On Seeing D2

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It was just as I remember when, as a young boy, I first saw the giant trilithons of Stonehenge. I stood in awe struck silence. Before me then, in majestic stillness, rose an object almost beyond comprehension; a puzzling relic from the ancient past. Once a structure with a function and purpose known to all that surveyed it, Stonehenge is to us a steadfast mystery – an enduring skeleton of weathered stone upon which we may but hang conjecture and superstition.

It was not Stonehenge, however, that held me in thrall this past summer, but Charles Babbage's Difference Engine Number 2 (here after, D2). This incredible machine resides in a quiet corner on the second floor of the Science Museum in London. It is a sublime object. Made of resplendent brass and hardened-steel cogs, cams, levers and springs it is a calculating machine beyond comparison. From the very first glimpse it is clear that D2 is a machine born of a brilliant and subtle mind. Embedded in D2, if ever there was such an example is the essence of human imaginative greatness. Unlike Stonehenge, however, D2 is an ancient ghost given substance in modern times.

Charles Babbage (1791 – 1874) was a truly remarkable man and his genius touched upon many subjects (Swade, 2000). Calculating machines and computation, however, were his life-long passions. The origins of Babagge's interest in calculating machines began at an early age when, as an undergraduate at Cambridge University, he along with life-long friend John Herschel (1792 – 1871) and several other students formed the Analytical Society. The first formal meeting of the society[1] was held on May 11, 1812. One of the great pre-occupations of Analytical Society members, and Babbage in particular, was the testing and evaluation of numerical tables – especially tables of logarithms. Such tables were typically constructed via the method of differences[2] whereby only additions and subtractions are needed to obtain the required results. Human computers were employed to make these long and tedious calculations, and these same computers (prone as we all

1 – Article from The Journal of the Royal Astronomical Society of Canada, **100** (3), 118-120 (2006).

are) made occasional arithmetical mistakes. Not only did errors result through calculation slips, however, they were also introduced at the copying and typesetting stages. Baily (1824) provides an overview of the mathematical tables commonly used by astronomers in the early nineteenth century – for indeed, they were the lifeblood by which precision reductions of data could be made. Alarmingly, however, for one particular set of tables Baily comments that on just one page "no less than 40 errors occur, not one of which is noticed in the printed list of the errata". In more ways than one the situation was desperate. Indeed, Sir John Herschel commented in all seriousness (Swade, 2000) to the British Chancellor of the Exchequer in 1842, that "an undetected error in a logarithmic table is like a sunken rock at sea yet undiscovered, upon which it is impossible to say what wrecks may have taken place". The sentiment is, indeed, literally true – errors in printed logarithm tables could result in shipwrecks and the loss of life at sea because of faulty navigational determinations (observational error aside).

During an Analytical Society meeting in which logarithmic tables were being checked, Babbage recalls that at one stage his head began to loll forward, his eyes focused in a dream-like state on the expansive tables spread out before him. A friend noticing his glazed expression asked what he was dreaming about, to which Babbage replied, "I am thinking that all these tables might be calculated by machinery" (Babbage, 1864). This 'dreamers' comment literally changed Babbage's life and it led him directly to the consideration of how such calculating machines might be designed and constructed. For indeed, Babbage realized that the unavoidable calculating and printing errors which riddled the mathematical tables of that time could be swept away, at a single stroke, by a machine capable of being programmed to do a set of calculations and which could print out its own results.

On Tuesday, January 18th, 1820 astronomer Sir John Herschel recorded in his diary: "*Spent morning at Dr. Pearson's. Babbage came about 1 hr. Read over & arranged address for circulation with the notice of formation of y^{e} Astronomical Soc. Dined & returned with Dr. P. and Babbage to the meeting of the C^{tee} in the evening*" (Turner, 1923). Thus were the origins of the Royal Astronomical Society in London laid, and ultimately Babbage was to become the Societies first Secretary (1820 – 1824). Amongst the very first papers to be published in the Memoirs of the Astronomical Society [Royal charter was not to be bestowed until 1831] was, "*A note respecting the application of machinery of the calculation of astronomical tables*" by Babbage (1822a). In this remarkably short communication, dated June 14, 1822, Babbage announces that he has designed and built an 'engine' to construct "tables of square and triangular numbers, as well as a table from the singular formula $x^2 + x + 41$, which comprises amongst its terms so many prime numbers[3]". Francis Baily[4] commented in November 1823 that he had seen Babbage's machine and that it performed "all that it was intended to do, not only with perfect accuracy, but also with much greater expediency than [he could] perform the same operations with a pen" (Baily, 1824). Sadly and remarkably the calculating engine that Babbage demonstrated to the assembled Fellows of the [Royal] Astronomical Society in June of 1822 has been lost. Not only has the engine disappeared but no plans or drawings relating to its design or construction have ever been found - as Swade (2000, p. 85) comments, "it remains one of the unfound treasures of the history of the period".

While this first difference engine was limited to performing very specific sets of calculations, in a second communication to the Society, read on December 13, 1822, Babbage (1822b) outlined his plans for a much grander and more versatile calculating engine. Babbage's Herculean efforts to construct a working version of D2 (and its predecessor D1) have been told many times over, and they need not be repeated here. History does tell us, however, that a completed version of D2 was not to be made in Babbage's lifetime (figure 1). The machine on display in the Science Museum, however, is D2 exactly as designed by Babbage, but it was built by modern engineers[5] and completed in 1991. Indeed, the D2 I saw this past summer is the embodiment of a dreamer's musings realized in physical form some 179 years after its articulation.

Next to the cabinet enclosing D2 stands a television display. The screen, with clockwork repetition, shows a video sequence of D2 in action. The human operator must turn a massive crank four times around to complete one step of each calculation. It takes some considerable effort to turn the machine over and the operator can be seen to arch his back, with one leg set back slightly behind the other, as the full force of his body is pressed into the machine. Human sweat is literally converted into physical number. After each turn of the hand crank there is a solid and reassuring ‘clank’ from the machine. Indeed, the sound of that numinous ‘clank’ still haunts me now. It was the sound of certainty; a confidence announced. A true and infallibly correct calculation has been completed. Towards the end of each calculation cycle a series of levers, which signify a carry of ten, ripple along the addition gear columns. The levers undulate like the legs of a sure-footed millipede - their motion is rhythmical and precise, and I couldn’t help but think that I was seeing a fluidity of live mathematics. Surely, even the ancient music of the spheres could not have sounded as sweet and as harmonious as the engagement of gears and levers that I heard from D2 this past summer? I was both hypnotized and enthralled.

References

Babbage, C. 1822a. Mem. Astron. Soc. **1**, 309.

Babbage, C. 1822b. Mem. Astron. Soc. **3**, 65.

Babbage, C. 1864. *Passages from the life of a philosopher*. Longman, London.

Baily, F. 1824. Astron. Nachricht. **2** (46), 409.

Swade, D. 2000. *The Cogwheel Brain: Charles Babbage and the quest to build the first computer*. Abacus, London.

Turner. H. H. 1923. In *History of the Royal Astronomical Society: 1820 – 1920*. Dreyer, J. L. E and Turner H. H. (Eds). Roy. Astron. Soc. Pub. London. p.1.

Notes:

1. Babbage and eight friends apparently made the decision to form the Analytical Society on May 7, 1812 (see, www.scholarly-societies.org). During the first meeting the members outlined their goals as being the promotion of analytical techniques, the discouragement of geometrical demonstrations in calculus and the abandonment of Newton’s fluxion notation in which a ‘dot’ (rather than Leibnitz’s ‘*d*’) is used to indicate differentiation. The Analytical Society was formally dissolved at the end of 1813 when Babbage and the other founding members graduated from Cambridge.

Babbage and Herschel considered the possibility of rejuvenating the Analytical Society, on a national basis, in 1817, but nothing every came of the proposal.

2. Babbage (1864, p. 49) explains that “the Difference Engine is not intended to answer special questions. Its object is to calculate and print a series of results formed according to given laws”. For this reason, difference equations are adopted as an iterative method of generating tables of specific sequences of numbers. The triangular numbers 1, 3, 6, 10, 15, 21,… can, for example, be generated by the difference equation: $T_n - T_{n-1} = \Delta_{1n}$, $T_0 = 0$, where $\Delta_{1n} = n$, and where n = 1, 2, 3, 4, 5, …. is the sequence number.

3. The triangular numbers were discussed in note (2). The sequence of squares 1, 4, 9, 16, 25,…. can be generated by the difference equation $T_n - T_{n-1} = \Delta_{1n}$, $T_0 = 0$, where $\Delta_{1n} = (2n - 1)$, and where n = 1, 2, 3, 4, 5,…. is the sequence number. The ‘singular formula’ that is rich in primes provides the sequence: 41, 43, 47, 53, 61, 71, 83, 97, 113 as x runs from 0 to 8. This sequence of numbers contains 100% of the primes between 41 and 53, 75% of the primes between 41 and 71, and 50% of the primes between 41 and 113. As x increases, so the fewer the number of sequential primes generated in a given sequence. The prime sequence can be generated by the difference equation $T_n - T_{n-1} = \Delta_{1n}$, $T_0 = 41$, where $\Delta_{1n} = 2(n - 1)$.

4. Francis Baily (1774 - 1844) was one of the founding members of the Astronomical Society and at various times served as its Secretary and its President. He is perhaps best remembered for the eclipse phenomenon known as ‘Baily’s Beads’; a phenomenon he described after observing the 1836 annular eclipse. Baily was awarded the Societies Gold Medal in 1827 for his completion of the ‘Cavendish experiment’ in which a pendulum is used to determine the gravitational constant.

5. It should be pointed out that the failure to construct a fully functional version of D2 in Babbage’s lifetime was not because the engineering and manufacturing skills did not exist in the Victorian era. The problems surrounding its manufacture were entirely

related to squabbles between Babbage and the manufacturers, and delays relating to the decision on who should pay for the machine and concerns relating to how much it might cost to construct (Swade, 2000).

Figure 1: While a complete Difference Engine Number 2 was never to be fabricated in Babbage's lifetime, a working (and programmable) arithmetic unit was assembled for its predecessor Difference Engine Number 1 in1832. The portion constructed represented about one-seventh of the (unfinished) full-size machine, and contained nearly 2,000 gears and levers (Swade, 2000). The arithmetic unit is on display next to D2 at the Science Museum in London, and it measures some 72 x 59 x 61-cm.