# Introduction

Written language is a supreme achievement that distinguishes humans from animals. For many millions of people across the world, being literate gives access to vital parts of social and cultural life, and being illiterate results in more limited opportunities. For employment as an academic, journalist, and of course writer, writing is central to the work. For professional people, writing is a main vehicle for getting work done. For other jobs, writing is vital to efficient practices including health and safety. And for many people, writing as a source of pleasure, recreation, and reflection is what they value most. One thing all writers have in common is the challenge to write well. The challenge for a tiny minority is to reach 'immortality' in their writing, but for most people the challenge is making writing effectively reflect the meanings and messages they want to create and communicate. For children, the challenge is learning to write in the first place, and for teachers the challenge is helping their learners to do this. But in spite of the thousands of years of history of writing, and in spite of its global use today, writing has attracted less attention from researchers, particularly compared to oral language and reading.

The beginning of my exploration of writing was informed by both seminal and more recent books written by people with different kinds of relevant expertise, for example by classicists (e.g. Eric Havelock, *The Muse Learns to Write*), philosophers (Aristotle, *On Interpretation*), anthropologists (Jack Goody, *The Interface between the Written and the Oral*), cognitive scientists (Steven Pinker, *The Language Instinct*), psychologists/educationalists (David Olson, *The World on Paper*), linguists (David Crystal, *The Stories of English*), literary/media theorists (Marshall McLuhan, *The Gutenberg Galaxy*), journalists (Lynn Truss, *Eats, Shoots & Leaves*), and accounts by writers (Stephen King, *On Writing*). In answer to a question about the origins of his poems the poet Ted Hughes said:

> Well, I have a sort of notion. Just the tail end of an idea, usually just the thread of an idea. If I can feel behind that a sort of waiting momentum, a sense of some charge there to tap, then I just plunge in. What usually happens then – inevitably I would say – is that I go off

in some wholly different direction. The thread end of an idea burns away and I'm pulled in – on the momentum of whatever was there waiting. Then that feeling opens up other energies, all the possibilities in my head, I suppose. That's the pleasure – never quite knowing what's there, being surprised. Once I get onto something I usually finish it. In a way it goes on finishing itself while I attend to its needs. It might be days, months. Later, often enough, I see exactly what it needs to be and I finish it in moments, usually by getting rid of things.[1]

Hughes was not only a great poet, he was also interested in how people learn to write, so much so that he published a book on the matter, *Poetry in the Making*, subtitled *A Handbook for Writing and Teaching*. The aims behind Hughes' book prompt a wider question about the ways in which writing and language might be taught and learned. If people are to learn, there needs to be some agreement about things to be taught and the best ways of doing so.

One of the first examples of a book designed to teach English language use was published in no less than 100 editions. The author became a household name in the UK and in the USA, and a citation to his name was even used by Charles Dickens in *Dombey and Son*[2]. And the title of this book?:

WALKER'S
PRONOUNCING DICTIONARY
OF THE
ENGLISH LANGUAGE.
ABRIDGED
FOR THE USE OF SCHOOLS
CONTAINING
A COMPENDIUM OF THE
PRINCIPLES OF ENGLISH PRONUNCIATION
WITH THE
PROPER NAMES
THAT OCCUR IN
THE SACRED SCRIPTURES
TO WHICH IS LIKEWISE ADDED,
A SELECTION OF GEOGRAPHICAL PROPER NAMES AND DERIVATIVES.[3]

The author, John Walker (1732–1807), had a first job as a professional actor, including a run in London's Covent Garden. But his second career was as an educator: initially setting up his own school. After a disagreement with the co-founder of the school, Walker took up the teaching of elocution, at which he excelled. So much so that he was soon educating royalty. His major contribution was a theory of inflections. His attention to the pitch of the voice built on the

1 Heinz, 'Ted Hughes', 17. 2 Crystal, *Stories of English*, 406.
3 Planned in 1774 then finally published in 1791.

work of Joshua Steele who had investigated vocal pitch in relation to music.[4] As is clear from the title of Walker's book, he was concerned that young people should learn to use language 'correctly' as he saw it. However, his wasn't a book about the composition of writing but more about other important elements of language. Books directly about writing were to come later.

*How Writing Works* is about the process of writing: the place of meaning as the driving force of writing; and the 'ear of the writer' that enables writing. The work on the book was driven by the following questions:

In what ways does meaning drive writing?
How should we understand writing theoretically?
How do key moments in the history of writing enable us to reflect on writing now?
What are the relationships between the composition of meaning, and the technical elements of writing such as structure, sentences, words, letters, and sounds?
What are the relationships between oral and written language?
How are conventions and standards of language established and applied, and in what ways do and should they impinge on writing?
What is the nature of creativity in writing?
And consequently: how does writing work and therefore how is writing best taught?

Although the book does make occasional comparisons with other languages, when appropriate, its main focus is on writing in English. My intention is to present a new and more complete account of the process of writing. By way of introduction to some of the themes of the book, and I hope as a means to engage you, I begin with seven short stories of writing.

**1**

It was a cold morning and the sky was brilliant blue. The crowd waited expectantly. A countdown commenced. At 'zero' the roar of rocket engines vibrated through people's chests. The shuttle moved slowly at first, as if the shackles would stop it escaping, but then with gargantuan force its forward momentum quickened. The white of its tiled hull, and the white smoke from the rockets, contrasted strongly with the blue sky. In a few short minutes, the shuttle was out of sight and had left the earth's atmosphere. At NASA's Mission Control the pictures of the *Columbia* Space Shuttle's orbit were clear, and radio contact with the crew was fully functional.

While one of the NASA mission control team had been watching the launch, he thought he spotted something. On playback of the launch video, 82 seconds in, the scientist saw what looked like a small object bouncing off the wing of the shuttle. He alerted his manager. Emergency meetings were convened. PowerPoint presentations of technical information were discussed.

[4] Beal, 'Walker, John' in Oxford Dictionary of National Biography.

Having considered the PowerPoint slides, high-level NASA officials decided that the *Columbia* was not in danger, and further investigations were not necessary, not even the option of powerful military spy cameras that could have photographed any damage to the Shuttle for further analysis.

Twelve days later, on 1 February 2003, the Columbia disintegrated on re-entry to the earth's atmosphere, killing all seven crew members.

The *Columbia* disaster was a tragic event that highlighted the risks astronauts take in the exploration of space. An uncomfortable aspect of the *Columbia* disaster was that writing, in the particular structural and communicative form of the PowerPoint presentation package, was seen as a contributing factor in the disaster because it resulted in key messages being missed. 'Death by PowerPoint' could never have been more serious or literal.

The problem with PowerPoint involved the ways in which meaning was structured. Bullet points at higher levels, and in the executive summaries, suggested that *Columbia* was safe[5]. Technical points that suggested that fatal damage to the shuttle was a possibility were lower in the textual hierarchy of bullet points. At the same time the PowerPoint slides were being produced, NASA engineers were exchanging emails (more simply structured texts) about what they saw as a credible danger.

A formal report into the tragedy by the Columbia Accident Investigation Board concluded that:

> As information gets passed up an organization hierarchy, from people who do analysis to mid-level managers to high-level leadership, key explanations and supporting information are filtered out. In this context, it is easy to understand how a senior manager might read this PowerPoint slide and not realise that it addresses a life-threatening situation.
>
> At many points during its investigation, the board was surprised to receive similar presentation slides from NASA officials in place of technical reports. The Board views the endemic use of PowerPoint briefing slides instead of technical papers as an illustration of the problematic methods of technical communication at NASA.[6]

**2**

Pierre was happy. He had finished work for the day and was free to spend a precious hour or two on his hobby. A few months ago, he had found *Arithmetica*, a new translation of ferociously difficult mathematical problems. He had already easily solved seven of the problems in the *Arithmetica*. Most of the problems required extended mathematical proofs written out in lengthy series of equations. But Pierre was impatient to get through, so as a shortcut he would begin the solution to a problem, then when he was certain he could solve

[5] Tufte, *Cognitive Style of Powerpoint*. [6] Tufte, *Cognitive Style of Powerpoint*, 11

it, leave a note, sometimes in the margin of the page he had got to. While solving problem number eight in the *Arithmetica* Pierre realised that there were some intriguing possibilities. One in particular excited him. Having thought about possible solutions his mind was certain. He wrote in the margin:

> Cuius rei demonstrationem mirabilem sane detexi hanc marginis exiguitas non caperet. [I have a truly marvellous demonstration of this proposition which this margin is too narrow to contain.][7]

And what was the proposition? There is no whole-number solution to $x^n + y^n = z^n$. In other words, although we can find whole-number solutions to Pythagoras' theorem $x^2 + y^2 = z^2$, it is not possible to solve the equation if $^n$ is a whole number greater than two.

This was how one of the most famous mathematical problems of all time, and an associated prize, was established some 300 years ago as a result of the note from the French mathematician Pierre de Fermat.[8] The proposition became known as Fermat's last theorem.

It is extraordinary enough that a simple handwritten note in the margin of a notebook should attract and challenge the world's greatest mathematicians for 300 years. And the physical survival of Fermat's written notes over such a long period of time is in itself impressive. This was only made possible because Fermat's eldest son, Clément-Samuel, realised the importance of his father's hobby, so he carefully collected and published the notes and thoughts that his father had scribbled onto his copy of *Arithmetica*.

The note Fermat left in the margin is only the starting point for this story. When Andrew Wiles was a child, he came across an account of the riddle of Fermat's last theorem. Unlike most children, Wiles was intrigued straight away. He even made an attempt to solve the problem on the assumption that as Fermat was an amateur mathematician, and as Wiles knew as much mathematics as Fermat knew, he could perhaps solve it. He soon realised, like so many mathematicians throughout history, that the problem was very difficult indeed.

It wasn't until Wiles went to the University of Cambridge that he started to think seriously about what might be involved in the solving of Fermat's last theorem. At first Wiles knew that he had to familiarise himself with major areas of complex mathematics. One area of maths that would one day be useful to him was the *elliptical equations* recommended by his tutor at Cambridge.

An unusual feature of Wiles's approach to the problem was to break with the tradition of collaboration that mathematicians in the modern era have adopted,

[7] An image of the original text can be seen here: http://commons.wikimedia.org/wiki/File:Diophantus-II-8-Fermat.jpg#/media/File:Diophantus-II-8-Fermat.jpg.
[8] The information for this story is taken from Singh, *Fermat's Last Theorem*.

by working alone and with complete secrecy. One of the reasons for this was the fear that if he shared some of his work, having made progress on solving the problem, another mathematician might supply the final piece in the jigsaw and claim the lucrative prize. Wiles even pretended to be working on elliptical equations, and published a series of minor papers so that he would not be suspected of his work on the theorem. But the other reason for his solitude was in order to maintain the high levels of concentration without distraction, over seven years, that Wiles knew would be necessary. In a description of the mental space required for creativity, Wiles said:

> Leading up to that kind of new idea there has to be a long period of tremendous focus on the problem without any distraction. You have to really think about nothing but that problem – just concentrate on it. Then you stop. Afterwards there seems to be a kind of period of relaxation during which the subconscious appears to take over and it's during that time that some new insight comes.[9]

Wiles also described the moment when he finally solved the problem.

> One morning in late May, Nada [his wife] was out with the children and I was sitting at my desk thinking about the remaining family of elliptical equations. I was casually looking at a paper of Barry Mazur's and there was one sentence there that just caught my attention. It mentioned a nineteenth-century construction, and I suddenly realised that I should be able to use that to make the Kolyvagin-Flach method work on the final family of elliptical equations. I went on into the afternoon and I forgot to go down for lunch, and by about three or four o'clock I was really convinced that this would solve the last remaining problem. It got to about tea-time and I went downstairs and Nada was very surprised that I'd arrived so late. Then I told her – I'd solved Fermat's Last Theorem.[10]

Wiles chose to announce his discovery at a conference at the Sir Isaac Newton Institute at the University of Cambridge. In a series of three lectures, it was not obvious in the first two lectures what Wiles was going to announce, but lecture by lecture the rumours grew, and by the time of the third lecture the atmosphere was electric. With the words 'I think I'll stop here', Wiles had solved the riddle.

Or had he? In order for the prize to be awarded Wiles's paper had to go through the standard procedure of peer-review, where experts in the same field review the paper and decide whether its argument is correct. One problem was that no other single person in the world had the same expertise. So the journal editor appointed six reviewers who would each look at one of the six sections of what was a document of more than 100 pages.

One of the referees emailed a series of questions to Wiles which he answered easily. But then there was a question for which his answer did not satisfy the reviewer. Wiles was in turmoil. After seven years of work and a public

[9] Singh, *Fermat's Last Theorem*, 228. [10] Singh, *Fermat's Last Theorem*, 265.

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announcement that generated press coverage around the world, it appeared that he had not after all solved the riddle.

Wiles was resigned to simply learning from the mathematics he had successfully done. But after six months of additional work, he had a revelation:

> I realised that, although the Kolyvagin-Flach method wasn't working completely, it was all I needed to make my original Iwasawa theory work. I realised that I had enough from the Kolyvagin-Flach method to make my original approach to the problem from three years earlier work. So out of the ashes of Kolyvagin-Flach seemed to rise the true answer to the problem . . . It was so indescribably beautiful; it was so simple and so elegant. I couldn't understand how I'd missed it and I just stared at in disbelief for twenty minutes. then during the day I walked around the department, and I'd keep coming back to my desk looking to see if it was still there. It was. I couldn't contain myself. I was so excited. It was the most important moment of my working life. Nothing I ever do again will mean as much.[11]

Wiles' mathematical proof, 108 pages divided into five 'chapters', are notable for the story I have told but also, in themselves, as a variant of written language: the language of very high level maths, which as you can see is not just numbers but has a clear narrative in words (something that is clear from the first page of the published proof, Figure 0.1).

## 3

In 1979, age 15, I became interested in computer technology. The full extent of computer resources in my secondary school was one 'tele printer' machine. This was the size of a small desk and consisted of an electronic typewriter keyboard and a paper spool (about the width of A4 paper). You typed a line of computer code which then was sent down the telephone line to a mainframe computer (often described as a computer that filled a whole room), then some seconds later the response came back printed on the spool of computer paper that was part of the tele printer. My curiosity was not dimmed by this very basic technology – in fact at the time it seemed rather exciting!

In 1977 one of the first PCs that would reach people's homes was presented at the US West Coast Computer Faire, it was called the *Commodore Pet*[12]. Three years later I was using this computer to write the computer programme for a project as part of the first nationally available *A Level* in computer studies in the UK. One third of the assessment of this A level was a practical project that required the writing of a computer programme.

11 Singh, *Fermat's Last Theorem*, 298.
12 Centre for Computing History, 'Commodore International Shows Its Commodore Pet 2001'.

Let $f$ be an eigenform associated to the congruence subgroup $\Gamma_1(N)$ of $\mathrm{SL}_2(\mathbf{Z})$ of weight $k \geq 2$ and character $\chi$. Thus if $T_n$ is the Hecke operator associated to an integer $n$ there is an algebraic integer $c(n, f)$ such that $T_n f = c(n, f)f$ for each $n$. We let $K_f$ be the number field generated over $\mathbf{Q}$ by the $\{c(n, f)\}$ together with the values of $\chi$ and let $\mathcal{O}_f$ be its ring of integers. For any prime $\lambda$ of $\mathcal{O}_f$ let $\mathcal{O}_{f,\lambda}$ be the completion of $\mathcal{O}_f$ at $\lambda$. The following theorem is due to Eichler and Shimura (for $k = 2$) and Deligne (for $k > 2$). The analogous result when $k = 1$ is a celebrated theorem of Serre and Deligne but is more naturally stated in terms of complex representations. The image in that case is finite and a converse is known in many cases.

THEOREM 0.1. *For each prime $p \in \mathbf{Z}$ and each prime $\lambda \mid p$ of $\mathcal{O}_f$ there is a continuous representation*

$$\rho_{f,\lambda}\colon \mathrm{Gal}(\bar{\mathbf{Q}}/\mathbf{Q}) \longrightarrow \mathrm{GL}_2(\mathcal{O}_{f,\lambda})$$

*which is unramified outside the primes dividing $Np$ and such that for all primes $q \nmid Np$,*

$$\operatorname{trace} \rho_{f,\lambda}(\operatorname{Frob} q) = c(q, f), \qquad \det \rho_{f,\lambda}(\operatorname{Frob} q) = \chi(q)q^{k-1}.$$

We will be concerned with trying to prove results in the opposite direction, that is to say, with establishing criteria under which a $\lambda$-adic representation arises in this way from a modular form. We have not found any advantage in assuming that the representation is part of a compatible system of $\lambda$-adic representations except that the proof may be easier for some $\lambda$ than for others.

Assume

$$\rho_0 : \mathrm{Gal}(\bar{\mathbf{Q}}/\mathbf{Q}) \longrightarrow \mathrm{GL}_2(\bar{\mathbf{F}}_p)$$

is a continuous representation with values in the algebraic closure of a finite field of characteristic $p$ and that $\det \rho_0$ is odd. We say that $\rho_0$ is modular if $\rho_0$ and $\rho_{f,\lambda} \bmod \lambda$ are isomorphic over $\bar{\mathbf{F}}_p$ for some $f$ and $\lambda$ and some embedding of $\mathcal{O}_f/\lambda$ in $\bar{\mathbf{F}}_p$. Serre has conjectured that every irreducible $\rho_0$ of odd determinant is modular. Very little is known about this conjecture except when the image of $\rho_0$ in $\mathrm{PGL}_2(\bar{\mathbf{F}}_p)$ is dihedral, $A_4$ or $S_4$. In the dihedral case it is true and due (essentially) to Hecke, and in the $A_4$ and $S_4$ cases it is again true and due primarily to Langlands, with one important case due to Tunnell (see Theorem 5.1 for a statement). More precisely these theorems actually associate a form of weight one to the corresponding complex representation but the versions we need are straightforward deductions from the complex case. Even in the reducible case not much is known about the problem in the form we have described it, and in that case it should be observed that one must also choose the lattice carefully as only the semisimplification of $\overline{\rho_{f,\lambda}} = \rho_{f,\lambda} \bmod \lambda$ is independent of the choice of lattice in $K^2_{f,\lambda}$.

Figure 0.1 One page of Wiles' mathematical proof of the solution of Fermat's last theorem. Wiles, A. 'Modular elliptic curves and Fermat's Last Theorem'. *Annals of Mathematics*, 142, (1995), 443–551. By permission of Andrew Wiles.

The writing of a computer programme, like any writing, first and foremost requires the creation of a purpose for the programme, perhaps a problem to solve. My interest in music, including singing for the local church choir, had led to my involvement in church tower-bell ringing. Bell ringing beyond the most basic stages requires each bell ringer to learn the different bell ringing 'methods'. A method is a particular combination of 'changes' to the sequence of bells rung. So, if there are six church tower bells being rung, the starting sequence is always what are known as 'rounds': bell one, bell two, bell three, four, five, six, with bell one being the smallest highest pitched bell called the 'treble', and the largest and lowest pitched bell called the 'tenor' (and by one of those curious coincidences the 'Tower Captain's' surname was Alan Treble). A bell ringing *method* changes this sequence by allowing the 'movement' of bells from a starting position in the sequence, up or down one place in the sequence. For example, you can see in Figure 0.2 that the person ringing bell number two follows the path shown by the *blue line* (the darker vertical line in figure 0.2).

The path of the blue line for their bell has to be memorised by the bell ringers.[13] My idea for the computer studies project was to create a simulation and teaching package for bell ringers (now inevitably there is a website devoted to this). The programme required the user to input the correct position of their bell using the numbers of the keyboard within a set number of seconds. When a correct answer was supplied, the screen added the relevant segment of the blue line (the bell's path), and a connected amplifier was used to play the synthesised sound of the bells ringing the change. If an incorrect answer was supplied the computer would reveal the correct answer.

At the time of the Commodore PET, storage of programmes was on audio cassettes (small hard drives to fit inside computers had not been developed: at that time a hard drive was the size of a large suitcase). The Commodore's total RAM (Random Access Memory) was 4KB which is 4,000 times less memory than my current mobile phone which has 16 GB.

The programming language I used was BASIC, a language that is still used in variants such as *smart BASIC* today. The writing of the computer programme was built as several 'modules'. Figure 0.3 shows one page of the BASIC language that I wrote for one of the modules. The number 8850 indicates that it is a draft version of the programme at that moment, something corroborated by my note ('255 not completely correct: odd [number] bells?').

Looking at the programme and the report again after more than 30 years, I could barely understand its meaning, certainly not the detail of the logic. I'm assuming that most readers of this book will understand even less of the specific

[13] A 'Bob' is a quick alteration of the path of the method, called by an instruction from the tower captain, if a longer period of ringing than one iteration of the complete method is required. It enables the method to be rung again but with an entirely different set of number sequences. In this kind of bell ringing, the same sequence is not allowed to be repeated.

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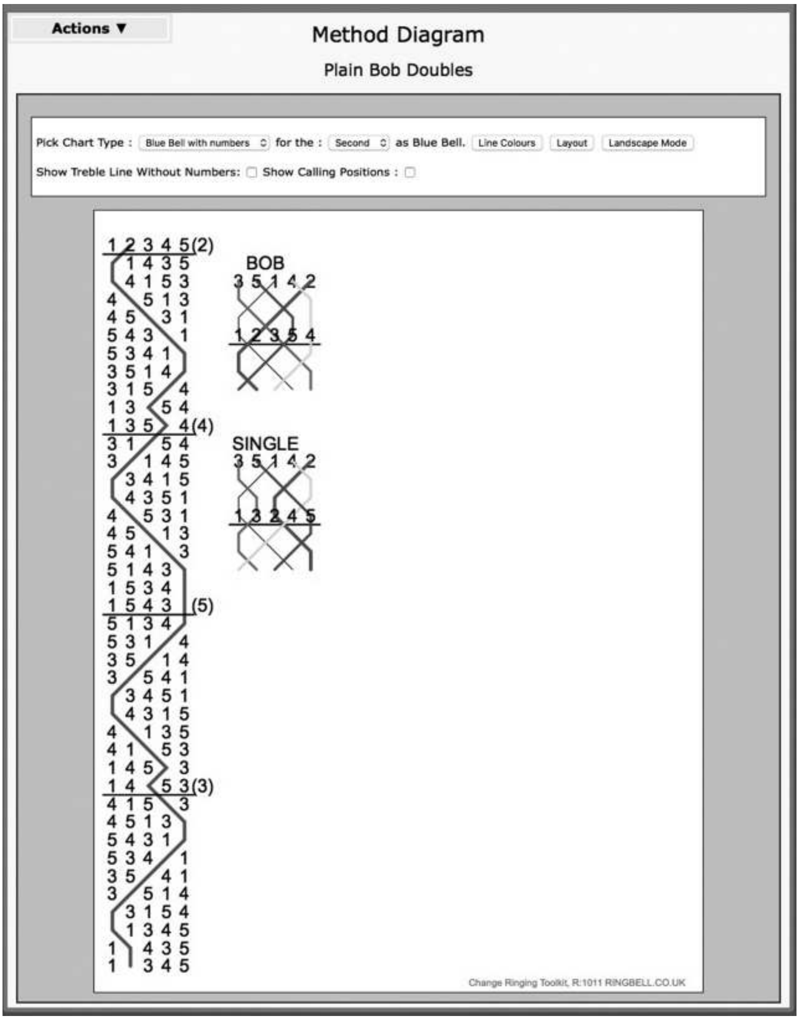


Figure 0.2 A bell-ringing ‘method’. Change Ringing Toolkit. ‘Method Diagram Plain Bob Minor.’ 2016. (Source: Steve Scanlon).

meanings. The submission of the project for the A Level assessment also required an account of the design of the project. Figure 0.4 is an extract from my account of the final version of the programme presented for the submission. Once again my understanding of the detail of the computing logic in Figure 0.4 has largely faded; in fact, it came as something of a surprise to think that I