A Rough History of Computing

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This short article is compiled from the notes I used in preparation for the banquet address I delivered at the first GEDAE conference in Philadelphia on 6th March 2003. My information is drawn from a number of references which I have listed at the end of the article. It was not my intention to produce a definitive history, more an entertainment, and I ask my readers to keep this in mind and to forgive my errors. At the same time, I do believe that the information provided here is broadly accurate and I hope it may encourage some to dig into the references where the fascinating story can be found.

It is wholly appropriate that in delivering an address in Philadelphia, to experts in modern computing, I should choose to base it on the history of computation. Philadelphia, and the Moore School of Electrical Engineering, was, of course, the home of the ENIAC, the first practical electronic computer and a marvel of engineering enterprise. I'll tell you about it in due course. However, the story starts a long time before the foundation of the city of brotherly love, in the period of the classical Greek empire, some centuries before the birth of Christ.

The golden age of Greek culture retained a profound impact on science and philosophy in Europe well into the renaissance period. The geometry of Euclid reigned supreme until the beginning of the nineteenth century and the teachings of Aristotle formed the basis of university courses in philosophy and natural science. It was the logic of Aristotle that invaded the mind of the child prodigy, Gottfried Wilhelm Leibniz. Liebniz's father was Professor of philosophy at the University of Leipzig. He died in 1652 when Gottfried Wilhelm was six years old. The devastating Thirty Years War, fought mostly on German soil, had ended in 1648 leaving the country divided into some 1000 fiefdoms. By the age of eight, Gottfried Wilhelm was devouring the deceased Professor's library, much against the advice of his teachers and his nascent genius was already apparent. While the fragmentation of Germany in that time meant that his education at the University of Leipzig failed to cover the emerging mathematics in France and England, it did equip him with a foundation in Aristotelian logic. This inspired a vision of amazing grandeur. Leibniz dreamt of an encyclopaedic compilation of all human knowledge, of a universal mathematical language in which knowledge could be expressed and of a calculus which could capture the interrelationships between propositions with mathematical precision. He called this vision his "wonderful dream". It remained with him throughout his life.

For his Batchelor's degree at Leipzig, Leibniz produced a thesis on Aristotelian metaphysics. His Master's thesis dealt with the relationship between philosophy and the law. He completed a second Batchelor's degree on the application of systematic logic to matters of legal determination and extended this to a Doctoral submission. For reasons we don't know, the University of Leipzig refused to grant his Doctorate and he had to submit to the University of Altdorf near Nuremberg.

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At the age of twenty-one, Leibniz had completed his formal education and rejecting the option of a professorship, he embarked upon a career that depended upon aristocratic patronage. France had emerged from the thirty year war as the super-power of Europe and the focus of Liebniz's first assignment for his patron, Baron Johann von Boineburg, Elector of Mainz. In 1672 he was dispatched to Paris with the aim of directing French attention away from Germany towards military adventures in Egypt and to untangle some of von Boineburg's financial affairs. Von Boineburg's death during Liebniz's first year in Paris was insufficient to bring the young Liebniz home and; in fact, he remained for five very productive years in the company of the intelligentsia of the age. Proximity to London allowed him to visit there, where his genius was quickly recognised. His exhibition of a four-function calculating machine gained him membership of the Royal Society. His calculator much surpassed the earlier efforts of Blaise Pascal and its essential mechanism, the Leibniz wheel was used in mechanical calculators well into the twentieth century.

A great deal more could be said about Leibniz, his rivalry with Isaac Newton, his disputed invention of the integral and differential calculus, his life-long employment as family historian to the House of Hanover and his strategies which helped to put the Hanoverian George I on the British throne. In the development of computing it is his adherence to "his wonderful dream" that matters. Leibniz's writings inspired generations to follow him. In particular, the influence of Leibniz on the English genius George Boole led to Boole's publication, "The Laws of Thought" in 1854. This was the next big advance in the science of computing. It gave us "Boolean Algebra".

George Boole was the son of a cobbler in the town of Lincoln, in the south-east of England, the eldest of four children. His father, John Boole showed some aptitude for design and construction of scientific instruments, but displayed little gift for business. In consequence, George Boole was raised in poverty and was largely self-taught, though his genius was apparent to all who encountered him. He mastered Latin, Greek, German and French and by the age of sixteen, after collapse of his father's business, he took on the support of his family through a job as teacher in a Methodist school. Boole could not accept the doctrine of the divinity of Christ, but he lived according to strict Christian morality. However, his Methodist employers frowned on his study of mathematics on Sunday, considering this to be irreligious and he was fired after two years. At this stage, Boole's interest turned more and more to mathematics. In later years, reminiscing, he explained that on a very limited budget, mathematics books represented best value since they took longer to work through than other books.

At nineteen years of age George Boole started his own school in Lincoln and for fifteen years, until he was appointed Professor of mathematics at the newly formed University of Cork, Ireland, this venture was the sole financial support of his family.

Boole's lasting contribution was the recognition that algebraic manipulation could be used to make logical deduction if the concept of "classes" is admitted. He claimed that the basic idea stemmed from his time in the Methodist school, but he developed it much later, prompted by a controversy between his friend Augustus De Morgan (remember De Morgan's theorem[2]!) and the eminent Scottish Mathematician Sir

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[2] Not (A and B) = Not (A) or Not (B) etc

William Hamilton[3]. Boole's system of logic replaced the syllogisms of Aristotle and went far beyond, but yet fell short of the "wonderful dream" of Leibniz. That distinction fell to another German genius Gottlob Freige. However, before I speak of Freige, it seems appropriate to mention some of the contemporary developments in machine computation attributed to the Englishman, Charles Babbage.

Babbage was a competent mathematician but even more, a business visionary. He contributed to the practical side of computing rather than the underlying framework. In his age, Victoria (of the house of Hanover) sat on the English throne, the financial city of London was forming, the Empire was expanding, the Insurance industry began and commerce was developing in support of the industrial revolution. Babbage plied the government and aristocracy for support for his concept of a calculating machine. Before he ran out of favour in government circles, he extracted as much public money as would have built a battle-ship. Babbage's concept was well founded and he was in no doubt about the scale needed to support commercial application; he understood that a useful machine would fill a factory and require the power of several steam engines to drive it. The machines he built were mere models and even then his Analytical Engine remained unfinished until a few years ago when the Science Museum in London completed and tested it successfully. His Differential Analyser was designed to compute tables for the navy and the military and was successfully demonstrated, but needed to be scaled up significantly if it were to be of practical use.

Babbage's name is usually linked with Ada, Countess of Lovelace and Ada is often cited as the first programmer[4]. That is probably true, Babbage's machines were certainly programmable from a calculators point of view. That she was a mathematical genius is a myth. She was the daughter of a short marriage between a misguided and somewhat puritanical aristocratic spinster and the licentious Lord Byron, the romantic poet. Ada's mother married Byron in the belief that she could transform his raucous ways and specifically save his soul by diverting him from his incestuous relationship with his sister. Alas, Byron looked on his daughter only once before departing for continental debaucheries that prematurely ended his life. Ada was brought up by straight-laced aunts who suspected that she might have inherited the licentious blood of her father. In consequence they forced her into study of mathematics as a pursuit diametrically opposed to art and poetry and hence likely to divert or delay the consequences of her "bad blood". Babbage took advantage of this situation, seeking aristocratic patronage for his ventures. For all that, Charles Babbage and Ada Lovelace came very close to radically changing the world. If Babbage's plan had succeeded and commerce had been automated in the mid-nineteenth century, the whole story of computers may have taken a very different course.

But that is what didn't happen. What did shake the world was the work of Gotlobb Frege to which we return.

In 1902, in the medieval town of Jena, later to be part of East Germany, Frege was completing the second volume of a thesis that represented his life's work when he received a letter from Bertrand Russell, praising his work, but raising a fatal flaw that

[3] Not to be confused with the contemporary Sir Rowan Hamilton, the inventor of "Quaternions".
[4] The U.S. DoD standard computing language is called after Ada Lovelace, hence, "Ada", not "ADA".

invalidated a fundamental assumption with catastrophic consequence. Forty years later, Russell wrote of his admiration for Frege's intellectual honesty in acknowledging the error. The problem that beset his work also defeated Russell's "Principles of Mathematics" and was to strike at the very heart of mathematics.

Nevertheless, Frege's contributions were of immense benefit. He provided the first fully developed system of logic that incorporated all the deductive reasoning in ordinary mathematics and his pioneering work using the tools of logical analysis to study language led to major developments in philosophy. Frege was born in 1848, the son of an evangelical theologian. He received a PhD in mathematics but never progressed his academic career beyond the level of Associate Professor. His colleagues didn't seem to value his work and in later life he espoused the Nazi doctrine of national socialism which may indicate a personality attribute that explains his isolation in academic circles. In 1897, Frege published a booklet of only one hundred pages entitled, "BEGRIFFSSCHRIFT"[5]. It was sub-titled "A Formula Language modelled on that of Arithmetic, for Pure Thought". This work has since been acknowledged as perhaps the most important single work ever written in logic.

Boole's logic used the symbology of algebra and applied it to classes. Frege went much further. He developed a whole syntax. His intention was to show that all mathematics could be founded on logic. His BEGRIFFSSCHRIFT[6] allowed him to develop logical propositions syntactically, in a precise language, where inferences could be developed mechanistically. It is true to say that BEGRIFFSSCHRIFT was the precursor of all computer languages.

As Frege and Boole wrestled with the "wonderful dream" of Leibniz, and made prodigious strides, the mathematical world had a sense of unease. Bertrand Russell and Alfred Whitehead's efforts to rigorously reconcile mathematics and logic had been exhaustive and not really satisfactory. The issue of completeness was outstanding. There were doubts about the ability of mathematics to provide proofs of all true conjectures within a consistent system. In addition, the work of Cantor on trans-infinite sets further upset the stability of the accepted framework.

The prominent mathematician of the age was David Hilbert at the University of Gottingen. Hilbert believed passionately in the need to move the subject along by setting challenges; he judged the health of mathematics by the quality of its unsolved problems. At the International Mathematics Congress held in Paris in 1900, all focus was on Hilbert and he determined to use his influence to set the challenges for a new century.

Hilbert carefully concocted twenty-three problems, ten of which he delivered in his keynote address and the full set he distributed, tactfully in French, in a paper circulated after his speech to the Congress. He ended his address with an emotional statement, ***"…there are absolutely no unsolvable problems. Instead of the foolish*** *ignorabimus*[7]***, our answer is on the contrary,***

we must know,
we shall know".

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[5] Roughly translated this means "concept-script" or "mode of writing".
[6] Fascinating examples are given in Reference 1.
[7] Latin, 1st person, plural, future tense, "we shall not know".

Hilbert's second problem concerned the completeness of mathematics; it proposed to prove a rigorous axiomatic foundation for arithmetic.

The mathematical congress met again in Bologna in 1928, this time attended by the young Kurt Gödel, still an unknown student from Brno, a German-speaking city, now part of the Czech Republic and the famous Hungarian-American, John Von Neumann. In the margins of the conference, Von Neumann realised that Gödel had a basis for deciding Hilbert's second problem. Probably, Von Neumann's encouragement was seminal in giving Gödel the courage to take his ideas seriously and in leading to the famous paper in 1931. It is a fact that after his 1928 discussion with Gödel, Von Neumann never again applied himself to problems in logic, he hailed Gödel as the most important logician of all time. Godel's proof has been the subject of many books[8] and interpretations. Effectively, Kurt Gödel collapsed Hilbert's world – he showed that there were true conjectures that could not be proved within a consistent mathematical framework, the Incompleteness Theorem, – imposing a limit on mathematics which Hilbert never expected.

After war broke out in Europe and following Germany's rapid advance on Poland, in December 1939, Gödel and his wife Adele fled to the US where he was assisted to enter the Institute of Advanced Studies at Princeton. Einstein is quoted as saying that he went to the office every day to enjoy walking with Gödel. You can find the famous picture of both of them in Reference 1.

Liebnitz dreamed of human reason reduced to calculation. Frege in BEGRIFSSCHRIFT gave the rules and framework. Gödel's 1930 doctoral thesis proved the completeness of Frege's rules but his 1931 paper delivering the incompleteness theorem showed a basic limitation for proof of propositions within a formal system, negating Hilbert's ambition. Nevertheless, the mathematical world was still occupied by Hilbert's goal which had become known as the decision problem or, *"Entscheidungsproblem".* Hilbert was asking for an algorithm of unprecedented scope, effectively the mechanisation of mathematical proofs.

Many mathematicians of the day were of the view that the *Entscheidungsproblem* was a false quest. It was entirely another matter to make a clear disposal of it. At Cambridge University, in the Spring term of 1935, the Topologist, Max Newman, a Don at St John's College gave a series of lectures on the foundations of mathematics and ended with an exposition of Gödel's Incompleteness Theorem. His audience included the brilliant Alan Turing[9]. Turing was inspired to take up the *Entscheidungsproblem.*

Turing's draft paper arrived on Max Newman's desk at the same time as a copy of the American Journal of Mathematics containing an article by Alonzo Church entitled, "An Unsolvable Problem in Elementary Number Theory". In this paper Church showed through abstract concepts[10] that there were algorithmically

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[8] Reference 5 is more readable than most and conveys the principles of the proof.

[9] *"Turing,*
Must have been alluring,
To be made a Don,
So early on!"

[10] "Lambda-indefinability"and "General Recursiveness".

unsolvable problems. He didn't refer to the *Entscheidungsproblem,* but he did so in a note to the Journal of Symbolic Logic, early in 1936.

By the time Turing's paper was published, it was clear that US mathematicians had already covered the same ground. Nevertheless, Turing's approach was compelling and much more acceptable to the world at large. Gödel, for example, was unconvinced by Church's paper but immediately embraced Turing's approach. There was no rivalry between Turing and Church, on the contrary, the allure of Church brought Turing to join him at Princeton and some of his best work was accomplished there under Church's direction before he became engaged in his war-time code-breaking activity at Bletchley Park.

It is a lecture for another day to describe how Turing solved the *Entscheidungsproblem*. All I can sensibly do is to say that he invented an abstract but easily understood mechanism which would be very obvious and seemingly elementary to computer engineers today. A paper tape, a means for moving forwards and backwards in discrete steps, a means of writing and reading a symbol on the tape and a means deciding the next primitive action in terms of the current machine state.

Turing was able to show that the machine was universal; it could mimic all machines of its class. He could show that there were algorithms for which the machine would never halt and hence provide no solution. In a simple and universal framework the *Entscheidungsproblem* died.

The story of Turing is so fascinating that there is a real danger that it dominates any discourse that even neighbours on his activity. I am going to resist this and refer you to the fascinating biography[11] by Andrew Hodges, another Cambridge mathematician. If you read this you will see that Turin was much more than a mathematician, he was a specialist in electronics and signal processing even while the subjects were still unrecognised.

I'll jump the war years, despite the lure of Enigma and Bletchley Park, and turn to Turin's influence on the evolution of computers. At Princeton, Turin would have conversed with John Von Neumann; they would have shared an understanding of the algorithmic basis of computation. In England, Turin was principal consultant to the Ferranti Company in Manchester and was embarked upon the construction of a computer for commercial applications. In the US, the final stages of the war led to the construction, here in Philadelphia, of the ENIAC, as a tool for military calculation. The ENIAC was a marvel of electronics engineering and a tribute to the circuit ingenuity of its designer John Presper Eckhart, but to a logician such as Von Neumann or Turin, it was an affront. The machine was far too specific in its architecture. Turin opted for minimalism in the instruction set and register structure, wanting to put the flexibility into the programmes. He saw the ENIAC as a waste of engineering skill. The EDVAC, which followed ENIAC, was influenced by Von Neumann and set the architecture that bears his name to the present day. The developments that followed really gave computation to the world. Turing's efforts with Ferranti led to the world's first computer as a commercial product and

[11] Reference 10, an insightful, sensitive biography of a genius destroyed by the prejudices of a narrow society. Enjoyable reading.

ultimately to the founding of the ICL Company, though the product of the day was primitive indeed by modern expectation.

The rest, as they say, is history. The silicon revolution, for me, began about 1970 with the Intel 4004 microprocessor, and if I plot the complexity of computer chips over the next thirty years until the end of the millennium, I see a 100,000 fold increase. This is Gordon Moore's "law" and it is staggering. It should hold true at least until 2015, after which some new principles, probably Quantum-based will be needed.

The really interesting thought is to consider how that enormous complexity ratio (100 dB), reflects in utility gain over the period. Most of us might agree that in thirty years we have seen between 10 and 100 times growth in system utility. I might even argue that it is closer to 10 than to 100. What has gone wrong?

It is clear that the powerful foundation of the machine, its universality, the limitations related only to the fundaments of mathematics, do little to make it useful. That needs programmes, human thought, human guidance of the machine execution. We very quickly got to a stage where non-mathematicians could talk to the machine in a reasonably efficient way. The ALGOL-based "languages" with recognisable syntax were practical, if error prone. We then focussed on the errors and, in an era where there was no alternative, attacked the error through rigor in the human process. That approach is what limits the utility we extract from the machine.

We use software as a means of defeating complexity. It allows us to deal with exponential increases in complexity with less than exponential increase in hardware. The intellectual value of design resides in the algorithm, the mathematical or procedural construct that is a morphism for the system construct we want to implement. Software is just a means to an end, it adds no intellectual value.

I see GEDAE[12] as a paradigm. It is a new age when we can map algorithms onto the machine without the syntactical nightmare of language. It is a much more direct communication with the machine, an abstraction at the algorithmic level and one suited to the natural parallelism of algorithms. I will not try to describe the advantages, as GEDAE Users you know already, but maybe you have not seen the significance of the point at which you stand in the history of machine computation. I believe we are on the way to unleashing into systems the complexity value that Moore's law records for hardware. There is a lot of gain in utility to be had and those companies wise enough to be represented here tonight will be the first to benefit.

I believe this first GEDAE Users' Conference will take its place in the history of computing and in retrospect will be seen as a milestone as important as ENIAC and EDVAC and so I consider it to be a great privilege to have had the opportunity to participate in it by speaking to you. I thank you for your attention and wish you a very convivial and memorable evening.

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[12] See GEDAE web-site, http:\www.gedae.com

References

I have plagiarised freely from the following books and papers in composing my talk. I can recommend this reading list for enjoyment, with the exception of Reference 9 which I include to encourage the curious to sample for interest, but I doubt if it really repays the considerable effort needed to digest it.

1. "The Universal Computer", Martin Davis, Pub. Norton.
2. "Ada Lovelace, Bride of Science", Benjamin Wooley, Pub. MacMillan.
3. "The laws of Thought", George Boole, 1854, currently reprinted by Dover.
4. "The Hilbert Challenge", Jeremy J Gray, Pub. Oxford University Press.
5. "Gödel, A Life of Logic", John L. Casti and Werner DePauli, Perseus Publishing.
6. "The Cambridge Quintet", John L. Casti, Pub. Abacus.
7. "On Computable Numbers, with an application to the Entscheidungsproblem", A.M. Turing, http://www.abelard.org/turpap2/turpap2.htm
8. "Explorations in Quantum Computing", Colin P. Williams and Scott H. Clearwater, Pub. Springer Verlag (Included for a good description of the Turing machine and for a glimpse of the future).
9. "The Principles of Mathematics", Bertrand Russell, Pub. Allen and Unwin.
10. "The Enigma", Andrew Hodges.