Simply Turing

MICHAEL OLINICK

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Contents

Praise for *Simply Turing*

"*Simply Turing* explores the nooks and crannies of Alan Turing's multifarious life and interests, illuminating with skill and grace the complexities of Turing's personality and the long-reaching implications of his work."

—Charles Petzold, author of *The Annotated Turing: A Guided Tour through Alan Turing's Historic Paper on Computability and the Turing Machine*

"Michael Olinick has written a remarkably fresh, detailed study of Turing's achievements and personal issues. Bravo!"

—Brian Winkel, Director of SIMIODE and Professor Emeritus of Mathematical Sciences at the United States Military Academy

"Michael Olinick presents an impressive work, covering Turing's early life, the wartime period of code-breaking, and his post-war life and death. Most touching was Turing's request, as an adult, that his parents give him a teddy bear for Christmas, as he had never had one as a boy. On the war years, Olinick draws us methodically through a simple, clear history of codes and code-breaking, featuring Turing's contributions. Most fascinating are Olinick's questions about Turing's death: Was it a suicide, as the inquest declared, or a tragic accident? Or perhaps something more sinister? Perhaps we will never know."

—Paul Wonnacott, Professor Emeritus of Economics, University of Maryland and Middlebury College

"Michael Olinick has written a vibrant and absorbing biography of Alan Turing. Turing's work as a cryptographer during WW II and his pioneering the development of the digital computer helped us win that war and make our technology-driven world of today possible—all this against the backdrop of the homophobic world Turing tried to navigate."

—Joseph Malkevitch, Professor of Mathematics at York College (CUNY) and CUNY Graduate Center

"As the father of the field of computer science, every aspect of Alan Turing's life and work is important to us today as we benefit from his brilliant insights. Michael Olinick's book makes them all interesting and accessible. He highlights the development of Turing's fascination with the biology of the human body and brain and the idea that they can be considered as complex machines. He shows how this idea formed the basis of much of Turing's work and how his understanding of the mechanistic principles of biological systems coupled with his ability to 'think outside the box' and his thorough understanding of mathematical principles informed and guided his developing ideas about how to design thinking machines that would ultimately lead to his 'universal computing machine'. Reading *Simply Turing* is like walking alongside this fascinating man. Olinick has meticulously researched and clearly explained Turing's life, his passions, and his work so that his personality comes alive, his brilliant creativity astounds and we come away feeling that we have lost a close and dear friend."

–Tom Perera author of *Inside Enigma* and *The Story of the Enigma* and Professor Emeritus of Neuroscience at Montclair State University

“Michael Olinick tells the story of Alan Turing in clear, energetic prose. Those who don’t know Turing’s story will find *Simply Turing* to be a compelling introduction to one of the key pioneers of computer science, artificial intelligence, and logic. Olinick includes enough technical details, easily accessible to the undergraduate mathematics student, to help the reader understand the breadth and creativity of Turing’s contributions. Far from the conventional story of a colorful and misunderstood martyr, *Simply Turing* shows why Turing was a foundational figure in computer science and why the ultimate prize for innovation in computer science is named in his honor.”

–David Alan Grier, author of *When Computers Were Human* and Former President of IEEE Computer Society

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Series Editor's Foreword

Simply Charly's "Great Lives" series offers brief but authoritative introductions to the world's most influential people—scientists, artists, writers, economists, and other historical figures whose contributions have had a meaningful and enduring impact on our society.

Each book provides an illuminating look at the works, ideas, personal lives, and the legacies these individuals left behind, also shedding light on the thought processes, specific events, and experiences that led these remarkable people to their groundbreaking discoveries or other achievements. Additionally, every volume explores various challenges they had to face and overcome to make history in their respective fields, as well as the little-known character traits, quirks, strengths, and frailties, myths, and controversies that sometimes surrounded these personalities.

Our authors are prominent scholars and other top experts who have dedicated their careers to exploring each facet of their subjects' work and personal lives.

Unlike many other works that are merely descriptions of the major milestones in a person's life, the "Great Lives" series goes above and beyond the standard format and content. It brings substance, depth, and clarity to the sometimes-complex lives and works of history's most powerful and influential people.

We hope that by exploring this series, readers will not only gain new knowledge and understanding of what drove these geniuses, but also find inspiration for their own lives. Isn't this what a great book is supposed to do?

Charles Carlini, Simply Charly
New York City

Preface

One mid-afternoon in late June 2012, people of all ages gathered along Sackville Street in Manchester, England. As the hour advanced, the crowd grew until it was four or five deep. Many took seats along a wall on the north side of the street, beyond which lay a small park, Sackville Gardens. The opening ceremony of the London Olympics was but a few weeks away, and the Olympic torch was due to pass this spot in a few minutes.

The arrival of half a dozen motorcycle police heralded the start of the procession, which included other security personnel on foot, on bicycles, and in cars and vans. Large buses trumpeted commercial sponsors of the Olympics: red ones for Coca Cola, blue ones for Samsung, green ones for Lloyds Trustee Savings Bank. Other coaches ferried torch carriers, Olympic officials, dancers, instrumentalists, and local celebrities. At last, the torchbearer ran down the center of the street, flanked by a dozen security men and women in jogging attire.

Carrying the lighted torch in his left hand was 30-year-old Martin Hewitt, whose right arm was paralyzed by a bullet as he led his troops in a battle in Afghanistan five years earlier. Martin overcame the injury to join the British Disabled Ski Team and participated in expeditions to the North Pole and Mount Everest. Onlookers cheered and waved British and Olympic flags, but suddenly turned and ran into the park when Hewitt passed by. He had turned the corner and headed toward a bench in the park's center where the crowd had reformed. Waiting at the bench with his yet unlit torch was the next carrier, 14-year-old Jonathan Whitehead, who was selected for battling epilepsy and raising funds for Epilepsy Action UK.

Why was this spot chosen for the passing of the Olympic flame? On the bench behind Hewitt and Whitehead sits a nearly life-size bronze statue of a man. He is dressed in a modest suit of mid-20th-century design, his necktie loosened, and the top button of his shirt unfastened. He stares straight ahead and holds an apple in the palm of his right hand. His face is framed by the inverted V formed as the two torches are brought together to transfer the flame from one to the other. The bench is covered with bouquets of fresh flowers; rainbow sashes and scarves adorn the statue. The ceremony clearly honors this man—but who is he?

The inscription on the vertical face of the bench behind the statue gives some clarity, but deepens the puzzle at the same time. It reads:

ALAN MATHISON TURING 1912-1954
IEKYF RQMSI ADXUO KVKZC GUBJ

Who was Alan Turing? Why was he being honored? What is the gibberish below his name? A plaque at the statue's feet reveals even more intriguing information:

Father of Computer Science
Mathematician, Logician,
Wartime Codebreaker,
Victim of Prejudice
–

"Mathematics, rightly viewed, possesses not only truth,
but supreme beauty – a beauty cold and austere,
like that of sculpture." – Bertrand Russell

The Olympic torch passing at Turing's statute took place on June 23, 2012, his 100th birthday. A major conference on Turing's intellectual legacy convened that morning in Manchester's City Hall, following the close of another such meeting at Cambridge University the day before.

A year earlier, Barack Obama became the first United States president given the rare honor of addressing Parliament in London. In his speech, he singled out three British scientists: Isaac Newton, Charles Darwin, and Alan Turing. The names and achievements of Newton and Darwin are known throughout the world. Famous in their own time, they were honored in death—Newton in 1727 at age 84 and Darwin in 1882 at 73—by burial in Westminster Abbey, with thousands attending their funerals.

Turing, by contrast, died in relative obscurity at the tragically young age of 41. His contributions to the creation of computer science were not widely known, and his codebreaking achievements shortening World War II by an estimated two years remained secret for two decades after his death. His concerns about the creation of artificial intelligence seemed premature in the 1950s when only a handful of computers existed. His pioneering ideas on developmental biology lay unnoticed for nearly half a century. Only a handful of close relatives and friends observed the scattering of his cremated ashes in a garden. Instead of being honored by the nation he had helped save, Turing was prosecuted by the state for his sexual orientation and forced to undergo a process of chemical castration that may have driven him to suicide by cyanide poisoning.

We will explore why Turing's work earns him a place alongside Newton, Darwin, and Albert Einstein in the pantheon of great scientists, as we also trace the arc of a life that recalls the tragic heroes of dramatic plays.

Michael Olinick
Middlebury, VT

Acknowledgements

My deepest appreciation goes to Andrew Hodges for his masterful work, *Alan Turing: The Enigma*, as well as his creation and maintenance of an online Turing archive. I strongly encourage readers wishing to study Turing's life and work in greater depth to read Hodges' book. The Turing archive provides an opportunity to examine many important letters, documents, and photographs.

I have also benefited greatly from the works of Jack Copeland, David Leavitt, and Dermot Turing listed in the *Suggested Reading*. Thanks are also due to Charles Carlini, who invited me to prepare this book, and to Helena Bachmann, whose careful copyediting substantially improved the manuscript.

I owe a special note of gratitude to my friend and colleague Robert P. Martin, who first suggested we develop and teach a course about Alan Turing together. I had the pleasure of working with Bob both inside and outside the classroom over many years. This work builds on many of his ideas and suggestions.

Finally, and most importantly, a special note of thanks to my wife Judy for her encouragement and support. Her careful reading of the manuscript has substantially improved the presentation and writing. Any errors of fact and infelicities of language remain the responsibility of the author. Please direct any comments to me at *molinick@middlebury.edu*.

1. Roots and Childhood

It was a shipboard romance.

Ethel Sara Stoney (1881-1976) was the 26-year-old daughter of the Madras Railway Company's chief engineer. Born in India, she spent much of her childhood in Ireland, studied at the Sorbonne in Paris, and returned to India at age 19. In April of 1907, she joined her family for a long trip to Ireland, traveling by ship over the Pacific, train through the United States, and another ship across the Atlantic. Julius Mathison Turing (1873-1947) was a fellow passenger. He was the second son of a curate who died when Julius was 10 years old, leaving the family struggling financially. Julius earned a scholarship to Oxford and won a placement in the Indian Civil Service, arriving in Madras in December 1896. After serving a decade, he took his first leave to England and met Sara Stoney on the voyage.

The ship-board romance progressed quickly. The couple married in October of 1907 in Dublin and soon returned to India. September saw the birth of their older son, John Ferrier Turing (1908-1983) in Coonoor. Although John had fond memories of his early years in India ("I saw much of the elephants for they were wont to wash themselves with great drenchings and slurping from their trunks outside my father's bungalow"), he contracted a serious case of dysentery from infected cow's milk. Because of John's dangerous illness, Sara decided to have her second child in England.

Alan Mathison Turing entered the world on Sunday, June 23, 1912, at the Warrington Lodge Medical and Surgery Home for Ladies in London. At that time, Britain was a rigid, class-based society. There were stirrings of discontent and challenges from Irish nationalists, suffragettes, and the trade unions, among others. War clouds gathered over Europe as tensions fueled an arms race. Five days after Alan's second birthday, Austria's Archduke Franz Ferdinand was killed, triggering the start of World War I.

In the biography of her younger son, Sara Turing noted that "It had been intended to take Alan out to India, but owing to his having slight rickets it was thought better to leave him in England. Despite his delicacy, he was an extremely vivacious and forthcoming small child." Julius returned to India in the spring of 1913; Sara followed in September when Alan was only 15 months old.

It was common for Britons serving in India to leave the children behind, and John's bout with dysentery and Alan's with rickets also affected the decision. While their action strikes modern sensibilities as cruel abandonment, Julius and Sara were following the wisdom of the times. The London-published *The Care of Infants in India: A Work for Mothers and Nurses in India Upon the Feeding and Management of Infants in Health and Sickness* advised:

> European children demonstrate most forcibly the unfavourable effects of hot climates, and in India it is generally thought desirable to bring them at an early age to a cold climate like that of this country to escape the effect of the tropical heat, and few sights are more pleasing than to see these puny, pallid, skinny, fretful little ones converted, by British food and British meteorology, into fat and happy English children.

Sara and Julius left their boys in the care of a retired army colonel and his wife who presided over Baston Lodge, a large house in St. Leonards-On-Sea, with their four daughters, several nieces, a nanny, and various servants. Baston Lodge was "home" to Alan and John for eight years, their fostered childhood punctuated by brief periods when their parents visited on leave.

The long family separations had significant impacts on both boys. In "My Brother Alan," a postscript to the Centenary Edition of Sara's biography *Alan Turing* (originally published in 1959), John wrote:

> But it was a harsh decision for my mother to have to leave both her children in England, one of them still an infant in arms. This was the beginning of a long sequence of separation from our parents, so painful to all of us … I am no child psychologist, but I am assured that it is a bad thing for an infant in arms to be uprooted and put in a strange environment … [B]oth of us were, in our different ways, sacrificed to the British Empire … [T]he unsettled existence of our childhood was to leave its mark on us both.

From infancy until age four, Alan saw little of his parents; but his mother stayed in England when Julius made the dangerous wartime trip back to India in 1916, and remained until the war's end. When Sara saw Alan again in 1921, she was alarmed about changes in his personality: "From having been extremely vivacious—even mercurial—making friends with everyone, he had become unsociable and dreamy," she wrote.

Alan's relationship with his mother was especially complex and challenging. His early letters to his parents began "Dear Mother and Daddy," a curious blend of the informal for Julius and the formal for Sara. Later in life, he made disparaging remarks about her to his friends, told his psychiatrist that he hated his mother, and reported dreams that revealed hostility toward her. John observed that while his father viewed Alan's eccentricities with amused tolerance, his mother displayed constant exasperation, "nagging him about his dirty habits, his slovenliness, his clothes and his offhand manners … achieving nothing by it except a dogged determination on Alan's part to remain as unconventional as possible."

> My mother implies [John wrote] that his many eccentricities, divagations from normal behaviour and the rest were some kind of emanation of his genius. I do not think so at all. In my view, these things were the result of his insecurity as a child, not only in those early days … but later on as his mother nagged and badgered him.

Thus, the unconventional behaviors that continued throughout Alan's life appeared quite early. As a child, Alan showed an intense interest in the biological, chemical, and physical aspects of nature. One example was *regeneration*. Many animals are capable of growing new body parts to replace those damaged or lost. Spiders can regrow missing legs, lizards can sprout new tails, and starfish can replace lost arms. If cut into chunks, each piece of a flatworm can develop into a new worm. Humans can display modest regeneration, particularly of fingertips and certain kidney tissues. Turing's last major research concerned morphogenesis: how biological form and structure are generated. Alan's interest in regeneration was evident already at age three when one of his toy wooden sailors broke into pieces. He planted the arms and legs in the garden, hoping that whole new toys would grow.

Budding interest in mathematics and science

At age six, Alan began his formal education at St Michael's school in Hastings. When Sara removed him from the school three years later, the headmistress told her that Alan was a genius. She was perhaps the first person to note his extraordinary mental powers, but Sara was alarmed by his “unsociable” and “dreamy“ personality. She focused her energy for a time on her son, but left for India once again, placing Alan at Hazelhurst, a small boarding school.

The Turing brothers were two of the 36 boys attending Hazelhurst in 1922—John in his last year and Alan in his first. Alan was a lackluster student. He shied away from the emphases on group sport, scouting, and carpentry. He engaged other students in origami, but more importantly pursued a deepening understanding of mathematics, complaining, for example, that the algebra instructor “gave quite a false impression of what is meant by *x*.”

An important influence on Alan’s thinking was the book *Natural Wonders Every Child Should Know*. Author Edwin Tenney Brewster introduced human physiology to help a young reader answer such questions as, “By what process of becoming did I myself finally appear in the world?” and “What have I in common with other living things and how do I differ from them?” *Natural Wonders* revealed to Alan that there was a field of knowledge called *science*, and its description of the human body as a machine impacted his views on the nature of intelligence. Turing’s adult speculations about minds and machines, along with the provocative question, *Can Machines Think*? will occupy our attention later. In part, however, their roots lie in Brewster’s words:

> We shall learn about how the body of the plant or animal feeds itself and keeps alive, and how the different parts of it, the bones and skin and leaves and bark, manage to get on with one another, and work together like a well-made **machine**. For, of course, the body is a **machine.** It is a vastly complex **machine**, many, many times more complicated than any **machine** ever made by hands; but still after all a **machine**. It has been likened to a steam engine. But that was before we knew as much about the way it works as we know now. It really is a gas engine; like the engine of an automobile, a motorboat, or an airplane.

Turing had certainly shown an interest in science before reading *Natural Wonders*. He would run a magnet along street gutters to pick up iron filings left by metal cartwheels, or ask how hydrogen bonded to oxygen to make water, or pen, at age eight, a one-sentence book, *About a Microscope*: “First you must see that the lite is rite.” Brewster’s book, however, was special to Alan. Sara wrote that it “greatly stimulated his interest in science and was valued by him all his life.”

Hazelhurst’s curriculum focused on Latin, French, English, history, geography, mathematics, and Scripture. Science was definitely not a mainstream topic, so Alan spent much of his time outside of class reading and thinking about scientific ideas, as well as planning and carrying out his own experiments.

He began to display another lifelong trait: a determination to design and build things on his own from basic materials. At age 10, he wrote a letter home using a fountain pen he had invented himself. A few months later, he described plans for building a typewriter.

In his final years, Turing set aside “the nightmare room” in his house for conducting experiments and creating new compounds, including his own weed killer and sink cleaner. These projects often involved home-made electrical contraptions. His carelessness frequently resulted in high-voltage shocks. One contemporary observed that Alan was “like a child when experimenting, not only taking in the observed mentally but testing it with his fingers.” One project used potassium cyanide to gold-plate a spoon using gold from his grandfather’s watch.

Turing's death by cyanide poisoning could have been a suicide, as commonly believed, caused by accidental ingestion when he ate an apple without washing the lethal toxin from his fingers.

The year 1924 brought major changes for the Turings. Exasperated at being passed over for promotion, Julius suddenly resigned from the Indian Civil Service. He received an annual pension of 1,000 British pounds, roughly equivalent to 70,000 U.S. dollars today. Julius considered this sum sufficient to sustain his family and pay school fees, but worried about further erosion by British income taxes. He and Sara decided to live in Dinard, a French town on the Brittany coast, taking advantage of a provision exempting them from British taxes if they spent no more than two weeks a year in the United Kingdom. Alan and John commuted to and from France during school vacations.

Now in more regular physical contact with Alan, Mrs. Turing launched an effort, by no means entirely successful, to make him more presentable to the outside world. She tried to get him to improve his penmanship, hired a tutor to help him prepare for the secondary school entrance examinations, and considered carefully where he should continue his education after Hazelhurst. The fateful decision was Sherborne.

2. Sherborne and Christopher Morcom

Sherborne is one of the oldest independent boys' schools. In England, these institutions are called *public* schools. Many were founded by particular churches exclusively for their own members. They adopted the term *public* when church affiliation was dropped as a matriculation requirement.

Sherborne, which traces its roots back to the eighth century, was re-founded as a grammar school for local boys by King Edward VI (1537-1553), the first English monarch raised as a Protestant, and became a private boarding school in 1869. When Alan arrived in May of 1926, Sherborne was considered a "moderately distinguished" educational institution of 400 male students.

Notable Sherborne graduates before Turing include the mathematician and philosopher Alfred North Whitehead (1861-1947), co-author of *Principia Mathematica*, a major work in mathematical logic. Alumni closer to Alan's time at Sherborne were Evelyn Waugh (1903-1966), author of the novels A *Handful of Dust* and *Brideshead Revisited*, and Cecil Day-Lewis (1904-1972), poet laureate of the United Kingdom.

Alan had an auspicious start at Sherborne. He had taken an overnight ferry from France to Southampton, England, intending to travel to the school by rail. He landed on Monday morning, May 3, at the beginning of a general strike protesting plans to cut coal miners' pay and lengthen their workday. The strike shut down mass transportation throughout the country. Alan was apparently stuck on the docks, 60 miles from Sherborne, with a trunk full of clothes and books.

But the 13-year-old had his bicycle and was determined not to be overly late. He checked his luggage with the baggage master, telegraphed his housemaster about his delayed arrival, bought a map, and set out for Sherborne. He stopped for lunch and a minor bicycle repair, staying overnight at a hotel. He completed the ride the next day, to everyone's astonishment, earning a mention in the local newspaper and a reservoir of esteem and goodwill at the school. When his subsequent behavior and academic performance fell below Sherborne's expectations, his housemaster, Geoffrey O'Hanlon, defended Alan with the comment "Well, after all he *did* bicycle here." Even today, Sherborne boys honor Turing by recreating his ride each May.

At Sherborne, Turing pursued his interests in mathematics and science, paying insufficient attention, in the eyes of the staff, to the parts of the curriculum and the extracurricular program they considered more important. A generation earlier, the school focused on "rugby, religion, and relentless Latin." A new headmaster broadened the classical education to include chemistry and physics, but continued to emphasize Latin, Greek, English, and French—subjects which held little appeal for Alan.

The initial admiration earned by Turing's solo bicycle trip gradually shifted to tolerance and then exasperation over the neglect of his studies and his idiosyncratic attitude toward his personal appearance. In the fall of 1926, O'Hanlon reported:

> Slightly less dirty and untidy in his habits: & rather more conscious of a duty to mend his ways. He has his own furrow to plough, & may not meet with general sympathy.

But by the next spring, the housemaster observed:

> He is frankly not one who fits comfortably for himself into the ordinary life of the place.

And by autumn of 1927, O'Hanlon noted:

> I have seen cleaner productions from this specimen … No doubt he is very aggravating: & he should know by now that I don't care to find him boiling heaven knows what witches' brew by the aid of two guttering candles on a naked wooden window sill.
>
> In the headmaster's report at the same time, we find the conclusion that Alan "is the kind of boy who is bound to be rather a problem in any school or community."

Alexander H. Trelawny-Ross, his English and Latin teacher, who caught Alan doing algebra during a divinity lesson, thundered:

> I can forgive his writing, though it is the worst I have ever seen, & I try to view tolerantly his unswerving inexactitude and slipshod, dirty work … but I cannot forgive the stupidity of his attitude towards sane discussion on the New Testament … [in Latin] he is ludicrously behind.

Trelawney-Ross posited that Germany had lost World War I because it believed "science and materialism were stronger than religious thought and observance." He characterized scientific subjects as "low cunning" and had little patience for Alan's favorite study. "This room smells of mathematics," he sniffed, exclaiming to Turing, "Go out and fetch a disinfectant."

Boys facing the regimen of public schools like Sherburne, which aimed to produce graduates suited to a class society of masters and servants, reacted in different ways. Most accepted the program, a few rebelled, and some withdrew. Alan disengaged as much as he could. While the adults bemoaned his lack of school spirit, passive resistance to academic lessons, and avoidance of team sports, many of his peers reacted with hostility. "His ways sometimes tempted persecution," O'Hanlon reported. Ostracism was perhaps the mildest response from the other boys, while bullying was common, especially in his first year. They trapped him under the floorboard of a dorm room at least once and kept him there until he nearly suffocated.

Turing biographer Andrew Hodges describes how the teenager appeared to his peers at Sherborne and some of their reactions to him:

> But he made himself 'a drip' by letting down his house contingent at the gym with his 'slackness.' He was also called *dirty*, thanks to his rather dark, greasy complexion, and a perpetual rash of ink stains. Fountain pens still seemed to spurt ink whenever his clumsy hands came near them. His hair, which naturally fell forward, refused to lie down in the required direction; his shirt moved out of his trousers, his tie out of his stiff collar. He still seemed unable to work out which coat button corresponded to which buttonhole. On the Officers Training Corps parade on Friday afternoons, he stood out with cap askew, hunched shoulders, ill-fitting uniform with puttees like lampshades winding up his legs. All his characteristics lent themselves to easy mockery, especially his shy, hesitant, high-pitched voice—not exactly stuttering, but hesitating, as if waiting for some laborious process to translate his thoughts into the form of human speech.

Essentially friendless in his early time at Sherborne, Alan focused his mental energy on mathematics and science. At age 15, he carefully studied Einstein's theory of relativity, writing notes to explain it to his mother. One of the strong appeals to Turing was that Einstein rejected the axioms about place and time that had dominated physical thought from the times of Euclid and Newton, substituted his own, and derived new conclusions that revolutionized science.

Any system of deductive thought begins with a set of *axioms* or *postulates*, statements presumed to be true as the initial step for further reasoning. Euclid had laid down a small set of axioms about plane geometry. In the 19th century, other mathematicians showed that discarding or revising some of these axioms could result in interesting and applicable geometries.

Turing's imagination was captured by the notion that one could negate the axioms others accepted, that what appeared "obvious" need not be so, or even true. One could start by denying the obvious and construct from a new set of axioms a consistent and perhaps even useful set of results. As his brother John observed, such a belief could be annoying:

> "You could take a safe bet that if you ventured on some self-evident proposition, as, for example, that the earth was round, Alan would produce a great deal of incontrovertible evidence to prove that it was almost certainly flat, ovular, or much the same shape as a Siamese cat which had been boiled for 15 minutes at a temperature of 1,000 degrees Centigrade."

Meeting Morcom

Alan's loneliness and isolation from his peers at Sherborne underwent a profound change that affected him deeply for the rest of his life: the discovery of a kindred spirit and his first love, Christopher Morcom.

Morcom was a year older than Turing and in the next form (roughly equivalent to *grade*), small for his age, but intensely interested and gifted in mathematics and science. Turing was struck by and attracted to Morcom's appearance, wanting "to look at his face again." The two boys connected with mathematics. "During this term," Alan wrote, "Chris and I began setting one another our pet problems and discussing our pet methods." On Alan's side, it was more than exchanging ideas. "I worshipped the ground he trod on," Alan confessed later to Morcom's mother. "It never seems to have occurred to me to make other friends besides Morcom, he made everyone else seem so ordinary."

In the spring of 1929, Alan advanced to the same form as Christopher. He sat next to him in all their classes. Morcom was such a model of academic success and excellent work habits that Alan began to expend extra energy to organize his own efforts:

> Chris' work was always better than mine because I think he was very thorough. He was certainly very clever but he never neglected details. … One cannot help admiring such powers and I certainly wanted to be able to do that kind of thing myself. Chris always had a delightful pride in his performances and I think it was this that excited one's competitive instinct to do something which fascinated him and which he might admire.

Alan's efforts to be more exact and tidier earned him better reports from his teachers and greater respect for his mental abilities and originality. He concentrated on preparations for the university scholarship exams. When Chris, at age 18, set out to take the tests for a scholarship to Trinity College Cambridge, Alan decided to try as well, so they might work together for the next three years. They spent a week at Cambridge in early December 1929, taking exams during the mornings and afternoons, enjoying meals together, playing games, and going to movies in the evening. “Chris knew I think so well how I like him,” Alan wrote describing what he said had been the happiest week of his life, “but hated me shewing [sic] it.”

Chris did win his Trinity scholarship, but Alan, whose education lagged by a year, did not score well enough to qualify. During the Christmas holidays, they exchanged letters about the test results, as well as more detailed descriptions of the astronomical observations they were making from their respective homes. They returned to Sherborne in mid-January 1930. Barely three weeks into the term, tragedy struck.

Unknown to Alan, Christopher had been suffering from bovine tuberculosis for years. Early on the morning of Friday, February 7, Chris was rushed by ambulance to London. Doctors performed two operations but were unable to save his life. He died on February 13, 1930, at the age of 18.

Morcom’s death devastated Turing, who was “nearly knocked out by the shock,” as one classmate observed. Although Alan’s own religious stance had gone from skepticism of Church of England teachings to agnosticism to atheism, he hoped that somehow, at some level, he might reunite with Chris’ spirit. “I feel that I shall meet Morcom again somewhere and that there will be some work for us to do together as there was for us to do here,” Alan wrote to his mother. In his first letter to Mrs. Morcom, he observed, “I know I must put as much energy if not as much interest in my work as if he were alive, because that is what he would like me to do.” He asked for a photograph of Chris “to remind me of his example and of his efforts to make me more careful and neat. I shall miss his face so, and the way he used to smile at me sideways.”

Morcom’s attitude toward Turing was apparently more a passive friendship than Alan’s ardent romantic attachment to Chris. Alan’s letters and comments to friends in later years show he regarded Chris as his first love, one he would never be able to consummate or match in any of his many future homosexual relationships.

Working out teenage hormonal changes and yearnings was complicated in the setting of an all-male boarding school. In the 19th and early 20th centuries, these schools tolerated, if they did not actually encourage, strong homoerotic friendships between students. Many of the relationships established at school continued long afterwards, some developing into adult sexual partnerships.

Memoirs and fictional accounts about school show how central these same-sex “crushes” and “romances” were. The novelist Desmond McCarthy gives a not atypical description:

> As time went on it became clear to me that this thing, this abomination in our midst, was next to games and, perhaps for a very few, their studies, the most important element in school life. When I say that, I am including its emotional off-shoots, which were of the most varied nature, grading up from prompt animalism through jokes to gay tenderness, even to restless passion and Platonic idealism. Some boys would be made happy for the day by a chance meeting, a few casual words exchanged. Others would discuss chances of seduction with the cynicism and aplomb of a Valmont.

On an emotional level, Christopher Morcom’s sudden death brought despair to Alan Turing; but it also triggered new lines of thought and intellectual inquiry as he struggled to comprehend how a mind that had been alive and active a few days earlier could apparently be gone so quickly. Turing was absorbed by the question of whether *mind* could be separated from *body*. Could thought be transferred to or manifested by an entity immune to the ravages that afflict the human organism?

Turing remained at Sherborne an additional year, probing the mysteries of quantum mechanics, winning prizes in mathematics and science, making some new friends, and coping well enough with school strictures to earn an important leadership position. The reports on his performance and character decidedly improved. “He wins respect both by brains and character,” wrote the housemaster, while the headmaster noted, “He is a distinguished and useful member of the community.”

Turing retook the Cambridge entrance exams in December of 1930, doing sufficiently better to win a scholarship to King’s College. He arrived the following October to begin the next phase of his remarkable life.

3. Cambridge Days

The University of Cambridge can be intimidating, particularly to an awkward teenager. Founded in 1208, it is home to 31 constituent colleges, each of which admits, houses, and supervises the instruction of its undergraduate students. The colleges have their own endowments and fund some of the university's senior research positions.

Henry VI founded King's College in 1441. Although even now its enrollment is small compared to that of an average American college (about 400 undergraduates and 300 graduate students), its graduates and faculty include Nobel Prize winners in peace, physics and chemistry, the novelists E. M. Forster, Salman Rushdie, and Zadie Smith; the philosopher George Santayana, and the economist John Maynard Keynes.

Keynes (1883-1946) was one of the most influential economists of the 20th century. The founder of modern macroeconomics, his ideas that government should employ fiscal and monetary policies to stabilize the economy were adopted in many capitalist countries. His theories formed the basis of *Keynesian Economics*, an approach underlying policies the Obama administration adopted to deal with the global financial crisis of 2007-2008.

Keynes was a very successful investor, amassing a private fortune. He became bursar of King's College in 1924, assuming responsibility for its financial well-being. His stewardship of King's funds paid enormous dividends to the college over a two-decade period.

Keynes and others also established a spirit of liberal tolerance at King's, particularly in the comfortable environment it created for homosexuals, an emphasis on moral autonomy, and interaction between the dons and undergraduates. In an essay titled "My Early Beliefs," Keynes described the attitude of his King's College peers in the generation before Turing's—the generation that shaped the community Alan entered:

> We entirely repudiated a personal liability on us to obey general rules. We claimed the right to judge every individual case on its merits, and the wisdom, experience and self-control to do so successfully. This was a very important part of our faith … We repudiated entirely customary morals, conventions and traditional wisdom … we recognized no moral obligation on us, no inner sanction, to conform or to obey.

"It was an attitude," Hodges notes, "very different from the cult of duty, which made a virtue out of playing the expected part in the power structure. King's College was very different from Sherborne School." King's provided an environment that encouraged Turing to think for himself, however unorthodox his ideas may have seemed to others.

Cambridge undergraduates attended university-wide lectures but also met weekly in a tutorial in their own colleges. These sessions, called *supervisions* at Cambridge, typically lasted an hour and provided challenging examinations of a student's arguments. Alan's King's College tutors were the number theorist Albert Edward Ingham and the group theorist Philip Hall.

Hall entered King's College as a student in 1922 and remained at Cambridge for most of his career, working on Italian and Japanese cipher systems during World War II. As a graduate fellow in 1928, Hall discovered an important generalization of a classic result in Group Theory, a major field of study in modern abstract algebra. It concerns mathematical structures that have binary operations obeying a few simple properties. Groups occur throughout mathematics and appear also in various settings in physics and chemistry.

Hall became one of the world's leading group theorists, his work earning him several prizes,

4. Birth of the Computer

For centuries, mathematics was considered a solid structure of unchallengeable truths. Mathematicians had erected a seemingly impregnable edifice atop a rock-solid foundation. However, this view changed substantially during Turing's lifetime, and he contributed significantly to that shift.

Euclid made no attempt to define "point" and "line," since everyone presumably shared a common mental picture of these concepts and because of the self-evident nature of his five axioms. But there was one troublesome feature: the parallel postulate did not seem so self-evident; it spoke of extending lines *indefinitely*, an action beyond human experience. After hundreds of unsuccessful attempts to derive the parallel postulate from the other axioms, mathematicians Nikolai Lobachevsky and Jonas Boylai demonstrated that one could build new geometries as consistent as Euclid's, but in which the parallel postulate failed.

These discoveries led to new fields based on different collections of undefined terms and axioms. These often were tantalizingly complex realms bearing rich intellectual fruit and important new applications. Other mathematicians turned their focus to the axiom systems underlying the geometry and arithmetic we use every day. The leading figure of this movement was the German mathematician David Hilbert (1862-1943).

On August 8, 1900, Hilbert delivered an address, modestly titled *Mathematical Problems*, to the International Congress of Mathematicians meeting in Paris. In perhaps the most important lecture in the history of mathematics, Hilbert posed 23 major unsolved problems he thought mathematicians should focus on.

The second problem Hilbert proposed was "The Compatibility of The Arithmetical Axioms:"

> When we are engaged in investigating the foundations of a science, we must set up a system of axioms which contains an exact and complete description of the relations subsisting between the elementary ideas of that science. The axioms so set up are at the same time the definitions of those elementary ideas; and no statement within the realm of the science whose foundation we are testing is held to be correct unless it can be derived from those axioms by means of a finite number of logical steps …
>
> But above all, I wish to designate the following as the most important among the numerous questions which can be asked with regard to the axioms: To prove that they are not contradictory, that is, that a finite number of logical steps based upon them can never lead to contradictory results.

Some of Hilbert's 23 problems were solved fairly quickly; others resisted resolution for decades, and some remain open questions to this day. The second problem, like the others, provoked considerable research. Thanks in part to Hilbert himself, it was known by 1900 that the consistency of Euclidean geometry rested on the consistency of arithmetic: if it was impossible to derive a contradiction from the axioms of arithmetic, then it was impossible to do it from those of geometry. The challenge was to prove that the axiom system underlying arithmetic was free from self-contradiction.

One ambitious attempt was the three-volume *Principia Mathematica* by Whitehead and Russell. They tried to create axioms and inference rules in symbolic logic from which one could, in principle at least, prove all mathematical truths. The original editions appeared between 1910 and 1913 with an important revision a decade later. Though they failed to attain their goal of putting mathematics on an unassailable perch, their efforts spurred others to try.

Hilbert formulated three essential demands of an axiomatic basis for mathematics and the propositions deduced from it. *Propositions* are declarative utterances such as “2 + 2 = 4” or “The square of the hypotenuse of a right triangle is equal to the sum of the squares of its legs,” or “All numbers are odd.” A proposition is either true or false. The three demands were Consistency, Completeness, and Decidability.

- *Consistency* means it is impossible to derive both the truth of a proposition and its negation.
- *Completeness* means all true propositions can be deduced from these axioms.
- *Decidability* means one can definitively establish, using a clearly formulated procedure, whether a given statement follows from the given system. This was Hilbert’s *Entscheidungsproblem* or *Decision Problem:* could an effective procedure be devised which would demonstrate—in a finite time—whether any given mathematical assertion was, or was not, provable from a given set of axioms?

Hilbert was confident that such axiom systems and proof procedures must exist. Others argued that knowledge was inherently limited. They adopted the Latin maxim *ignoramus et ignorabimus*: “We do not know and we will not know.” Hilbert vigorously denied this claim. He wrote, “We must not believe those who today, with philosophical bearing and deliberative tone, prophesy the fall of culture and accept the *ignorabimus*. For us there is no *ignorabimus*, and in my opinion none whatever in natural science. In opposition to the foolish *ignorabimus*, our slogan shall be: *Wir müssen wissen—wir werden wissen!* We must know—we will know!”

Hilbert’s hopes were dashed a few years later. In 1931, the young Austrian logician Kurt Friedrich Gödel (1906-1978) published two remarkable “Incompleteness Theorems.” The first proved that in any consistent axiomatic system rich enough to enable the expression and proof of basic arithmetic propositions, one could construct a true statement such that neither it nor its negation would be provable from the given axioms. Thus, no consistent system can be complete.

Gödel’s second Incompleteness Theorem essentially states that no sufficiently rich, consistent, axiomatic theory can prove its own consistency. Gödel ingeniously found a way to encode statements about mathematical relationships (for example, that a specific sequence of propositions provides a proof of some statement P) as statements within arithmetic. See Richard Tieszen’s *Simply Gödel* for a more complete exposition.

Gödel’s incompleteness theorems did not settle the *Entscheidungsproblem*. He demonstrated that any consistent axiomatic system for arithmetic would leave some arithmetical truths unprovable. This does not rule out, however, the possibility of some “effectively computable” decision procedure which would, in a finite number of steps, reveal whether a particular proposition was provable. This is where Turing stepped into the picture.

In the Lent Term of 1935 (which at Cambridge begins in mid-January and lasts until mid-March), Alan learned about Gödel’s work in a course called *Foundations of Mathematics*, taught by Max (Maxwell Herman Alexander) Newman (1897-1984). The British mathematician and codebreaker entered St. John’s College Cambridge in 1915, interrupting his studies for service in World War I. He graduated in 1921, subsequently becoming a fellow and then lecturer. Newman’s and Turing’s lives intersected at many critical points, including these lectures on Hilbert’s program and Gödel's theorems, secret cryptology work during World War II, and the construction of one of the first digital computers at Manchester University.

As the winter of 1935 waned, Alan sat in an old lecture hall, thinking about Newman's presentation of Hilbert's *Entscheidungsproblem.* Hodges noted that Newman posed the question in a very specific way that had particular appeal to Turing: is there a *mechanical* process for resolving the Decidability Problem? For Alan, *mechanical* meant "something that can be done by a machine." He set out to explore just what could be done by a computing machine. To demonstrate the impossibility of a decision procedure, Turing first had to give a precise mathematical explanation of what it means to be computable by a strictly mechanical process.

Recall the impact Edwin Brewster's *Natural Wonders Every Child Should Know* had on the 10-year-old Turing with its assertion that "Of course, the body is a machine." Throughout the book, Brewster employed this metaphor, comparing the human body to other complex systems, such as automobiles and houses. In Chapter 37, "Men in Glass Boxes," for example, he wrote:

> One curious thing about these explosion engines of ours is that, when all goes well with our little insides, we get just exactly the same amount of work out of each mouthful of food, that we should get, if we should dry the food, grind it to fine dust and explode the dust mixed with air in the cylinder of an automobile—as it would be quite possible to do if one wanted to take the trouble.

Groundbreaking discovery

A theme running throughout Turing's life was the similarities and differences between naturally evolving humans and technology-produced machines. Recall that as a very young child, Alan buried broken toy soldiers, hoping they might grow new limbs. Later, of course, he explored in depth the question of whether machine *intelligence* was possible and the consequences of an affirmative answer. It was therefore natural that Turing's answer to the *Decidability Problem* used the concept of a machine.

Alan had taken to running long distances, going as far as Ely, a town about 16 miles from Cambridge. One summer day in 1935, he stopped for a rest. Lying in the Grantchester Meadows along the River Cam, he came up with the key idea that revolutionized our world.

Turing's landmark 1936 paper, "On Computable Numbers, with an Application to the Entscheidungsproblem," showed that there were undecidable mathematical results. This work, however, achieved much more than this. He created a precise definition of what *computable* meant in terms of a theoretical machine. The essential ideas behind this device are embodied in every computer used today, justifying Turing's recognition as "father of computing."

Although the physical design of digital computers—their shape, size, input and output devices, as well as components—changed dramatically over the past several decades, they are all, in a mathematical sense, equivalent to the simple machine Turing described more than 80 years ago.

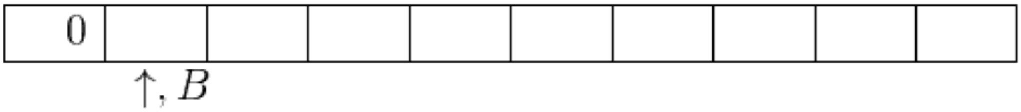
A full understanding of Turing's 1936 paper demands working through quite a bit of highly technical mathematics. The central ideas, however, are easy to grasp. The basic machine he described is quite simple.

Imagine first an extremely long paper tape divided into equal-sized squares. Each square is either blank or displays one of a finite set of symbols. The machine has a scanning head which can read the contents of one square at a time. In response to the symbol on the square, the internal state of the machine, and the rules it is following, the scanner can change the symbol on the tape, move the tape one square to the left or right, and switch to a new state or remain in the current one. There is a finite number of such internal states. “It is difficult today,” Newman wrote in 1954, “to realize how bold an innovation it was to introduce talk about paper tapes and patterns punched in them, into discussions of the foundations of mathematics.”

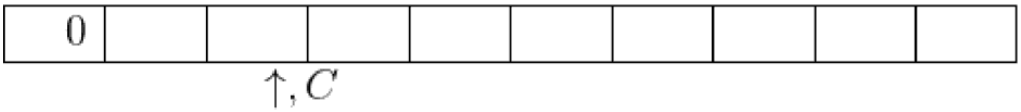
The first example Turing described is a machine that will print an endless sequence of alternating 1’s and 0’s, separated by blank spaces. The machine has four states: A, B, C, and D. It can print the symbol 0 or the symbol 1 on a square and it can execute a command *Right*, which means “the machine moves so that it scans the square immediately on the right of the one it was scanning previously.” The machine begins in state A and the entire tape is initially blank. The table below describes the complete behavior of the screen.

Current State	Symbol on Tape	Action	New State
A	None	Print 0, Right	B
B	None	Right	C
C	None	Print 1, Right	D
D	None	Right	A

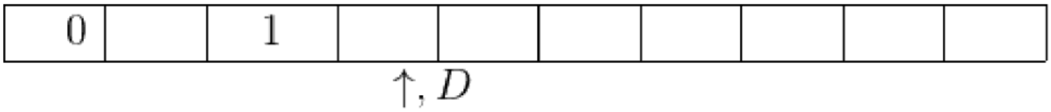
Since the entire tape is originally free of symbols and the machine only moves to the right, it will always see a blank square before taking an action. Its behavior will only depend on its current state. Because the machine begins in state A, it will print a 0 in the first square, move the scanning head one square to the right, and enter state B. The diagram below shows the current status of the tape, the position of the scanning head (with a vertical arrow), and the current state:



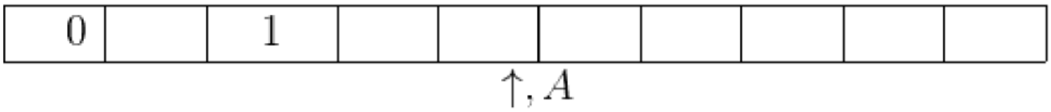
Being in state B and seeing no symbol on the state, the machine simply moves one square to the right and alters its internal state to C:



Once in state C and scanning a blank square, the machine prints 1 in that square, moves one square to the right again, and enters state D:



The machine’s instruction is now to move to the right and enter state A:



Now the same sequence of actions will repeat itself over and over again, resulting in a tape that looks like this:

As a second example, we describe a machine that can add together any pair of positive integers. There are many ways to represent a number. We could use the familiar symbol 5, the Roman numeral V, the English word "five," a string of vertical bars, |||||, or 1's of appropriate length. We will use this last approach, denoting the number 5 as 11111. If we want the machine to add 3 and 4, we could prepare a tape of the form

to form the *input*. We want the output to be a tape that reads:

Note that the tape fed into the machine marks the beginning and end of the input data with the symbol # and the separation of the two integers with the symbol @. Here is the table of instructions that defines the machine:

Current State	Symbol on Tape	Action	New State
A	Blank	Right	A
A	1	Right	B
B	1	Right	B
B	Blank	Print 1, Right	C
C	1	Right	C
C	Blank	Left	D
D	1	Erase 1	*Stop*

The reader should enjoy verifying that this machine can indeed correctly add any two positive whole numbers.

Both of these examples involve elementary calculations with relatively straightforward instruction tables. Turing saw that such conceptually simple machines could tackle more complicated problems. In fact, he suggested that anything computable could be computed by such devices, now universally called *Turing Machines*. What is required is simply a sufficient number of places to function as states and other memory locations for data and instructions. Turing gave a mathematical formulation for the digital computers first built in the 1940s, their subsequent descendants, the devices we use today, and the ones that will emerge in the future. Each is mathematically equivalent to a Turing Machine.

Alan devised a rigorous notion of effective computability based on the Turing Machine. Not