.[10]

Zuse and IBM

Representatives of IBM's subsidiary in Germany, Dehomag,[11] first approached Zuse when he lived in the late 1940s in Bavaria, visiting him in 1947 [37, p.37]. In a passage from his autobiography [61] he explains:

'In Hinterstein I had given [Helmut O. Goeze] a demonstration of the Z4, and it made a powerful impression on him. […] He succeeded in attracting the attention of the then President of IBM, Thomas Watson, in me and my Z4. Watson then passed on the instructions to Hollerith Germany.

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9 English translation (2023) of [41] available at [56].

10 Sperry Rand have been reported as asking for royalties of $250 million from Honeywell at first, reducing to $20 million before litigation began, and a total of $150 million from other computer manufacturers [50], [57]. Other reports state 1.5% royalties [32].

11 In April 1949 IBM's German subsidiary, *Dehomag*, an abbreviation of *Deutsche Hollerith-Maschinen GmbH* (i.e. *German Hollerith Machines LLC*), changed its name to *IBM Deutschland*.

[…] Two of Hollerith's managers, Hummel and Scharr, headed off in one of the few company cars. […] Negotiations continued, and finally an options contract for the acquisition of my patents was concluded. […] Much to our chagrin, IBM was interested solely in my patent rights. In the eyes of the Americans, that we wished to continue work on the Z4, even wanted to undertake new developments, were "perfectly foolish conditions." […] Clearly I could have made a good deal on my patent rights; and then IBM would have been on my side in subsequent disputes. […] In the face of such incalculability, I finally decided to continue to build up my company. […] I probably had no other choice. IBM would not even guarantee that I would be able to continue to work in the computer field.'
[61, pp.114-115]

Zuse withdrew from these negotiations, choosing instead to develop his company. Then in about 1949 [37, p.39] he contracted with Remington Rand[12] to build a punched-card machine, the M9 (Mithra-9).[13]

Konrad Zuse believed for the rest of his life that Triumph-Werke had received help from IBM [61, p.109 and pp.114-115], something that is clearly stated in this excerpt from Uta Merzbach's interview of Zuse in 1968:

'UM: Who represented the opposition. Who was their lawyer?
KZ: That was, I believe, Hagen. Hagen was his name.
UM: Who did he represent?
KZ: Yes, officially Triumph Corporation, but unofficially, IBM. He was with IBM.'
[37, p.31]

After the above rejection of IBM's overtures in 1947, IBM would not have wanted Zuse's patent, or probably any computer patent that might place IBM at a competitive disadvantage, to be granted[14]. In 1953-54 IBM considered contesting the ENIAC patent by claiming Atanasoff and Berry's ABC technology as prior art [50]. But in 1956 Sperry Rand, who by then owned the ENIAC patent rights, cross-licensed patents with IBM[15]. In 1959 IBM began research and development on their 360 series, introduced in 1964, the same year that ENIAC's American patent [24] was granted. The conundrum for IBM would have been how to stop Zuse's patent using evidence of prior work (e.g. Ludgate 1909) without that evidence compromising the viability of the ENIAC patent.

During this period Hagen's correspondence with the Patent Office over this patent application gave no indication of any involvement of IBM. However, Hagen was in fact acting for IBM Deutschland at this time in other patent matters. For example, even during the critical period 1959-1960, Hagen simultaneously acted for an IBM patent application filed (given as for IBM New York) on 16th December 1959 [27] and another filed on 14th September 1960 [28].

It is evident that IBM took patenting very seriously, being very active in patenting from 1932 onwards under the direction of James Bryce[16] (who later knew of Babbage's work [1]), as described by IBM's own history webpages:

'*By hiring engineering consultant [James Wares] Bryce in 1917, Watson showed that he recognized the importance of pure inventing. Rather than developing products, Bryce's job was*

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12 The c.1949 contract was for Zuse to provide "calculating punches" to Remington Rand, Norwalk, Connecticut [61, p.115]. There is a curiously triangular involvement of Zuse & IBM, Zuse & Remington (later Sperry Rand), and IBM & Sperry Rand.

13 In the biography of Dudley Buck (MIT Whirlwind team member, inventor of the Cryotron and of content-addressable memory) [22, p.58] it is suggested the c.1949 contract with Remington Rand was part of "Operation Paperclip" c.1949-54, and was aimed at attracting Zuse to America [11], [37, p.50], [39], [61, p.116], and so illustrating their high regard for him.

14 For example, Hasler AG (now Ascom) planned to market ERMETH (an electronic replacement for the Z4) worldwide [10] under a 1954 license from ETH (Eidgenössische Technische Hochschule, Zürich), potentially with a sub-license from Zuse. At the end of 1955, before ERMETH's completion, its principal designer Ambros Speiser [51], one of the two postgraduates who ran the Z4 rented by Professor Eduard Stiefel from Zuse [9], left ETH to establish and lead IBM's Zürich Laboratory in nearby Rüschlikon, so thwarting Hasler AG's plans, leading to discord and total loss of interest in ERMETH [8].

15 The cross-licensing agreement between Sperry Rand and IBM was signed on 21 August 1956 [57]. IBM has been reported as paying royalties of $10M [32], $1M/year [40], or $1M/year over 8 years [52], with $200k of $10M relating to ENIAC [44].

16 Bryce's US patent specification 2 141 598 was cited in a letter by Hagen [56, letter of 2nd December 1965, p.64] and in a dismissive response by Weber-Schäfer [56, letter of 20th December 1965, p.58].

to dream up new ways of doing things and patent them. He established a patent development department in 1932, hiring [Arthur Halsey] Dickinson' [17]

There are very few mentions of IBM in the voluminous Zuse patent litigation records. In fact, the first explicit mention of IBM in the Zuse patent litigation appears to be in 1963 in a letter to Zuse from his patent attorney Weber-Schäfer:

> *'Relating to these two applications, according to the attachments, IBM has asked for permission to inspect the files. We will not object to their request.'*
> *[56, letter of 16th August 1963, p.476]*

The next mentions began two years later when Zuse's patent attorney Johannesson attempted to amplify statements made in an essay by a senior IBM researcher, that:

> *'the applicant would like to refer to the subsequently published article on the question of the technical progress achieved by the invention on which this application is based: Dr. Karl Ganzhorn "Historical Development of Information Processing" in Issue 164 of IBM News, Volume 14, February 1964, pages 2152 to 2156'*
> *[56, letter of 22nd October 1965, p.66]*

Dr. Ganzhorn's essay [25], which favourably mentioned Zuse and his Z3, was in *IBM Nachrichten*, the public-relations magazine of IBM Deutschland. Ganzhorn was born in 1921 in Sindelfingen near Stuttgart and died there in 2014. He was a physicist, and was founder and long-time Director of the IBM Deutschland laboratory in Böblingen.

Following this, in a 2nd December 1965 letter[18] to the Patent Court, Hagen contradicted the praise of Zuse by Ganzhorn, suggesting Valtat[19], Couffignal and Bryce as forerunners to Zuse, prompting, on the 7th January 1966, Johannesson to respond to the Patent Court on behalf of Zuse, for the first time specifically expressing their perception of IBM's role in supporting the rejection of the patent application:

> *'The objecting party is in a difficult position, as it obviously receives information to fight this application from IBM, but cannot deny that an important IBM voice (Dr. Ganzhorn) has recognized openly and sincerely the famous 'Z 3' as a milestone in computing history.'*
> *[56, letter of 7th January 1966, p.53]*

In this letter, and a subsequent letter of 3rd October 1966 to the Patent Court[20] in regard to an earlier letter from Dr. Hagen, Johannesson mentioned "*Lizenzverhandlungen* (license talks)" between Telefunken and IBM and accusations from IBM that the Telefunken patent department had slowed down the litigation process. While this seems somewhat tangential to the views expressed in the letter above, it may have precipitated an explicit disclosure of IBM's role, since finally, one month later in November 1966, Hagen wrote to the Patent Court (Fig.2), defending the right of companies to seek support from other companies, and for the first time providing clear evidence implying that IBM had been helping Triumph-Werke, just as Zuse had always alleged.

> *'In the present case, the applicant, Zuse KG, is being advised by Telefunken AG and its employees. If the IBM company assists the opposing party in an advisory capacity, then the opposing party is simply exercising its right to do so.'*
> *[56, letter of 17th November 1966, pp.14-15]*

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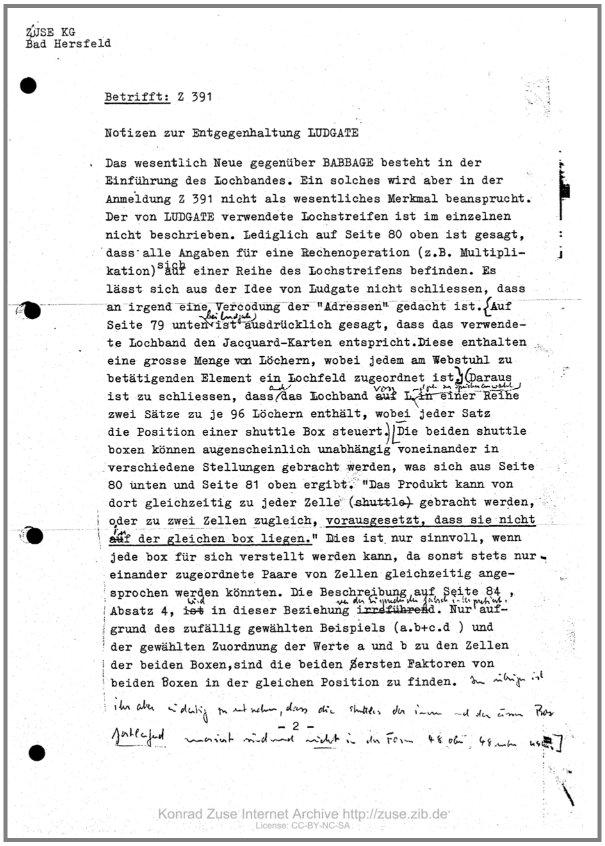
17 apollotv.online, also accgian's blog and equant.org, archived extracts of retired IBM webpage "IBM Patents and Innovation", available at [56].

18 [56, letter of 2nd December 1965, pp.62-65].

19 Raymond Louis André Valtat applied for a patent on a binary calculator in 1931 and published a theoretical analysis in 1936 [43].

20 [56, letter of 3rd October 1966, pp.18-20].



ZUSE KG
Bad Hersfeld

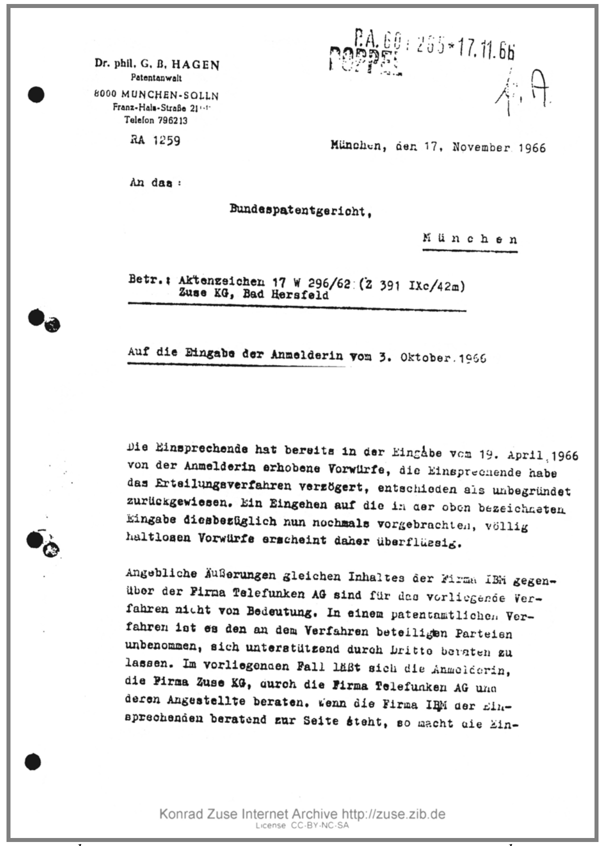
Betrifft: Z 391

Notizen zur Entgegenhaltung LUDGATE

Das wesentlich Neue gegenüber BABBAGE besteht in der Einführung des Lochbandes. Ein solches wird aber in der Anmeldung Z 391 nicht als wesentliches Merkmal beansprucht. Der von LUDGATE verwendete Lochstreifen ist im einzelnen nicht beschrieben. Lediglich auf Seite 80 oben ist gesagt, dass alle Angaben für eine Rechenoperation (z.B. Multiplikation) sich auf einer Reihe des Lochstreifens befinden. Es lässt sich aus der Idee von Ludgate nicht schliessen, dass an irgend eine Vercodung der "Adressen" gedacht ist. Auf Seite 79 unten ist ausdrücklich gesagt, dass das verwendete Lochband den Jacquard-Karten entspricht. Diese enthalten eine grosse Menge von Löchern, wobei jedem am Webstuhl zu betätigenden Element ein Lochfeld zugeordnet ist. Daraus ist zu schliessen, dass das Lochband auf L. in einer Reihe zwei Sätze zu je 96 Löchern enthält, wobei jeder Satz die Position einer shuttle Box steuert. Die beiden shuttle boxen können augenscheinlich unabhängig voneinander in verschiedene Stellungen gebracht werden, was sich aus Seite 80 unten und Seite 81 oben ergibt. "Das Produkt kann von dort gleichzeitig zu jeder Zelle (shuttle) gebracht werden, oder zu zwei Zellen zugleich, vorausgesetzt, dass sie nicht auf der gleichen box liegen." Dies ist nur sinnvoll, wenn jede box für sich verstellt werden kann, da sonst stets nur einander zugeordnete Paare von Zellen gleichzeitig angesprochen werden könnten. Die Beschreibung auf Seite 84, Absatz 4, ist in dieser Beziehung irreführend. Nur aufgrund des zufällig gewählten Beispiels (a.b+c.d) und der gewählten Zuordnung der Werte a und b zu den Zellen der beiden Boxen, sind die beiden ersten Faktoren von beiden Boxen in der gleichen Position zu finden.

- 2 -

Konrad Zuse Internet Archive http://zuse.zib.de
License: CC-BY-NC-SA



Dr. phil. G. B. HAGEN
Patentanwalt
8000 MUNCHEN-SOLLN
Franz-Hals-Straße 21
Telefon 796213

P.A. 60 : 265 * 17.11.66

RA 1259

München, den 17. November 1966

An das:

Bundespatentgericht,

München

Betr.: Aktenzeichen 17 W 296/62 (Z 391 IXc/42m)
Zuse KG, Bad Hersfeld

Auf die Eingabe der Anmelderin vom 3. Oktober 1966

Die Einsprechende hat bereits in der Eingabe vom 19. April 1966 von der Anmelderin erhobene Vorwürfe, die Einsprechende habe das Erteilungsverfahren verzögert, entschieden als unbegründet zurückgewiesen. Ein Eingehen auf die in der oben bezeichneten Eingabe diesbezüglich nun nochmals vorgebrachten, völlig haltlosen Vorwürfe erscheint daher überflüssig.

Angebliche Äußerungen gleichen Inhaltes der Firma IBM gegenüber der Firma Telefunken AG sind für das vorliegende Verfahren nicht von Bedeutung. In einem patentamtlichen Verfahren ist es den an dem Verfahren beteiligten Parteien unbenommen, sich unterstützend durch Dritte beraten zu lassen. Im vorliegenden Fall läßt sich die Anmelderin, die Firma Zuse KG, durch die Firma Telefunken AG und deren Angestellte beraten. Wenn die Firma IBM der Einsprechenden beratend zur Seite steht, so macht die Ein-

Konrad Zuse Internet Archive http://zuse.zib.de
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Figure 2: left: German original of Page 2 of Zuse's response of 2nd March 1960 to Hagen's letter of 11th January 1960. right:German original of Page 1 of Hagen's letter to the Federal Patent Court of 17th November 1966. Courtesy of the Konrad Zuse Internet Archive [30]

From Ludgate's 1909 paper to Hagen's 1960 letter

Given the low-profile Ludgate's work had until Randell's 1971 paper [42] and 1973 book [43], the question arises: how did Triumph-Werke and its patent attorney learn of the existence and obtain a copy of Ludgate's 1909 paper? In an attempt to answer this question, we have extensively investigated how Ludgate's 1909 paper was disseminated, what evidence exists of it having been read and appreciated, and who might have been involved in passing on information about the paper and his ideas.

Here we summarize our findings and provide a graphical portrayal of the numerous possible information flow routes we have identified, and of our very subjective assessment of their likely relative probability. Full details of this investigation are provided in two online reports, one an analysis[21] underpinning this summary, the other a forensic investigation of sources[22], in the hope that other researchers will be motivated and able to augment our findings, and indeed come to more definite conclusions regarding the route from Ludgate to Hagen.

Ludgate's plans for an Analytical Machine did attract some attention in the scientific literature when they were published, specifically in a short paper "A New Analytical Engine" by Professor C.V. Boys [5] in the widely-circulated magazine *Nature* commenting enthusiastically on Ludgate's ideas, and in the informative entry "Analytical Machine" in the influential IEE *Science Abstracts: Section A.—Physics* [29].[23] Two popular engineering magazines (*Engineering* and *English Mechanic and World of Science*, published short but informative articles based on the 1909 paper within months of its publication, two of which included an explanatory drawing, almost certainly provided by Ludgate himself. Presumably these various papers and articles, all of which gave full bibliographical details of

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[21] Coghlan, B., Randell, B., Buelow, R., "How Hagen found Ludgate's 1909 paper", available at [56].

[22] Coghlan, B., Buelow, R., Randell, B., "Pre-1971 Known References to and Possible Dissemination of Ludgate's 1909 paper", available at [55].

[23] Coghlan, B., Randell, B., Buelow, R., "The Patent Attorneys of the Zuse Z3 Patent Litigation", available at [56], gives some biographical information on the patent attorneys of the Zuse Z3 patent litigation. Two of the principal attorneys, Hagen and Hoffmann, had physics degrees and so would be likely to be interested in physics abstracts.

Ludgate's paper, helped the initial spread of knowledge about his machine, but we have found no further actual evidence attesting to this happening.

We have established that the Royal Dublin Society journal in which the 1909 paper appeared was routinely distributed to several hundred other scientific societies world-wide, at least a few of which included brief listings of the contents of received journals in their own publications. Ludgate himself briefly mentioned his work on an Analytical Machine in the chapter on Babbage's Analytical Engine that he contributed to the 1914 *Napier Tercentenary Celebration Handbook* [34].

All the above information sources were available in a number of German libraries (which we detail in our report), so our impression is that Ludgate's paper could have been relatively easily found in 1960, even though well before the Internet era, *if it had been explicitly searched for*. The questions that remain include who, including the scientifically trained Hagen, might have undertaken searches, with what motivation, from what starting points, and when were these undertaken – and also what subsequent information transmission was involved.

The first search we have learned of was that which resulted in the 1938 Moore School of Electrical Engineering Report by Irven Travis "Bibliography of literature on calculating machines". This contains, in its relatively small Arithmetical Machines section, a full bibliographical citation for Ludgate's 1909 paper [53], but no details of the paper's contents. Travis[24] later testified that his bibliography was the result of extensive literature searches by students under his guidance and had been circulated widely in 1938 [54]. But it would appear that Travis made no mention of his bibliography, leave alone of Ludgate, when he gave a lecture on "The History of Computing Devices" in 1946 at the famed Moore School Lectures on 'Theory and Techniques for Design of Electronic Digital Computers'.

Another individual who became very knowledgeable about the early history of digital computers was Maurice Wilkes[25]. His 1956 book [58] contains, in an excellent survey and detailed discussion of the origins of computers, the only other full citation of Ludgate's 1909 paper we have found that was published in the period 1915-1960. Wilkes attended the Moore School Lectures, his book was a prominent early computer textbook, and our full analyses document a number of interactions he had which could have provided opportunities for transmission of information about Ludgate.

The third individual who is known to have searched diligently during this period for information relating to the origins of digital computers was Walter Hoffman[26], as can be seen from the extensive bibliography in his 1962 book [26]. There is in fact good reason to assume that Hoffman worked closely with Hagen, and was both equipped and motivated to find and pass on information which would help a challenge to the Zuse patent.

Thus any of these three individuals may have played a role, not necessarily knowingly, in allowing Hagen to find out about Ludgate's work and acquire a copy of his paper.

A quite different set of possible routes by means of which information about Ludgate's 1909 paper might have reached Hagen involves Ludgate's 1914 contribution to the Napier Tercentenary Handbook, since this included a mention of his work on an analytical machine, and a reference to his 1909 paper on it. The Handbook, and Baxandall's "Calculating Machines and Instruments: Catalogue of the Collection in the Science Museum" (1926) [4], were for many years the most prominent and accessible English-language sources of information about early calculators and computation[27]. Our investigation turned up evidence indicating the possible separate involvement of

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24 Irven Travis, Professor of Electrical Engineering at the Moore School of Engineering, Pennsylvania, in the 1930s built two differential analyzers, one for the US Army, the other for the Moore School, creating his bibliography in 1938, and later leading Burroughs Corporation computing.

25 Maurice Wilkes F.R.S., Director of the Computer Laboratory, Cambridge, U.K., in the late 1930s ran its Meccano differential analyzer, but after attending the 1946 Moore School Lectures (arriving late and so missing Travis' lecture) he initiated and led the development of EDSAC.

26 Walter Hoffman became the Head of IBM's Patent Operations in Rüschlikon, Zürich. From [2]: "Walter Hoffman [was] at this time an assistant of Professor Walther in Darmstadt. Walter Hoffman engaged in literature search and literature collection. Later he became a patent lawyer and worked for many, many years with IBM in one of the patent departments. […] He has a wealth of historical information on developments of this type and also how they eventually led to the state of the art which we have now. He helped quite a bit in getting literature and in getting literature spread around."

27 The most important other textbooks on the history of calculating machines from this period, neither of which was in English, were *Die Rechenmaschine* (1925) by Ernst Martin [36], and *Le Calcul Simplifié* (1928) by Maurice d'Ocagne [23].

either Leslie Comrie[28], Vannevar Bush[29], Howard Aiken[30] or Ambrose Speiser[14] in passing on information about Ludgate that had been gained via one or other of these two sources.

Some of these routes are distinctly more probable than others. For example, there is an intriguing possibility, involving Aiken, Speiser, Hoffmann then Hagen. Howard Aiken cited Ludgate indirectly in 1937, lectured at the Moore School Lectures in 1946, Aiken & Hopper cited Ludgate more concretely in 1946, then Speiser spent the year 1949 with Aiken, before returning to ETH Zürich, which rented Zuse's Z4 from 1949 for five years (for details of all these events see our online reports[21, 22]), after which Aiken visited Zürich c.1950 (meeting Zuse there) [37, p.50]. In late 1955 Speiser left ETH to establish IBM's Zürich Laboratory, joined in c.1957 by Hoffmann. The possibility that Speiser in 1959 alerted Hoffmann and thence Hagen to Ludgate's work, when Zuse's patent was about to be granted, also cannot be discounted.

There are however other quite different means by which Hagen could have learned about Ludgate. For example, perhaps interested IBM employees knew about Ludgate. IBM was well established in Germany, and since 1956 had an office in Dublin so obtaining Ludgate's paper would not have been difficult; yet John Moriarty, IBM Ireland's first graduate engineer and later Director of the Computer Laboratory (computing centre) at Trinity College Dublin, has no memory of any such request and never heard of Ludgate while working for IBM [14]. Or, although seemingly improbable, a Ludgate citation (in another patent application), or an actual Ludgate patent application, may have existed somewhere, perhaps not even in the records in the UK or Ireland, and that may have been amenable to one of the discovery methods available to patent attorneys (as well as providing much more detail on Ludgate's machine). However, we have not attempted any investigation of this to us rather arcane literature.

A graphical representation of the more likely possible routes by which information about Ludgate's Analytical Machine might have reached Hagen, and of their differing likelihood, is provided in Figure 3. It shows, for example, that in our judgement the most likely routes are those that begin with searches that revealed Ludgate's original paper, probably prompted by one or other of the 1909 reviews, and perhaps Wilkes' 1956 book.

The above analysis at minimum begins the attempt to unravel the mystery. But so far no direct evidence has been found of how Triumph-Werke and its various patent attorneys actually found and obtained a copy of Ludgate's paper describing his Analytical Machine, let alone of any information route all the way from Ludgate (1909) to Hagen (1960), so our analysis remains conjectural. Furthermore, the patent attorneys and IBM might have had some entirely different route via which they obtained Ludgate's 1909 paper – we may never know!

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28 In the U.K., one of Manchester University's two copies of Travis' Bibliography is marked as originating in the Scientific Computing Service, a company set up by Leslie Comrie. Comrie was an avid collector and sharer of literature on computation, was familiar with the *Handbook of the Napier Tercentenary Celebration*, and lent literature to Wilkes before the latter attended the Moore School Lectures. A visit to Wilkes in Cambridge in 1947 inspired Speiser before he spent 1949 with Aiken.

29 Vannevar Bush was a renowned Professor at MIT who in the 1930s created the first differential analyzer, a mechanical analog computer for solving differential equations [59].

30 Howard H. Aiken was Professor of Applied Mathematics at Harvard University, and conceived the Automatic Sequence Controlled Calculator (ASCC, funded and built by IBM, first operational in 1944, later renamed the Harvard Mark I) [17].

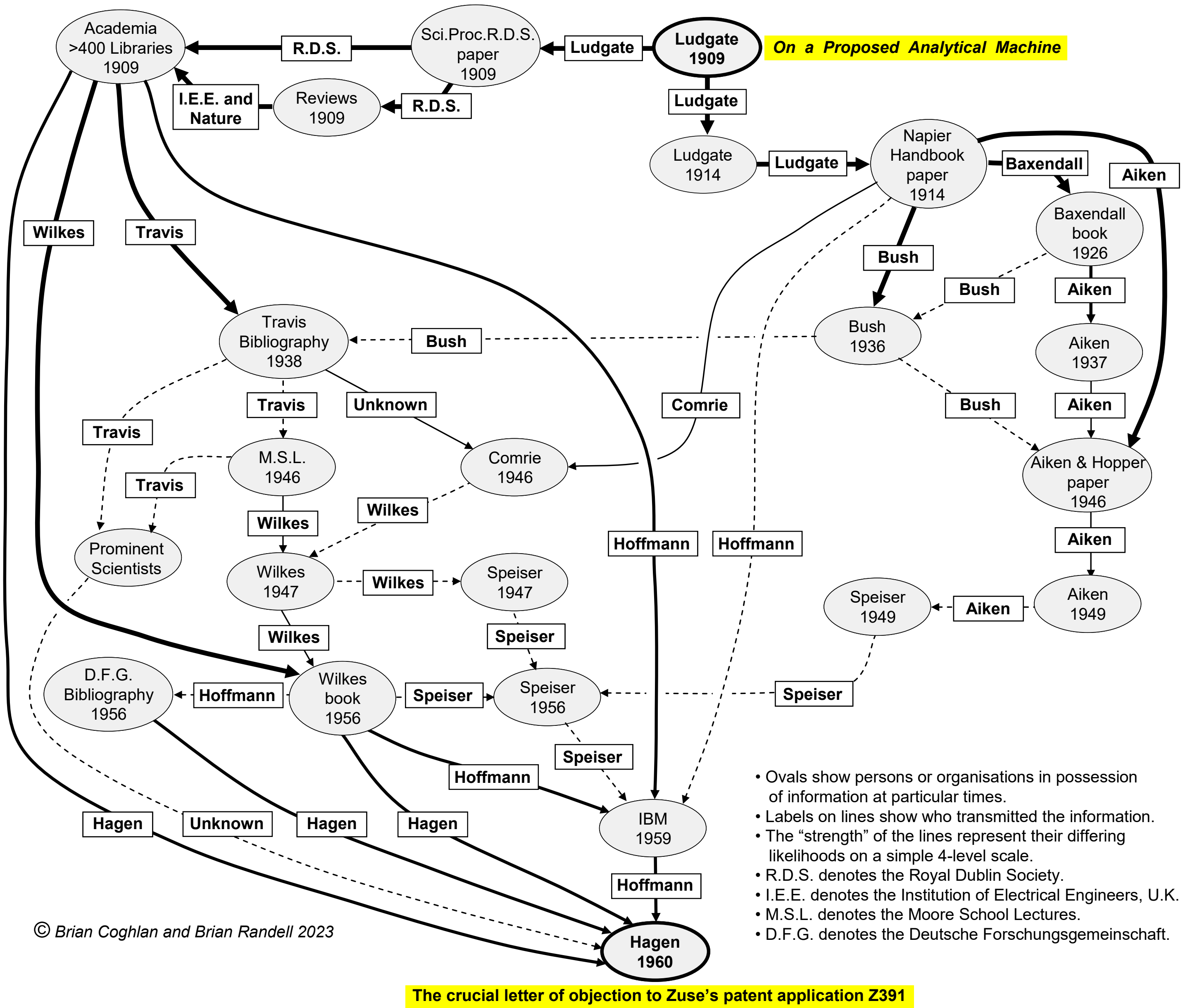

Figure 3: Graph of the more likely possible routes via which information in Ludgate’s 1909 paper might have reached Hagen in 1960.

Concluding Remarks

Although the potential impact of Zuse’s failure to gain a patent was previously discussed by Petzold, the present paper uncovers the part played by Ludgate’s prior publication on his Analytical Machine, and by IBM, in the fateful patent refusal. It provides much more detail on the players and activities involved in this refusal and broadens the dissemination of the whole issue from German to English language audiences.

The very fact that Ludgate’s 1909 paper on his Analytical Machine was employed to thwart Zuse’s attempt to patent the computer refutes the prevalent assumption that Ludgate had no influence on modern computing, and that his work is just of historical interest. Whatever the scale of their influence, patents can impact the commercial activities in the sector they apply to. Hence Ludgate’s paper clearly did have a potential influence on the commercial future of computers, even if his work was unknown to the developers of the early electronic computers. However, we have deliberately avoided speculating on the types or the extent of the possible commercial consequences, either to Zuse’s company, or to the rest of the computer industry, of the thwarting of Zuse’s attempts to obtain what would have been the first patent on a programmable computer. Similarly, we have chosen not to attempt to add to the now extensive literature on the technical merits and significance of Zuse's designs, as compared to subsequent machines such as ENIAC [6], [13].

While uncovering this story of how information about Ludgate's Analytical Machine was used we have found clear evidence of the actual role played by IBM in the Zuse patent litigation, an activity which Zuse had only been able to allege, which was something he did both at the time and thereafter, in particular in his autobiography [61]. Indeed, we have shown that IBM's role was finally admitted to the German Federal Patent Court in 1966 and have revealed evidence that IBM had in fact supported the denial of Zuse's German patent, while having acquired a license to the American ENIAC patent [52].

We have identified a number of ways in which Triumph-Werke and IBM's patent attorneys might have found out about Ludgate's Analytical Machine. We have identified the very few concrete primary references to Ludgate in the interval from 1909 to 1960, and potential secondary sources of dissemination. While this confirms the previous assumption that before 1960 Ludgate's 1909 paper had a very low profile, indeed this was the case until Randell's 1971 paper [42], it is now clear that the paper had a high profile within the Zuse patent litigation post-1960.[31] The previous assumption also overlooked the wide original distribution of Ludgate's paper, a distribution which makes the paper's subsequent obscurity rather surprising. However, in summary, although there is as yet no direct evidence of how Ludgate's paper was found prior to its use in 1960, our analysis,[21] drawing on our separate online report,[22] represents the beginnings of an attempt to unravel this mystery.

Acknowledgements

For ease of comparison by future scholars, we have provided supporting online documents showing full transcripts of the principal original microfilmed German-language litigation documents that we quote from in the paper, side-by-side with very careful translations to English by the present authors.[32] Figures in the present paper show images of the actual original pages that we deem to be the most interesting among these documents. The microfilm images of the original German documents referred to in this paper are derived from work by the Konrad Zuse Internet Archive [30], licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 3.0 Unported License [20], for which we offer thanks. We thank Charles Mollan for information on journal exchanges and accessions in the Royal Dublin Society, the staffs of the ETH Library Zürich, the Bayerische Staatsbibliothek, and the German Patent and Trade Mark Office Library for information on accessions in those libraries, and Deutsche NationalBibliothek for hosting their excellent ZDB-Katalog. Finally, we extend our thanks for the support of the School of Computer Science and Statistics, Trinity College Dublin, for their support for this work and for the John Gabriel Byrne Computer Science Collection.

References:

Please note:
(a) Copies of many of the published primary documents are available online at the SCSS Ludgate Webpage [55].
(b) Supporting documents, and translations of the complete texts of the letters we have quoted from are provided online (in double page format side-by-side with the complete German original letters), accessible via the Index of SCSS Ludgate-Zuse Files [56].

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[4] Baxandall, D., *Calculating machines and instruments: Catalogue of the Collection in the Science Museum*, 85pp., Science Museum, London, 1926.

[31] There are two obvious reasons for this not becoming more widely disseminated: firstly that it was confined to patent litigation circles, secondly that within those small circles it was further confined to German language speakers.
[32] One of the authors is a native German speaker, whilst the others are native English speakers. The authors do not guarantee the correctness of any of these translations, which without prejudice have been done on a best-effort basis.

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Author Biographies:

BRIAN COGHLAN is a retired Senior Lecturer with the School of Computer Science and Statistics, Trinity College Dublin, The University of Dublin, D02 X9W9, Dublin, Ireland. He is curator of The John Gabriel Byrne Computer Science Collection. Contact him at <coghlan@tcd.ie>.

BRIAN RANDELL is an Emeritus Professor of Computing Science with the School of Computing, Newcastle University, NE4 5TG, Newcastle upon Tyne, U.K. His book *The Origins of Digital Computers: Selected Papers* was first published in 1973, by Springer. Contact him at <Brian.Randell@ncl.ac.uk>.

RALF BUELOW is a former museum curator and a free-lance historian of technology and science journalist. He is based in Berlin and works for the Heinz Nixdorf MuseumsForum, 33102, Paderborn. Contact him at <ralf.buelow@t-online.de>.