Morgan Rae Reschenberg

17 March 2017

History 180T

<u>On the Development of Computer Science: Contributions of Charles Babbage and Ada Lovelace</u>

Prospectus

In the following paper, “On the Development of Computer Science: Contributions of Charles Babbage and Ada Lovelace”, the ideas developed by Ada Lovelace and Charles Babbage are detailed to provide context to the development of the field of Computer Science.

Considering a lesson on the difference between recursion[1] and iteration[2], this paper provides sufficient historical background and context to assist and inspire students as they define their own iterative and recursive functions. The Analytical Engine developed by Babbage implemented conditional branching, parallel processing, and was capable of iterative and recursive behaviour. All of these concepts are fundamental to any understanding of Computer Science and students in beginning and advanced courses will benefit from being exposed to information about their origin. Lovelace’s work with the Bernoulli Numbers program is an excellent historical example of applied conditional branching. The tabular representation of her program (Note G, Figure 1)[3] is also useful to provide a different representation of the same material for students who are visual learners.

Not only is the recursive/iterative method demonstrated in Lovelace’s program significant, but the content of her program is of importance as well. Traditionally, when learning a new language or learning how to program for the first time, students compose a program to find the Nth Fibonacci number. Lovelace’s program demonstrates how to decompose mathematical series (similarly to Fibonacci) into computer programs using the aforementioned conventions still employed today.

Furthermore, the work done by Lovelace as a historical actor is significant because it provides inspiration for women and other underrepresented genders in Computer Science.

---

[1] The process of having a function or computer program call itself

[2] The process of repeating/calling the same section of code within a program multiple times

[3] "The Babbage Engine." The Babbage Engine | Computer History Museum. Computer History Museum, n.d. Web. 14 Mar. 2017. [See page 12 for embeded image]

Students may be familiar with Turing and his Enigma Machine and Steve Jobs, Bill Gates, etc., but it is not likely they are familiar with the significant contributions made by Ada Lovelace. The inclusion of her work in the field will engage all students and inspire those who may find themselves lacking role models of similar backgrounds.

The exploration of Charles Babbage's development of the Babbage machines is important for the lesson as well. Students should understand that modeling, programming, and designing are themselves iterative processes. Much like Babbage had to refine his designs many times before being satisfied, they may encounter challenging situations which require perseverance and careful, critical analysis of their own work. Similar to the above example, by including authentic cases of revision, students may become motivated and inspired to work through similar struggles in the classroom. This real-world context provides another way to define concepts of iteration and recursion outside of the Computer Science classroom.

Additionally, the inclusion of this historical example will present students with an opportunity to look critically at the field they're engaging with. Advanced Computer Science students will recognise the computational thought employed by Babbage and Lovelace in their work and will be able to identify patterns within their own thinking. This should prompt a discussion on historical contingency and the similarity of programming basics now and then; we continue to use conditional branching, parallel processing, RAM and storage models, and many other concepts popularised by the Babbage machine. Not only are these concepts still in use, but they are arguably the pillars of the field. The question remains: what other options were possible given this history? What other histories are there associated with Computer Science? Is this history one we should be paying attention to when trying to study Computer Science?

Using the historical example provided in this paper in a lesson on recursion and iteration in a Computer Science classroom will engage students through a variety of avenues. It will provide social and historical context for the development of this relatively new field. It will also prompt discussion on the reasons for the historical similarities and encourage student speculation on future developments in the field.

Introduction

Though it is difficult to pinpoint a specific event leading to the origin of the field of Computer Science, Charles Babbage's invention of the Analytical Engine--a mechanical precursor to the modern computer--and the subsequent development of the Bernoulli Numbers program by Ada Lovelace can be considered the most significant historical event in the field. Together, their work laid the foundations for parallel processing, conditional branching, memory and data storage, and other concepts still fundamental in Computer Science today.

Charles Babbage

Charles Babbage, born in 1791, was a famed inventor and mathematician. Educated at Cambridge, Babbage went on to be instrumental in the founding of several intellectual societies including the the Royal Astronomical Society of London in 1820 and the Royal Statistical Society later in 1834. In both of these societies, Babbage worked to maintain the use of standards of measurement and standards of computation; his attention to detail and quest for standards of consistency in measurement, and therefore reproducibility, indicated the development of his computational thinking skills. Babbage's early ventures into the field we now know as Computer Science involved the construction of small, mechanical calculators and other single-function machines. In 1823, Babbage sought and was awarded government funding to construct a *larger* calculation machine--the Difference Engine.

In early designs, the Difference Engine functioned similarly to a calculator; such machines were employed to calculate and record solutions to polynomial functions utilising decimal variables--a stark contrast to the binary machines of today. Mechanically, the Engines utilised rotor systems similar to those employed in Turing's Enigma system. More complex arithmetic operations required more finely-milled components and expert mechanical engineering[4]. To avoid mechanical jams (what would later be termed “errors”), the Difference Engine refrained from using complex operations and instead reduced all computations to a simple set of arithmetic operations--repeated addition and subtraction.

Years after the initial construction of his Difference Engine, Babbage drafted a more complex version of the same machine that would later stand alone under a different name--the Analytical Engine. Unlike previous models of the Difference Engine, the Analytical Engine moved away from calculation tasks and instead functioned similarly to the modern computer. The machine could be programmed to execute many different operations repeatedly across a variety of variable inputs--after execution, it also had the ability to store computed values and re-use them in successive iterations of the same program. In theoretical operation, the machine used punch cards to input programs, could store data and intermediate results in a “Store” (a module like memory/RAM), and was capable of conditional branching and parallel processing. The machine was, in actuality, a series of constantly changing prototypes Babbage altered until his death in 1871. Only in 1991 was this “Difference Engine No. 2” constructed by British Scientists to Babbage’s specifications[5].

In his constant alterations of the machine, Babbage was unable to produce series of instructions, or programs, which would have shown the machine’s full skill set, however he did compile nearly two dozen programs running on various versions of the machine, each of which fell into one of three classes[6]. The first set of programs solved polynomials like the Difference Engine but with more precision. The next set dealt with calculating the same polynomial solutions iteratively, requiring fewer cards but more complex machinery. The last set of programs solved multiple equations via row reduction and Gaussian Elimination. Babbage’s

---

[4] "The Babbage Engine."
[5] The Editors of Encyclopædia Britannica. "Charles Babbage.”. Web. 12 Mar. 2017.
[6] Bromley, Allan G. "Charles Babbage's Analytical Engine." - Annals of the History of Computing 4.3 (1982): n. pag. Athena Union. Web. 14 Mar. 2017.

aim in writing programs was not to solve arduous math problems. Primarily, he was motivated to assess the behaviour of his machine under different circumstances as it performed a variety of calculations. Although the programs he produced were of mathematical significance, it should be noted that he was not driven to employ the machine to solve problems which had been previously termed unsolvable. The programs allowed him to troubleshoot the machine--they themselves were not his main objective.

Though the development of Babbage's various Engines shaped the structure and capabilities of the modern-day computer, the mechanical engineering and mediocre initial programming are not of stand-alone significance. In 1833, Babbage was introduced to Ada Lovelace and demonstrated to her the capabilities of the (current) Analytical Machine. In the years that followed, the pair corresponded over the machine's intricacies. Later, among other notable work surrounding the Engines, Lovelace scripted a program which would compute an Nth Bernoulli number of the user's choice. In this display of computational thinking, Lovelace not only brought to light the complexity of Babbage's invention, but also combined the hardware advancements of the time (RAM, memory, "Store", etc.) with applications of such devices in a programming context. Lovelace was able to demonstrate the machine was of practical importance.

Ada Lovelace

Augusta Ada Lovelace was born to Lord Byron and Annabella Milbanke on December 10th of 1815[7]. Lovelace's mother Annabella was a mathematician who, after she and her husband separated in 1816, ensured her daughter's education had a firm basis in logic and mathematics both for her own passion for the subjects and to steer her daughter away from the romantic, fanciful nature her father (a famed poet) possessed. Lovelace's education was highly

---

[7] Kim, Eugene Eric, and Betty Alexandra Toole. 1999. "Ada and the First Computer." Scientific American 281, 76-81. History of Science, Technology & Medicine, EBSCOhost (accessed March 13, 2017).

unusual (both for a child of the time period and for a girl)[8], but she proved to be high achieving. She studied extensively under DeMorgan and corresponded with famed mathematical and literary actors of the period. In correspondence, Babbage himself often referred to her as his “Enchantress of Numbers”.[9]

After Babbage and Lovelace met in 1833, Babbage presented his workings with the Analytical Engine to a group of interested scholars in Turin, Italy. There, Luigi Federico Menabrea, the future prime minister of Italy, became interested in Babbage’s work and published his “Sketch of the Analytical Engine”. As a mathematician himself, Menabrea’s paper focused on how the invention of such an engine would alter the future of the field of Mathematics. He noted that the methods used by the machine, namely the card input system “[was] merely a translation of algebraical formulae, or, to express it better, another form of analytical notation”. With Menabrea’s paper, connections between the nature Mathematics and Computer Science were formed. This connection is one which persists into modernity; as mentioned in the prospectus, most students begin programming by translating series and sequences into functions.

After securing a copy of Menabrea’s paper, Lovelace’s interest in the Analytical Engine was renewed. In the span of more than ten years since she’d met Babbage, she’d married William King, the earl of Lovelace, and had three children. In that time, she’d remained in contact with Babbage, but refrained from becoming more involved in the worlds of Mathematics and early Computer Science. This was likely because she fell very ill after the birth of her third child in 1839 and was consumed also with domestic life and recuperation. In 1843, she

[8] Kim, Eugene Eric, and Betty Alexandra Toole. "Ada and the First Computer."
[9] Letters from Ada Lovelace to Charles Babbage 2016, Museum of Applied Arts & Sciences, accessed 14 March 2017, <https://ma.as/150274>

translated Menabrea's original text from French to English with her own annotations at the encouragement of Babbage who was eager to hear her opinion on the material [10].

Despite the advancements affronted by the piece, Lovelace's work on the English translation of Menabrea is often used as a point of contingency to claim she did not truly invent the Bernoulli Numbers program for which she is often credited. Dorothy Stein of University of London is one of Lovelace's most vocal critics citing, in her early work on the translation, Lovelace failed to note a typo in Menabrea's work. As Kim and Toole explain, "Menabrea's original paper read 'le cos. de n = ∞,' when it should have read 'le cas de n = ∞.' The proper translation would have been 'in the case of n = ∞,' but [Lovelace] translated the statement literally to 'when the cos n = ∞,' a mathematical impossibility" [11]. This typo, which may perhaps be deemed an oversight at most, is incorrectly employed by Stein to claim Lovelace was not capable of inventing a program showcasing such high levels of mathematical understanding and proficiency with Babbage's Analytical Engine. In actuality, the carried-through error is insignificant and insufficient to call out Lovelace as unskilled when one considers the mathematical proficiency Lovelace demonstrated in her own annotations on the work and the notes she published in the following years.

Stein also claims that Lovelace misunderstood functional substitution and that this perceived inadequacy could not have rendered her a skilled mathematician in any means. Indeed, in her correspondences with De Morgan dated 1842, Lovelace wrestles with the concept of functional substitution:

> *"I do not know when I have been so tantalized by anything, [and] should be ashamed to say how much time I have spent upon it, in vain. These*

---

[10] MENABREA, Luigi Federico, Charles Babbage, Ada King Lovelace, and A. A. L. Sketch of the Analytical Engine Invented by Charles Babbage ... with Notes by the Translator. Extracted from the 'Scientific Memoirs, ' Etc. R. & J.E. Taylor: London, 1843. Print.

[11] "Ada and the First Computer."

> *functional Equations are complete Will-o-the-Wisps to me. The moment I fancy I have really at last got hold of something tangible [and] substantial, it all recedes further & further & vanishes again in thin air ... . I believe I have left no method untried"*[12]

Even Stein acknowledges, however, that "during the early years of marriage and motherhood she had not kept *au courant* [aware] of developments in the Analytical Engine, which would not have been easy in any case"[13]. This suggests that Lovelace's confusion with functional substitution was, like her lack of familiarity with new designs of the Analytical Engine, due to several years of absence from mathematics and not due to an innate inability.

Similarly, Lovelace is also recorded making occasional requests for clarification of mathematical theorems. In the correspondence with Babbage in which she communicates her desire to write the Bernoulli Numbers program, she asks him to remind her of the procedure to calculate Bernoulli Numbers. Stein claims her inability to produce the formula on her own indicates mathematical immaturity and ineptness. During the time period, however, it is worth noting that mathematics education was still under construction; Lovelace corresponded via post with a group of tutors throughout Europe and had not been lectured face-to-face in several decades[14]. Her inability to recall a formula she may have used only a few times in her youth is not indicative of major failings as a mathematician and is, instead, indicative of her humanity.

Conclusion: Continuing Applications

The field of Computer Science underwent rapid development following the invention of Charles Babbage's Analytical Machine and the accompanying publication of the Bernoulli Numbers program scripted by Ada Lovelace in 1837. As more sophisticated technology

---

[12]Stein, Dorothy, and Ada King Lovelace. Ada: A Life and a Legacy. Cambridge, Massachusetts: MIT, 1987. Print.

[13] Ibid

[14] Kim, Eugene Eric, and Betty Alexandra Toole. "Ada and the First Computer."

developed, the field shifted away from mechanical calculators and toward electronic computational machines, however the core ideas surrounding algorithmic computation remain important in modern applications. The instruction sets on which modern processors are built resemble the conservative engineering Babbage employed in his machine manufacturing (Reduced Instruction Set Computing -- RISC). Additionally, the elements which allow computers to make decisions and respond to variables in their environment (conditional branching) were introduced in the program developed by Lovelace. Without the contributions made by Babbage and Lovelace, modern Computer Science would be very different from what we know, and with the amount of technology ingrained into our daily lives, our world would look very different as well.

Bibliography

Bromley, Allan G. "Charles Babbage's Analytical Engine." - Annals of the History of Computing 4.3 (1982): n. pag. Athena Union. Web. 14 Mar. 2017.

Kim, Eugene Eric, and Betty Alexandra Toole. 1999. "Ada and the First Computer." Scientific American 281, 76-81. History of Science, Technology & Medicine, EBSCOhost (accessed March 13, 2017).

Letters from Ada Lovelace to Charles Babbage 2016, Museum of Applied Arts & Sciences, accessed 14 March 2017, <https://ma.as/150274>

MENABREA, Luigi Federico, Charles Babbage, Ada King Lovelace, and A. A. L. Sketch of the Analytical Engine Invented by Charles Babbage ... with Notes by the Translator. Extracted from the 'Scientific Memoirs, ' Etc. R. & J.E. Taylor: London, 1843. Print.

Stein, Dorothy, and Ada King Lovelace. Ada: A Life and a Legacy. Cambridge, Massachusetts: MIT, 1987. Print.

"The Babbage Engine." The Babbage Engine | Computer History Museum. Computer History Museum, n.d. Web. 14 Mar. 2017.

The Editors of Encyclopædia Britannica. "Charles Babbage.”. Web. 12 Mar. 2017.

[Figure 1]

Diagram for the computation by the Engine of the Numbers of Bernoulli. See Note G. (page 722 *et seq.*)

Number of Operation.	Nature of Operation.	Variables acted upon.	Variables receiving results.	Indication of change in the value on any Variable.	Statement of Results.	Data.			Working Variables.										Result Variables.			
						$^1V_1$ ○ 0 0 0 1 [1]	$^1V_2$ ○ 0 0 0 2 [2]	$^1V_3$ ○ 0 0 0 4 [n]	$^0V_4$ ○ 0 0 0 0	$^0V_5$ ○ 0 0 0 0	$^0V_6$ ○ 0 0 0 0	$^0V_7$ ○ 0 0 0 0	$^0V_8$ ○ 0 0 0 0	$^0V_9$ ○ 0 0 0 0	$^0V_{10}$ ○ 0 0 0 0	$^0V_{11}$ ○ 0 0 0 0	$^0V_{12}$ ○ 0 0 0 0	$^0V_{13}$ ○ 0 0 0 0	$^1V_{21}$ ○ B_1 in a decimal fraction. [B_1]	$^1V_{22}$ ○ B_3 in a decimal fraction. [B_3]	$^1V_{23}$ ○ B_5 in a decimal fraction. [B_5]	$^0V_{24}$ ○ 0 0 0 0 [B_7]
1	×	$^1V_2 \times {}^1V_3$	$^1V_4, {}^1V_5, {}^1V_6$	$\{^1V_2 = {}^1V_2;\ ^1V_3 = {}^1V_3\}$	$= 2n$	...	2	n	$2n$	$2n$	$2n$											
2	−	$^1V_4 - {}^1V_1$	$^2V_4$	$\{^1V_4 = {}^2V_4;\ ^1V_1 = {}^1V_1\}$	$= 2n - 1$	1	...	...	$2n-1$													
3	+	$^1V_5 + {}^1V_1$	$^2V_5$	$\{^1V_5 = {}^2V_5;\ ^1V_1 = {}^1V_1\}$	$= 2n + 1$	1	...	...	...	$2n+1$												
4	÷	$^2V_5 \div {}^2V_4$	$^1V_{11}$	$\{^2V_5 = {}^0V_5;\ ^2V_4 = {}^0V_4\}$	$= \frac{2n-1}{2n+1}$	...	...	...	0	0	...	...	...	...	...	$\frac{2n-1}{2n+1}$						
5	÷	$^1V_{11} \div {}^1V_2$	$^2V_{11}$	$\{^1V_{11} = {}^2V_{11};\ ^1V_2 = {}^1V_2\}$	$= \frac{1}{2} \cdot \frac{2n-1}{2n+1}$	...	2	...	...	...	...	...	...	...	...	$\frac{1}{2} \cdot \frac{2n-1}{2n+1}$						
6	−	$^0V_{13} - {}^2V_{11}$	$^1V_{13}$	$\{^2V_{11} = {}^0V_{11};\ ^0V_{13} = {}^1V_{13}\}$	$= -\frac{1}{2} \cdot \frac{2n-1}{2n+1} = A_0$	...	...	...	...	...	...	...	...	...	...	0	....	$-\frac{1}{2} \cdot \frac{2n-1}{2n+1} = A_0$				
7	−	$^1V_3 - {}^1V_1$	$^1V_{10}$	$\{^1V_3 = {}^1V_3;\ ^1V_1 = {}^1V_1\}$	$= n - 1\ (= 3)$	1	...	n	...	...	...	...	...	...	$n-1$							
8	+	$^1V_2 + {}^0V_7$	$^1V_7$	$\{^1V_2 = {}^1V_2;\ ^0V_7 = {}^1V_7\}$	$= 2 + 0 = 2$	...	2	...	...	...	...	2										
9	÷	$^1V_6 \div {}^1V_7$	$^3V_{11}$	$\{^1V_6 = {}^1V_6;\ ^0V_{11} = {}^3V_{11}\}$	$= \frac{2n}{2} = A_1$	...	...	...	...	...	$2n$	2	...	...	...	$\frac{2n}{2} = A_1$						
10	×	$^1V_{21} \times {}^3V_{11}$	$^1V_{12}$	$\{^1V_{21} = {}^1V_{21};\ ^3V_{11} = {}^3V_{11}\}$	$= B_1 \cdot \frac{2n}{2} = B_1 A_1$	...	...	...	...	...	...	...	...	...	...	$\frac{2n}{2} = A_1$	$B_1 \cdot \frac{2n}{2} = B_1 A_1$	....	B_1			
11	+	$^1V_{12} + {}^1V_{13}$	$^2V_{13}$	$\{^1V_{12} = {}^0V_{12};\ ^1V_{13} = {}^2V_{13}\}$	$= -\frac{1}{2} \cdot \frac{2n-1}{2n+1} + B_1 \cdot \frac{2n}{2}$ ...	...	...	...	...	...	...	...	...	...	...	....	0	$\left\{-\frac{1}{2} \cdot \frac{2n-1}{2n+1} + B_1 \cdot \frac{2n}{2}\right\}$				
12	−	$^1V_{10} - {}^1V_1$	$^2V_{10}$	$\{^1V_{10} = {}^2V_{10};\ ^1V_1 = {}^1V_1\}$	$= n - 2\ (= 2)$	1	...	...	...	...	...	...	...	...	$n-2$							
13	−	$^1V_6 - {}^1V_1$	$^2V_6$	$\{^1V_6 = {}^2V_6;\ ^1V_1 = {}^1V_1\}$	$= 2n - 1$	1	...	...	...	...	$2n-1$											
14	+	$^1V_1 + {}^1V_7$	$^2V_7$	$\{^1V_1 = {}^1V_1;\ ^1V_7 = {}^2V_7\}$	$= 2 + 1 = 3$	1	...	...	...	...	...	3										
15	÷	$^2V_6 \div {}^2V_7$	$^1V_8$	$\{^2V_6 = {}^2V_6;\ ^2V_7 = {}^2V_7\}$	$= \frac{2n-1}{3}$	...	...	...	...	...	$2n-1$	3	$\frac{2n-1}{3}$									
16	×	$^1V_8 \times {}^3V_{11}$	$^4V_{11}$	$\{^1V_8 = {}^0V_8;\ ^3V_{11} = {}^4V_{11}\}$	$= \frac{2n}{2} \cdot \frac{2n-1}{3}$	...	...	...	...	...	...	...	0	...	...	$\frac{2n}{2} \cdot \frac{2n-1}{3}$						
17	−	$^2V_6 - {}^1V_1$	$^3V_6$	$\{^2V_6 = {}^3V_6;\ ^1V_1 = {}^1V_1\}$	$= 2n - 2$	1	...	...	...	...	$2n-2$											
18	+	$^1V_1 + {}^2V_7$	$^3V_7$	$\{^2V_7 = {}^3V_7;\ ^1V_1 = {}^1V_1\}$	$= 3 + 1 = 4$	1	...	...	...	...	...	4										
19	÷	$^3V_6 \div {}^3V_7$	$^1V_9$	$\{^3V_6 = {}^3V_6;\ ^3V_7 = {}^3V_7\}$	$= \frac{2n-2}{4}$	...	...	...	...	...	$2n-2$	4	...	$\frac{2n-2}{4}$	...	$\left\{\frac{2n}{2} \cdot \frac{2n-1}{3} \cdot \frac{2n-2}{3} = A_3\right\}$						
20	×	$^1V_9 \times {}^4V_{11}$	$^5V_{11}$	$\{^1V_9 = {}^0V_9;\ ^4V_{11} = {}^5V_{11}\}$	$= \frac{2n}{2} \cdot \frac{2n-1}{3} \cdot \frac{2n-2}{4} = A_3$	...	...	...	...	...	...	...	...	0								
21	×	$^1V_{22} \times {}^5V_{11}$	$^0V_{12}$	$\{^1V_{22} = {}^1V_{22};\ ^0V_{12} = {}^2V_{12}\}$	$= B_3 \cdot \frac{2n}{2} \cdot \frac{2n-1}{3} \cdot \frac{2n-2}{3} = B_3 A_3$	...	...	...	...	...	...	...	...	...	...	0	$B_3 A_3$	....	......	B_3		
22	+	$^2V_{12} + {}^2V_{13}$	$^3V_{13}$	$\{^2V_{12} = {}^0V_{12};\ ^2V_{13} = {}^3V_{13}\}$	$= A_0 + B_1 A_1 + B_3 A_3$	...	...	...	...	...	...	...	...	...	...	....	0	$\{A_0 + B_1 A_1 + B_3 A_3\}$				
23	−	$^2V_{10} - {}^1V_1$	$^3V_{10}$	$\{^2V_{10} = {}^3V_{10};\ ^1V_1 = {}^1V_1\}$	$= n - 3\ (= 1)$	1	...	...	...	...	...	...	...	...	$n-3$							
					Here follows a repetition of Operations thirteen to twenty-three.																	
24	+	$^4V_{13} + {}^0V_{24}$	$^1V_{24}$	$\{^4V_{13} = {}^0V_{13};\ ^0V_{24} = {}^1V_{24}\}$	$= B_7$	...	...	...	...	...	...	...	...	...	...	....	....	....	......	......	......	B_7
25	+	$^1V_1 + {}^1V_3$	$^1V_3$	$\{^1V_1 = {}^1V_1;\ ^1V_3 = {}^1V_3;\ ^5V_6 = {}^0V_6;\ ^5V_7 = {}^0V_7\}$	$= n + 1 = 4 + 1 = 5$ .... by a Variable-card. by a Variable-card.	1	...	$n+1$	...	...	0	0										