Sir Alphabet Function, a knight much renowned,
Who had gained little credit on classical ground,
Set out through the world his fortune to try,
With nought in his pate but his x, v, and y.

Charles Babbage

ON 5 JUNE 1833, Ada attended a party where she met Charles Babbage. Babbage, who later dubbed himself Sir Alphabet Function, was a 42-year-old mathematician and widower, who, like Ada's father, had gone to Cambridge University. He was regarded as one of the greatest minds of the nineteenth century. His interests ranged from mechanical dolls to mechanical machines, from the probability of games of chance to the moves in a chess game. Compared to most of the adults Ada knew who were so very proper, Babbage was an iconoclast. He viewed politics, science, technology and mathematics in an unusual way.

When Babbage was a student at Cambridge, he founded the Analytical Society with his friends John Herschel and George Peacock. They wanted the university to adopt Leibnitz's notation of calculus rather than Newton's method. The three men were determined to do their best to leave the world wiser than they found it.

Herschel became a noted astronomer. George Peacock, later to become the Dean of Ely, was responsible for major educational reform at Cambridge. Babbage left us with the conceptual building blocks for the birth of the computer revolution. It all began, according to Babbage's autobiography, *Passages in the Life of a Philosopher* (see Appendix I), when Herschel encouraged Babbage's idea to build an engine that could calculate numbers by steam. Babbage thus became part of the history of brilliant mathematicians who turned their attention to the mechanical and technological manipulation of numbers.

One of the first mechanical calculating machines was invented in 1642 by the French mathematician Blaise Pascal, who was nineteen years old. Bored by working on his father's accounts, Pascal invented a machine that was capable of addition.

In 1671 the German mathematician Leibnitz designed a machine capable of multiplication by means of repeated additions using a stepped reckoner. Babbage adapted the stepped reckoner in the design of his first calculating engine, the Difference Engine.

Ada, in this series of letters, made only remote references to Charles Babbage, but it is evident even from these remarks that someone very special had come into her life. The bulk of her correspondence with him, which Babbage preserved, took place during the summer of 1843, when Ada was writing the Notes describing his Analytical Engine. For the years 1833-1835 we must rely on other sources to gain an idea of Ada's relationship with Babbage and the Difference Engine. The following information comes primarily from Lady Byron's diaries and letters found in the Lovelace-Byron Collection; Babbage's marvelous autobiography, *Passages*; Anthony Hyman's *Charles Babbage, Pioneer of the Computer*; and other sources listed in Appendix I.

In the Notes describing Babbage's Analytical Engine, which Ada wrote in 1843, one of her greatest strengths was her ability to distinguish between Babbage's calculating engines. Also, Ada's passionate support and belief that Babbage's engines were not only of practical advantage, but would lead to a deeper understanding of mathematics and science, most likely stemmed from her first encounter with the Difference Engine. It is important, therefore, to understand the history of the Difference Engine and highlight it as Ada first saw it and as Babbage described it in June 1833.

In 1823 Babbage received what can be considered the first government grant to support technological development to build his first calculating engine, the Difference Engine. The government supplied part of the cost, but by the time Babbage met Ada in June 1833, funding of the engine was in jeopardy. A part of the engine was built. It had a feedback mechanism and when completed would be able to print out logarithm tables that could be used for navigation. It worked on the theory of calculating differences.

Babbage had supervised construction of the engine in a fireproof building with a glass roof behind his house in Dorset Street. The machine was 29 inches tall, 27 inches wide and 36 inches deep, which is about the size of a small modern business computer.

Babbage was famous for Saturday night soirées at his home that attracted hundreds of the most prominent people of the time: the Duke of Wellington, Charles Darwin, Charles Dickens, Michael Faraday, Andrew Crosse (an experimenter in electricity), and Harriet Martineau (a popular science writer). The star attraction of these soirées was the Difference Engine.

Babbage was delighted to show the Difference Engine to his guests. When he showed it to the Duke of Wellington for the first time, he left pieces of music lying near it. He knew the Duke loved country dance music, and Babbage wanted him to associate the engine with music. Instead, the Duke remarked how the engine might be a help in handling all the variables a general might need in conducting a military campaign.

When one woman saw the Difference Engine, as Babbage recollected in *Passages*, she asked him: "If you put in the wrong figures, will the right answers come out?" Today, we refer to such statements as GIGO, or Garbage In Garbage Out. Harriet Martineau described Babbage's response to such questions: ". . . I always thought he appeared to great advantage as a host. His patience in explaining the machine in those days was really exemplary. I felt it so, the first time I saw the miracle, as it appeared to me."

Babbage invited Ada to see the miraculous Difference Engine a few weeks after they met. Ada's impression of the Difference Engine was recalled by Sophia Frend more than fifty years later: "Miss Byron, young as she was, understood its working, and saw the great beauty of the invention." An excerpt from Lady Byron's letter to Dr King on 21 June gives us more information about the first time she went with Ada to see the Difference Engine:

> We both went to see the thinking machine (for so it seems) last Monday. It raised several Nos. to the 2nd & 3rd powers, and extracted the root of a Quadratic equation. I had but faint glimpses of the principles by which it worked. – Babbage said it had given him notions with respect to general laws which were never before presented to his mind – For instance, the Machine could go on counting regularly, 1, 2, 3, 4, &c – to 10,000 – and then pursue its calculation according to a new ratio . . . He said, indeed, that the exceptions which took place in the operation of his Machine, & which could not be accounted for by any errors or derangement of structure, would follow a greater number of uniform experiences than the world has known of days & nights. – There was a sublimity in the views thus opened of the ultimate results of intellectual power.

Lady Byron's calling the Difference Engine a "thinking machine" was not an accurate description of its ability but a common name given to such machines at the time. It was a calculating engine. Numbers were put on successive carriages consisting of toothed wheels that had ten digits marked on the edge. Whenever any wheel, in performing addition, passed from nine to zero, the projecting tooth pushed over a certain lever. Babbage described how a calculation could be done in nine seconds, quickly and accurately.

Babbage's description, as Lady Byron recorded it, must have touched Ada, since it was more than just an explanation of the mechanical manipulation of numbers. To both Ada and Babbage the manipulation of numbers was not just a practical exercise but a path to mathematical and metaphysical understanding.

Metaphysics was not an area that interested Lady Byron. She regarded Babbage's metaphysical views as "the whim of the moment," and preferred for Ada to be grounded in what she considered the facts. She was always watching for signs of Lord Byron's influence – his passionate nature – in Ada's personality. Lady Byron enlisted the sober Dr King to help Ada not only with mathematics, but to insure that Ada's passions were directed along a proper path. Dr King wrote Ada sermons, and when she asked him concrete questions about mathematics, he replied that he was puzzled. He explained that as a student at Cambridge University he seldom read a book that was not assigned.

Despite Dr King's moralizing, when Ada met Babbage, learning more about mathematics, science and technology became

3.
Make It Part of Your Mind, Solving Unsolvable Equations, The Royal Road to Mathematics
[1834-1835]

EVEN THOUGH DR FREND was helpful in trying to answer Ada's questions, he was growing old. He encouraged her to become friendly with Mrs Somerville, a prominent scientist, whose *Connection of the Physical Sciences* had just been published. Today there is a college named in her honor at Oxford University.

Mary Somerville was essentially self-taught. Her interest in mathematics was sparked by reading mathematical puzzles in a sewing magazine. After the death of her first husband, she studied mathematics on her own, reading Newton's works in Latin. George Peacock (Babbage's friend) used her translation from French of LaPlace's work as a textbook at Cambridge University. In addition to respecting her as a scientist, everyone regarded Mrs Somerville as a gentle, humble, and kind human being.

From Mrs Somerville's letters to Ada, it is apparent that she was anxious not only to help Ada with her mathematics but also to put that passion in a proper perspective. As a result Mrs Somerville encouraged Ada in all pursuits from knitting caps to riding on the downs. Ada became a frequent visitor (sometimes at her own request) to the Somerville home at the Royal Hospital in the Chelsea section of London, where Dr Somerville (Mrs Somerville's second husband) was a physician.

This was Ada's first involvement with a traditional family. She became close friends with the whole family: Martha and Mary, Mrs Somerville's daughters, and Woronzow Greig, her son

from her first marriage. Greig became Ada's friend, confid and attorney. She spent many happy moments playing music, riding horses, and going to Babbage's home with members of the Somerville family.

Ada refers in her letters to Dionysius Lardner, who was a friend of Babbage's. Lardner was a popular scientific personality who gave lectures about the Difference Engine at the Mechanics Institute, which Ada attended. She used the mathematics textbooks he wrote and was particularly impressed by his article about the Difference Engine published in the *Edinburgh Review*. By June 1834 Lady Byron wrote that Ada regarded "the Difference Engine as a friend."

Ada continued to attend Babbage's Saturday night soirées. He sent her an invitation enticing her to come to see the "Silver Lady," one of the two automatic dolls he had. In *Passages* he described one of the dolls, "whose eyes were filled with imagination . . ."; however, from Ada's letters to Mrs Somerville, it appears that she was more captivated by the Difference Engine than by the "Silver Lady."

During the summer of 1834 Ada had a chance to see the Industrial Revolution in action. She went with her mother on a trip to the north of England and visited many of the new factories blossoming throughout England. They visited printers and ribbon factories in Coventry. Lady Byron drew a picture of a punched card used to instruct the loom. After several weeks of factory tours in the Midlands, they settled down with one of Lady Byron's friends, Lady Gosford, and her two daughters Annabella (named after Lady Byron) and Olivia (Livy) Acheson. While the mothers were busy with a health cure, Ada decided to make good use of her time and teach Annabella and Livy mathematics.

As a teacher Ada revealed how she approached a subject that normally does not evoke passion, especially in young women. She used both reason and imagination to get her mathematical message across. Like her mother, she insisted on excellent performance, but her method was not "tickets." Instead, she tried to build an esprit de corps by involving her students in only be an infinitesimal fraction of all I want to understand about the many connections & relations which occur to me, how the matter in question was first thought of & arrived at, &c, &c, I am particularly curious about this wonderful theorem.

However I try to keep my metaphysical head in order. . .
Yours most truly A.A. Lovelace

ADA ANALYZED her unique scientific skills, shaping them into a scientific Trinity. Her approach was and is for many people even today considered heretical. It moved effortlessly between science and imagination. She concentrated so much on her intuitive perceptions that she did not see the world of "facts," and Lady Byron would never let Ada forget those facts.

Lady Byron sent Ada letters from Paris detailing her latest illness and her involvement with Medora. Ada had received and commented on the pin cushion that Medora made, but most of Ada's responses to her mother's letters are filled with grand scientific dreams, the latest scientific developments, humor, and happiness. Then, like many people who walk confidently on a path, there is an unexpected and major diversion. Lady Byron revealed to Ada her "most strange and dreadful history."

To Lady Byron

Saturday, 6 February 1841 Ockham

Dearest Mama. By this time you have probably received my speculative letter. I have been reflecting since, that I much wish I could communicate to you the whole of my ideas & speculations, as they at present stand; more particularly about life & death. There are some so very extraordinary, & as I must firmly believe, so highly important, that I wish I could communicate a glimpse of them to any other mind capable of taking them in. And yours, dearest Mama, is more so than any. – At any rate it is my intention to make out notes of them by degrees, for my own future use, or in case anything should

happen to me; and I will certainly endeavor during this year at any rate, to put you in possession of them. –

And now I must tell you what my opinion of my own mind & powers is exactly; – the result of a most accurate study of myself with a view to my future plans, during many months. I believe myself to possess a most singular combination of qualities exactly fitted to make me pre-eminently a discoverer of the hidden realities of nature. You will not mistake this assertion either for a wild enthusiasm, or for the result of any disposition to self exaltation. On the contrary, the belief has been forced upon me, & most slow have I been to admit it even. And now I will mention the three remarkable faculties in me, which united, ought (all in good time) to make me see anything, that a being not actually dead, can see & know, – (for it is what we are pleased to call death, that will really reveal things to us).–

Firstly: Owing to some peculiarity in my nervous system, I have perceptions of some things, which no one else has; or at least very few, if any. This faculty may be designated in me as a singular tact, or some might say an intuitive perception of hidden things; – that is of things hidden from eyes, ears & the ordinary senses. . . This alone would advantage me little, in the discovery line, but there is

Secondly; – my immense reasoning faculties;

Thirdly; my concentrative faculty, by which I mean the power not only of throwing my whole energy & existence into whatever I choose, but also bringing to bear on any one subject or idea, a vast apparatus from all sorts of apparently irrelevant & extraneous sources. I can throw rays from every quarter of the universe into one vast focus.

Now these three powers; (I cannot resist the wickedness of calling them my discovering or scientific Trinity), are a vast apparatus put into my power by Providence; & it rests with me by a proper course during the next 20 years to make the engine what I please. But haste; or a restless ambition, would quite ruin the whole.

My ambition, & I cannot say with any truth, that I feel myself by any means able to banish ambition, must be of the most remote kind. And besides it is rather my belief that greatness of the very highest order, is never appreciated here, to the fullest extent, until after the great man (or woman's) death. My ambition should be rather to be great, than to be thought so. This however is a high philosophy, but I must believe perfectly attainable, as I say all in good time. Well, here I have written, what most people would call a remarkably mad letter, & yet certainly one of the most logical, sober minded, cool, pieces of composition, (I believe), that I ever penned; the result of much accurate, matter-of-fact, reflection & study. –

I could indeed tell you much that is curious. Meantime my course is so clear & obvious, that it is delightful to think how straight it is. And yet what a mountain I have to climb! It is enough to frighten anyone who had not all that most insatiable & restless energy, which from my babyhood has been the plague of your life & my own. However it has found food I believe at last. For 25 years have the feelers been out in every direction, trying all sorts of experiments.

Give me 30 more, & the feelers shall feel about to some purpose, & in a very different way from there hitherto grovelling groping. . .

It must, I think, be a comfort to you, to find that I have done on the whole, much better than might have been expected, without you this winter. Then to be sure, I have had your letters. You must manage if you die before me . . . to vibrate some little things now & then into my ear. Don't frighten me with a gawky, ugly ghost; but make some use of the little bit of an additional sense, which I affirm myself to have.

Or, if you will appear to my eyes, which I do not on the whole wish, pray be a very pretty comely-looking, & good-natured ghost.

To Lady Byron

[Undated, quoted in introduction, early 1841]

I have now gone thro' the night of my life, I believe. I consider that my being began at midnight, and that I am now approaching the Dawn.

My sun is rising with a clear, steady, & full, rather than dazzlingly brilliant light and is illuminating all around me. He will I expect gradually run his course, to his zenith, with the same full steady, even, light; and then maybe he will eventually set amidst rosy, golden, dazzling clouds, that may show to me something of the Spirit Land to which with his last rays I must gently depart, & he will tell me to leave for mankind in my footsteps a little of that brightness from Beyond, which has reflected on my head, an earnest, an indication, a glimpse of that which the Great Future will unroll! –

Now all this is highly figurative. Perhaps it is too figurative for you, or for anyone. Perhaps it is too glowing, too imaginative, too enthusiastic. . .

To Lady Byron

Sunday, 21 February [1841] Ockham Park

Dearest Mama. It is a pleasure to be able to say now how much better William now is; & that he yesterday celebrated his Birthday by a little waltz with me; (we are quite alone except my sisters), at which I felt much pleased & honored. . .

So you say, "I am under the dominion of electricity;" which amused me so much, that instead of receiving the accompanying scold with a grave & contrite face, I was seized with fits of laughter. – But there is a little truth in your saying, I do really believe. The King of my mind is rather electrical in his attributes certainly right now. –

To Charles Babbage

Monday, 22 February [1841] Ockham Park

My Dear Mr Babbage. We are to move to Town on Thursday; & I hope to see you as soon afterwards as you like, – the sooner the better. Remember that one o'clock is the best hour for a call. –

I believe I shall perhaps pass Sunday Evening with Mr &

To Augustus De Morgan

Sunday, 15 August [1841] Ockham Park

Dear Mr De Morgan. You must be beginning to think me lost. I have been however hard at work, with the exception of 10 days complete interruption from company. I have now many things to enquire; First of all; can I spend an evening with Mrs De Morgan & yourself on Tuesday the 24th? On that day we go to Town to remain till Friday, when we move down to Ashley for 2 months at least. . .

I have been especially studying this subject of Circulating Force, & believe that I now understand it very completely. I found that I could not rest upon it at all until I made the whole of the subject out entirely to my satisfaction. . . Yours most truly A.A. Lovelace

IN THE NEXT SERIES OF LETTERS Ada hypothesized a geometry of the "fourth dimension." Several popular books today deal with this subject: Rudy Rucker's *The Fourth Dimension*, Stephen Hawking's *A Brief History of Time*, and Philip Davis's *Descartes' Dream*. Also note Ada's mention of Bernoulli numbers, which are explained later when Ada suggested to Babbage that they be used in her description of the Analytical Engine.

The remains of Ada's correspondence to Augustus De Morgan are generally scattered, skewed, and undated; when they are dated, the dates are often incorrect. For example, Ada sent two letters to De Morgan Sunday 6 July, and the other Monday 6 July; both appear from their contents to have been written in 1841.

A constant theme in Ada's letters to De Morgan was the concern that she was taking up his time needlessly. She asked him whether he received the pheasants and whether he would like to come to visit. All her intense mathematical activity and correspondence with De Morgan prompted her to speculate. Many of her speculations, from extending geometry to other dimensions to her description of the nature of a function, have turned out to be correct.

Her correspondence with De Morgan in November 1841 was almost daily; she was working feverishly, "drowning in Calculus." Ada may also have been writing other feverish letters to Dr. Kay that do not remain because after Ada died he wrote Lady Byron: "No passage of my life is so full of marvel as the friendship with which I was honoured by your daughter. I felt that such a friendship as that with which she had distinguished me, must cease to be demonstrative after my marriage."

Whatever the exact nature of their relationship was, it can only be hinted at. There are hints. On 21 October Dr Kay wrote to Ada: "I have bethought me a new name for you which is prompted by your waywardness, beauty, & intangibility – You always elude my grasp, and seem to delight in leading me into some bog, while I am gazing on you half in admiration, half in wonder, somewhat in apprehension, and altogether in kindness. Henceforth you are christened 'Will-o'-the Whisp' A delusive & beautiful light flickering with wayward course over every dangerous pitfall."

On 27 October Ada decided to go to town, meaning London. She wrote her mother a letter about Byron and returned to Ashley Combe, Porlock. Ada found it difficult to understand graphing a functional equation, a wave, and generating that wave by graphing it point by point.

Lord Byron, as mentioned in the Introduction, described emotional relationships in terms of mathematical shapes, "princess of the parallelograms," "squaring her notions." Ada went in the opposite direction. In a letter written on 27 November [1841] she used the personal characterization Kay attributed to her, a "Will-o'-the Whisp" (Kay misspelled Wisp) to describe the whole functional equation. By doing that she revealed not only her frustration, but her understanding.

Using modern mathematical, scientific, and economic terminology, she laid a personal characterization on a mathematical term, much as a seamstress lays a pattern on material. Then Ada used the word "tangibility" to emphasize the "Will-o'-the-Wisp" metaphor.

10.

Working Like the Devil, A Fairy in Your Service, What a General I Would Make, An Analyst and a Metaphysician

[1843]

ADA GAVE WHEATSTONE, who was working with Richard Taylor, the publisher of a scientific journal, her translation of L. F. Menabrea's description of Babbage's Analytical Engine, which was published in French in a Swiss journal in October 1842. According to Babbage's recollection in his autobiography, *Passages,* many years after Ada's death, he wrote: "Some time after the appearance of his memoir [article] on the subject in the 'Bibliothéque Universelle de Génève,' the Countess of Lovelace informed me that she had translated the memoir of Menabrea. I asked why she had not herself written an original paper on the subject with which she was so intimately acquainted? To this Lady Lovelace replied that the thought had not occurred to her. I then suggested that she should add notes to Menabrea's memoir: an idea which was immediately adopted."

Babbage scribbled a note on 7 February 1843 stating that he had a meeting with Ada which was "under new circumstances." On 15 February Babbage, along with Dr Kay-Shuttleworth, attended the marriage of Hester King to Sir George Craufurd. Ada then started to "work like the Devil" for Babbage.

Chapters 10 and 11 contain Ada's correspondence during the period that she was writing the Notes. Her letters to Babbage reveal the process and the nature of their creative collaboration. Chapter 12 contains excerpts from Ada's Notes which, with the help of Colonel Rick Gross, have been annotated and related to the modern-day computer language named in her honor.

Ada's task was not easy because by the time Babbage died, he had filled over thirty volumes with plans for the Analytical Engine. Ada's job was to synthesize his ideas in such a way that the British government and scientists would recognize the value of Babbage's revolutionary invention. The publication, when completed, including Ada's translation of Menabrea's article and her Notes, was referred to as the Memoir. When Ada was finished with the Memoir, Babbage wanted to send it to Prince Albert, who had an interest in science. Babbage wanted to include a preface detailing the history of the British government's non-support of his calculating engines.

The letters that Ada wrote to Charles Babbage are located (with a few exceptions) in the British Library. The sequence of her letters to him can only be guessed at since so many are not dated. I have arranged a few letters in a different order from that in which they appear in the collection at the British Library.

Some biographers of Ada and Babbage call into question Ada's contribution to the Notes, almost as if Babbage wrote them and Ada was merely his secretary. It is hard to understand why that question even arose. Babbage in his autobiography clearly stated that Ada wrote the Notes based on the material he gave her. It was a collaborative effort because it was a description of Babbage's plans for an Analytical Engine. However, according to Babbage, Ada corrected a mathematical error that he had made. When Babbage tried to alter any of her Notes, Ada had something to say about his editing ability. The only help Babbage gave Ada, according to him, was in completing the table for the Bernoulli numbers as she was very ill at the time.

Ada began her task of writing the Notes by asking pertinent questions and selecting a mathematical model that would highlight the difference between Babbage's first calculating engine, the Difference Engine, and the Analytical Engine.

Ada's selection of the Bernoulli numbers was a perfect example to highlight the difference. To calculate Bernoulli numbers, one must perform many operations, then take the results of those operations and use them in other operations. For example, add, then divide, then raise to a power, and on and on. No mere calculator or calculating engine like the Difference Engine could perform this feat. Only the Analytical Engine could calculate Bernoulli numbers without the intervention of a "human hand or head" because numerical information and operational instructions would be received by means of a punch card (or punched card), which Babbage had adapted from Jacquard. Jacquard's punch card instructed the loom how to weave designs into a fabric.

Just as Ada was grounded in selecting a specific mathematical model that would show the power of the Analytical Engine, she was also developing a metaphysical understanding of the Analytical Engine. She began to see not only the technical details, but also the whole picture, the concept, of what the Analytical Engine could do. This was no easy task since Babbage had volumes of designs and many sample iterations of what today might be referred to as computer programs. Yet Ada, questioning and arguing with Babbage and distilling the information he gave her, was able to put his remarkable idea for the Analytical Engine in its proper perspective.

In the midst of this very serious undertaking, Ada wrote delightful and outlandish letters to Babbage. The letters are not only filled with discussions about Bernoulli numbers and the Medora melodrama, but visions of herself as a fairy, puzzle-pate and general. She even made references to flirtations with her Somerset neighbour, Frederick Knight. Babbage became her confidant, and she became his "interpretess."

To Charles Babbage

Thursday Morning [1843] Ockham

My Dear Babbage. I have read your papers over with great attention; but I want you to answer me the following question by return of post. The day I called on you, you wrote off on a

scrap of paper (which I have unluckily lost), that the Difference Engine would do. . . (something or other) but that the Analytical Engine would do. . . (something else which is absolutely general).

Be kind enough to write this out properly for me; & then I think I can make some very good Notes.

I have been considering about Prince Albert; but I much doubt the expediency of it. However there is time enough to consider of this.

I am anxious to hear how you are. Yours ever A.A.L.

ADA BEGAN TO MAKE headway with the Notes and sent some off for Babbage's inspection. As for her Note A, Babbage replied the next day: "If you are as fastidious about the acts of your friendship as you are about those of your pen, I much fear I shall equally lose your friendship and your Notes. I am very reluctant to return your admirable & philosophic Note A. Pray do not alter it . . . All this was impossible for you to know by intuition and the more I read your notes the more surprised I am at them and regret not having earlier explored so rich a vein of the noblest metal."

Babbage continued his compliments and wrote her that Note D was in her usual "clear style."

In 1840 Ada had started thinking about putting games into mathematical language when she wrote Babbage about the game Solitaire. Using indices as a means of tracing each step of an algorithm was a similar conceptual skill.

The Analytical Engine would receive information about number, operations, and variables by means of the punched card. Ada wanted Babbage to be very specific about how the Analytical Engine would handle variables. In J. M. Dubbey's *The Mathematical Work of Charles Babbage,* he describes how Ada had a slightly more elaborate and improved way than Menabrea of writing out the sequence of operations taking into account the variables. From Ada's questions, and the table included and

My only impediment would be my Mother's health which is not at this moment quite so good as I could wish.

Are you at Ashley? and is it still convenient with all your other arrangements that I should join you there? – and will next Wednesday or next Thursday or any other day suit you: and shall I leave the [?] road at Taunton or at Bridgewater and have you got Arbogast Du Calcul Des Derivations with you there at Ashley. I shall bring some books about that horrible problem – the three bodies which is almost as obscure as the existence of the celebrated book "De Tribes Impostoribus." So if you have Arbogast I will bring something else.

Farewell my dear and much admired Interpretess.

Evermost Truly Yours
C Babbage

12.
The Analyst and the Metaphysician, and the Analytical Engine: A Selection from Ada's Notes
[1843]

Mechanics is the paradise of the mechanical sciences because by means of it one comes to the fruits of mathematics.
Leonardo da Vinci (1452-1519)

I am a philosopher. Confound them all –
Birds, beasts and men: but no, not womankind. –
Lord Byron
quoted by Babbage on the title page
of his autobiography, *Passages*

BABBAGE'S IDEA FOR THE Analytical Engine was the conceptual birth of the computer revolution. There were four components to the Analytical Engine – input, storage, processing, and output. The input medium was the punched card. There were two sets of cards – variable and operational cards. Though there was no programming in the modern sense, by arranging the cards one could program the engine to perform a repeating cycle or process, taking numbers from the store. Babbage planned to store over 1000 fifty-digit numbers. The numbers were then processed in what Babbage called the "mill." In Babbage's *Passages* he stated that there were three mechanisms for the output of numerical information: an apparatus for printing on paper, a means for producing a stereotype mould of the tables or results it computes, and a mechanism for punching on blank pasteboard cards or metal plates the results of any of its computations.

Babbage covered thousands of pages with designs and diagrams. In that form, it would be difficult to absorb the information or support the building of a prototype. To describe how a system that had not been built would work is very difficult (that essentially was done in Menabrea's description). To relate that description to its value and its use and abuse is a difficult and critical task as well, e.g., having had in 1940 a clear statement describing the power of atomic energy, its potential use and abuse, and having that statement be meaningful today. Ada's Notes are still thought-provoking over 150 years later, especially in light of the interaction between the computer and nuclear power and our desperate need to know not only technology, but the ramifications of technology.

Babbage supplied the concept and design, and Ada, being both an analyst and metaphysician, put that concept and design in an appropriate context on both micro and mega levels. She asked critical questions that many of us who are not professional mathematicians, scientists, or software engineers would ask. By asking those questions she has given us a methodology and a language to understand the content and concept of a technological innovation. She integrated what we now refer to as digital or scientific skills of reason and analysis, from verbal to numerical, with the poetical skills of imagination and metaphor.

Ada's Notes foreshadowed the capability of the modern computer and the impact such a development would have on the language of science. The Notes were written for an educated Victorian audience and are probably not of interest to many people today. Those who are interested can read the original, which now has been reprinted in several books (see Appendix I). The selection presented here highlights some of the issues discussed at the time and how they relate to the modern computer and to the software language *Ada*. (To differentiate Ada Lovelace from the software language *Ada*, the latter is italicized in this chapter.) It is important to mention once again that this chapter, the annotation of the excerpts from Ada's Notes, is a collaboration between Colonel Rick Gross, United States Air Force, and me, and represents our views.

All quotations and page numbers refer to the original Memoir, which was printed in Scientific Memoirs, Selections from The Transactions of Foreign Academies and Learned Societies and from Foreign Journals, edited by Richard Taylor, F.S.A., Vol III London: 1843, Article XXIX. *Sketch of the Analytical Engine invented by* Charles Babbage *Esq. By* L. F. Menabrea, *of Turin, Officer of the Military Engineers* [From the Bibliothèque Universelle de Génève, No. 82 October 1842].

To start with, Ada added a footnote to her translation. She emphasized the difference between Pascal's machine, which can be compared to a calculator, and Babbage's Analytical Engine, which can be compared to a modern day computer. Ada translated what Menabrea wrote: "For instance, the much-admired machine of Pascal is now simply an object of curiosity, which, whilst it displays the powerful intellect of its inventor, is yet of little utility in itself. Its power extended no further than the execution of the first four operations . . ." Ada augments Menabrea's statement and clearly defines the boundaries of Babbage's Analytical Engine.

From Ada's footnote to her translation of Menabrea's work on p. 670:

> This remark seems to require further comment, since it is in some degree calculated to strike the mind as being at variance with the subsequent passage (page 675), where it is explained that *an engine which can effect these four operations* [+, –, x, ÷] can in fact effect *every species of calculation* . . . The explanation lies in this: that in the one case the execution of these four operations is the *fundamental starting-point*, and the object proposed for attainment by the machine is the *subsequent combination of these* in every possible variety. . . The one *begins* where the other *ends*. . .

❦

On p. 687 Ada made a mistake in the translation that was not caught by either Babbage or Wheatstone, who, as can be seen from Ada's correspondence, were supposed to be proofing the translation and Notes. Ada translated "cosine" incorrectly. However, Herschel Babbage, years later, corrected the mistake with another mistake, 1/0. While others have focused and made an issue of a minor typo, we would rather focus on what Ada did do.

In her first "Philosophical Note A," which Babbage liked so much, Ada defined the boundaries of the Analytical Engine, and the details of how the Analytical Engine would perform its tasks. She emphasized that the Difference Engine, Babbage's first calculating engine, was designed primarily for calculating and printing tables, but the Analytical Engine was a mechanical and conceptual leap.

From Ada's Note A, p. 691

> The Analytical Engine, on the contrary, is not merely adapted for *tabulating* the results of one particular function and no other, but for *developping and tabulating* any function whatever. In fact the engine may be described as being the material expression of any indefinite function of any degree of generality and complexity. . .

❦

Ada had now emphasized the fundamentally different capability of the Analytical Engine, that is, to be able to store a program (a sequence of operations or instructions) as well as data (informational values themselves). At this point, she began to recognize and to amplify the increased responsibility this new capability placed upon the machine's user, to specify the stored program both precisely and in complete accordance with the user's interest. Her recognition of this increased responsibility is a remarkable insight, in that the magnitude of this specification task (a task we refer to today as *software development*) is only now being appreciated.

It is accordingly most fitting that the programming language *Ada*, developed in the early 1980s by the U.S. Department of Defense, provides the most precise facilities for this software development (specification) task of any general-purpose software language for large-scale problems existing today.

In the following passage, Ada explained the difficulty of the software development task, that is, the difficulty of communicating to the machine what it is we expect it to do. But note that in so doing, she also extolled the power of mathematical language when it is precise. Thus, a software language capable of great precision in specification (like the *Ada* language) also provides great power.

Indeed, throughout this translation one is struck by the appreciation Ada exhibited for the principle that power comes from disciplined creativity. Neither her analyst nor metaphysician persona is allowed to overcome the other, resulting in a synergy of amazing potential. The powerful, innovative *Ada* software language is a fitting namesake. Its advanced features have been implemented in a framework that encourages their use in a structured, repeatable *software engineering* process. Indeed, Dr Frederick Brooks, a renowned modern software authority, forecasted that the *Ada* language's "greatest contribution will be that switching to it occasioned training programmers in modern software-design techniques."[1]

From Note A, p. 693

> The confusion, the difficulties, the contradictions which, in consequence of want of accurate distinctions in this particular, have up to even a recent period encumbered mathematics . . . It may be desirable to explain, that by the word *operation*, we mean *any process which alters the mutual relation of two or more things*, be this relation of what kind it may. This is the most general definition, and would include all subjects in the universe . . .
>
> They will also be aware that one main reason why the separate nature of the science of operations has been little felt, and in general little dwelt on, is the *shifting* meaning of many of the symbols used in mathematical notation. First, the symbols of *operation* are frequently *also* the symbols of the *results* of operations . . .

Secondly, figures, the symbols of *numerical magnitude*, are frequently *also* the symbols of *operations*, as when they are the indices of powers [e.g., 2 and 3^2] . . . [In] the Analytical Engine . . . whenever numbers meaning *operations* and not *quantities* (such as indices of powers), are inscribed on any column or set of columns, those columns immediately act in a wholly separate and independent manner . . .

One of Ada's first letters to De Morgan, which does not remain, dealt with acoustics. De Morgan directed Ada to the *Penny Encyclopedia* to find out more about the relationship between mathematics and music. Ada's great love was music and she speculated how the Analytical Engine might deal with it. We have highlighted in bold type sections which have been quoted often. For example, guest editor Denis Baggi's introduction to the July 1991 issue of *Computer* (devoted entirely to computer-generated music) began with an acknowledgment that Ada was the first to have suggested such an application.[2]

It is perhaps coincidental in this regard, but still appropriate, that one of the advanced features of the software language *Ada* is its strong typing capability. Strong typing allows an *Ada* software developer to define within the *Ada* language named mathematical objects (such as musical constructs, e.g., "tones") and a set of operations appropriate to those objects (e.g., "play," "store," etc.). Having done so, the developer can then refer to these objects and operations directly and abstractly, avoiding the requirement levied by less advanced languages to encode manually such objects and operations into alphanumeric values (a process both error-prone and cumbersome). The software language *Ada* thus supports Ada's suggestion that a machine like the Analytical Engine could operate directly on music.

From Note A, p. 694

Again, it [the Analytical Engine] might act upon other

things besides *number*, were objects found whose mutual fundamental relations could be expressed by those of the abstract science of operations, and which should be also susceptible of adaptations to the action of the operating notation and mechanism of the engine . . . **Supposing, for instance, that the fundamental relations of pitched sounds in the science of harmony and of musical composition were susceptible of such expression and adaptations, the engine might compose elaborate and scientific pieces of music of any degree of complexity or extent.**

Once Ada had made the distinction between numbers and the operations to be performed, it was not difficult for her to project further how the Analytical Engine would then be capable of giving two types of results – numerical and symbolic (e.g., algebraic). Because the Analytical Engine could generate new programs as well as numbers, it opened up a vast new territory for the analysis of information.

Here again, the *Ada* software language contains somewhat unique facilities corresponding in a sense to Ada's insight. One such *Ada* facility is the generic subprogram, a template for future software generation. Having defined a generic subprogram for data of one type, the *Ada* software developer can create new copies automatically tailored to data of other types.

A second unusual *Ada* facility, exception handling, reflects in a different but related way Ada's vision of the Analytical Engine's superiority over the Difference Engine. *Ada* exception handlers can be defined by the developer to deal in a controlled way with what Parnas and Wuerges called "undesired events,"[3] those combinations of input data that might otherwise cause aberrant program behavior. In this sense the *Ada* language exception handler operates at a level of control above the program itself, confirming Ada's foresight.

From Note A, p. 696

The former engine [the Difference Engine] is in its nature strictly *arithmetical*, and the results it can arrive at lie within a very clearly defined and restricted range, while there is no finite line of demarcation which limits the powers of the Analytical Engine. These powers are co-extensive with our knowledge of the laws of analysis itself, and need be bounded only with our acquaintance with the latter. Indeed we may consider the engine as the *material and mechanical representative* of analysis, and that our actual working powers in this department of human study will be enabled more effectually than heretofore to keep pace with our theoretical knowledge of its principles and laws, through the complete control which the engine gives us over the *executive manipulation* of algebraical and numerical symbols.

❦

In the seventeenth century, imagination was used interchangeably with fancy. However, by the nineteenth century, Wordsworth and Coleridge came to identify imagination with the creative processes in poetry and discovery. Imagination was considered the highest faculty. Ada continued along the Coleridgean path and used her imagination to speculate on how the Analytical Engine might be a path as well to "higher truth." In the following passage Ada looked at the Analytical Engine from a metaphysical point of view and explained its potential to aid science.

From Note A, p. 696

Those who view mathematical science not merely as a vast body of abstract and immutable truths, whose intrinsic beauty, symmetry and logical completeness, when regarded in their connexion together as a whole, entitle them to a prominent place in the interest of all profound

and logical minds, but as possessing a yet deeper interest for the human race, when it is remembered that this science constitutes the language through which alone we can adequately express the great facts of the natural world, and those unceasing changes of mutual relationship which, visibly or invisibly, consciously or unconsciously to our immediate physical perceptions, are interminably going on in the agencies of the creation we live amidst: those who thus think on mathematical truth as the instrument through which the weak mind of man can most effectually read his Creator's works, will regard with especial interest all that can tend to facilitate the translation of its principles into explicit practical forms.

❦

Ada repeated the distinction between the two engines again and again because many people criticized Babbage for not continuing to work on his first calculating engine, the Difference Engine, and instead putting all his efforts into the Analytical Engine. It is a distinction that even some people today have difficulty understanding.

In simple terms, the Analytical Engine used punch or punched cards, like the first modern mainframe computers, as an input device. It had a "store" to store numbers. It was not until the mid-1960s that the modern computer could store as many digit numbers as did the Analytical Engine. The Analytical Engine had a "mill" where the information was processed and is similar to the Central Processing Unit (CPU) in the modern computer.

Finally, the Analytical Engine used several methods to print out information, even in graph form. It was not programmable in the modern sense of that word. It was to be programmable in the software by arranging the punch cards by repetition of cycles. Ada emphasized this distinction by using a metaphor (highlighted in bold type) as accurate as one her father might have written.