Exercises in Programming Style

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Preface

THE CODE

This book is a companion text for code that is publicly available at http://github.com/crista/exercises-in-programming-style

WHO THIS BOOK IS FOR

The collection of code that is the foundation of this book is for everyone who enjoys the art of programming. I've written this book in order to complement and explain the raw code, as some of the idioms may not be obvious. Software developers with many years of experience may enjoy revisiting familiar programming styles in the broad context of this book and learning about styles that may not be part of their normal repertoire.

This book can be used as a textbook for advanced programming courses in Computer Science and Software Engineering programs. Additional teaching materials, such as lecture slides, are also available. The book is not designed for introductory programming courses; it is important for students to be able to crawl (i.e. learn to program under the illusion that there's only one way of doing things) before they can run (i.e. realize that there's a lot more variety). I expect that many of the readers will be students in their junior/senior year or in their early stages of graduate study. The exercise list at the end of each chapter is a good mechanism for testing the reader's understanding of each style. The suggested further readings are more appropriate for graduate students.

This book may also be of interest to writers, especially those who know a little programming or have a strong interest in programming technology. Despite important differences, there are many similarities between writing programs and writing in general.

MOTIVATION FOR THESE EXERCISES

In the 1940s, the French writer Raymond Queneau wrote a jewel of a book called *Exercises in Style*, featuring 99 renditions of the exact same story, each written in a different style. The book is a masterpiece of writing technique, as it illustrates the many different ways a story can be told. The story being fairly trivial and always the same, the book highlights form, rather than content; it

illustrates how the decisions we make in telling a story affect the perception of that story.

Queneau's story is trivially simple and can be told in two sentences: The narrator is on the "S" bus and notices a man with a long neck who is wearing a hat, and who gets into an altercation with the man sitting next to him. Two hours later, the narrator sees this same man near the Saint Lazare train station, with a friend, and the friend is giving this man some advice regarding an extra button on his overcoat. That's it! He then goes through 99 renditions of this story using, for example, litotes, metaphors, animism, etc.

Over the years, as an instructor of many programming-intensive courses, I noticed that often students have a hard time understanding the different ways of writing programs and of designing systems, in general. They have been trained in one, at most two, programming languages, so they understand only the styles that are encouraged by those languages, and have a hard time wrapping their heads around other styles. It's not their fault. Looking at the history of programming languages and the lack of pedagogical material on style in most Computer Science programs, one hardly gets exposed to the issue until after an enormous amount of experience is accumulated. Even then, style is seen as an intangible property of programs that remains elusive to explain to others – and over which many technical arguments ensue. So, in order to give programming styles the proper due, and inspired by Queneau, I decided to embark on the project of writing the exact same computational task in as many styles as I have come across over the years.

So what is *style*? In Queneau's circle of intellectuals, a group known as *Oulipo* (for French *Ouvroir de la littérature potentielle*, roughly translated as "workshop of potential literature"), style was nothing but the consequence of *creating under constraints*, often based on mathematical concepts such as permutations or lipograms. These constraints are used as a means to create something intellectually interesting besides the story itself. The ideas caught on, and over the years, several literary works have been created using Oulipo's constraints.

In this book, too, programming style is what results from writing programs under a set of constraints. Constraints can come from external sources or they can be self imposed; they can capture true challenges of the environment or they can be artificial; they can come from past experiences and measurable data or they can come from personal preferences. Independent of their origin, constraints are the seeds of style. By honoring different constraints, we can write a variety of programs that are virtually identical in terms of *what* they do, but that are radically different in terms of *how* they do it.

In the universe of all things a good programmer must know, I see collections of programming styles as being as important as any collection of data structures and algorithms, but with a focus on human effects rather than on computing effects. Programs convey information not just to the computers but, more importantly, to the people who read them. As with any form of expression, the consequences of *what* is being said are shaped and influenced by *how* it is being said. An advanced programmer needs not to just be able to write correct programs that perform well; he/she needs to be able to choose appropriate styles for expressing those programs for a variety of purposes.

Traditionally, however, it has been much easier to teach algorithms and data structures than it is to teach the nuances of programming expression. Books on data structures and algorithms all follow more or less the same formula: pseudo-code, explanation, and complexity analysis. The literature on programming tends to fall into two camps: books that explain programming *languages* and books that present collections of design or architectural *patterns*. However, there is a continuum in the spectrum of how to write programs that goes from the concepts that the programming languages encourage/enforce to the combination of program elements that end up making up the program; languages and patterns feed on each other, and separating them as two different things creates a false dichotomy. Having come across Queneau's body of work, it seemed to me that his focus on *constraints* as the basis for explaining expression styles was a perfectly good model for unifying a lot of important creative work in the programming world.

I should note that I'm not the first one to look at constraints as a good unifying principle for explaining style in software systems. The work on *architectural styles* has taken that approach for a long time. I confess that the notion that style arises from constraints (some things are disallowed, some things must exist, some things are limited, etc.) was a bit hard to understand at first. After all, who wants to write programs under constraints? It wasn't until I came across Queneau's work that the idea made perfect sense.

Like Queneau's story, the computational task in this book is trivial: given a text file, we want to produce the list of words in the file and their frequencies, and print them out in decreasing order of frequency. This computational task is known as **term frequency**. This book contains 33 different styles for writing the term frequency task, one in each chapter. Unlike Queneau's book, I decided to verbalize the constraints in each style and explain the example programs. Given the target audience, I think it's important to provide those insights explicitly rather than leaving them to the reader's interpretation. Each chapter starts by presenting the constraints of the style, then it shows an example program; a detailed explanation of the code follows; most chapters have additional sections regarding the use of the style in systems design and another section on the historical context in which the programming style emerged. History is important; a discipline should not forget the origins of its core ideas. I hope the readers will be curious enough to follow through some of the suggested further readings.

Why 33 styles? I chose 33 as a bounded personal challenge. Queneau's book has 99 styles. Had I set my goal to writing a book with 99 chapters, I probably never would have finished it! The public repository of code that is the basis for this book, however, is likely to continue to grow. The styles are grouped into nine categories: historical, basic, function composition, objects and object interactions, reflection and metaprogramming, adversity, data-centric, concur-

rency, and interactivity. The categories emerged as a way to organize the book, grouping together styles that are more related to each other than to the others. Other categorizations would be possible.

Similar to Queneau's book, these exercises in programming style are exactly that: *exercises*. They are the sketches, or arpeggios, of software; they aren't the music. A piece of real software usually employs a variety of styles for the different parts of the system. Furthermore, all these styles can be mixed and matched, creating hybrids that are interesting in themselves.

Finally, one last important remark. Although Queneau's book was the inspiration for this project, software is not exactly the same as the language arts; there are utility functions attached to software design decisions, i.e. some expressions are better than others for specific objectives.[1] In this book I try to stand clear of judgments of good and bad, except in certain clear cases. It is not up to me to make those judgments, since they depend heavily on the context of each project.

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[1] Maybe that's also the case for the language arts, but I'm afraid I don't know enough!

Prologue

TERM FREQUENCY

LIKE QUENEAU'S STORY, the computational task in this book is trivial: given a text file, we want to display the N (e.g. 25) most frequent words and corresponding frequencies ordered by decreasing value of frequency. We should make sure to normalize for capitalization and to ignore stop words like "the", "for", etc. To keep things simple, we don't care about the ordering of words that have equal frequencies. This computational task is known as **term frequency**.

Here is an example of an input file and corresponding output after computing the term frequency:

```
Input:
    White tigers live mostly in India
    Wild lions live mostly in Africa

Output:
    live - 2
    mostly - 2
    africa - 1
    india - 1
    lions - 1
    tigers - 1
    white - 1
    wild - 1
```

If we were to run this flavor of term frequency on Jane Austen's *Pride and Prejudice* available from the Gutenberg Collection, we would get the following output:

```
mr - 786
elizabeth - 635
very - 488
darcy - 418
such - 395
mrs - 343
much - 329
more - 327
```

```
bennet - 323
bingley - 306
jane - 295
miss - 283
one - 275
know - 239
before - 229
herself - 227
though - 226
well - 224
never - 220
sister - 218
soon - 216
think - 211
now - 209
time - 203
good - 201
```

This book's example programs cover this term frequency task. Additionally, all chapters have a list of exercises. One of those exercises is to write another simple computational task using the corresponding style. Some suggestions are given below.

These computational tasks are simple enough for any advanced student to tackle easily. Algorithmic difficulties out of the way, the focus should be on following the constraints that underlie each style.

WORD INDEX

Given a text file, output all words alphabetically, along with the page numbers on which they occur. Ignore all words that occur more than 100 times. Assume that a page is a sequence of 45 lines. For example, given *Pride and Prejudice*, the first few entries of the index would be:

```
abatement - 89
abhorrence - 101, 145, 152, 241, 274, 281
abhorrent - 253
abide - 158, 292
...
```

WORDS IN CONTEXT

Given a text file, display certain words alphabetically and in context, along with the page numbers of the pages in which they occur. Assume that a page is a sequence of 45 lines. Assume that context consists of the preceding and succeeding two words. Ignore punctuation. For example, given *Pride and Prejudice*, the words "concealment" and "hurt" would result in the following

output:

perhaps this **concealment** this disguise - 150
purpose of **concealment** for no - 207
pride was **hurt** he suffered - 87
must be **hurt** by such - 95
and are **hurt** if i - 103
pride been **hurt** by my - 145
must be **hurt** by such - 157
infamy was **hurt** and distressed – 248

Suggestion of words for the words in context task: concealment, discontented, hurt, agitation, mortifying, reproach, unexpected, indignation, mistake, and confusion.

PYTHONISMS

The example code used in this book is all written in Python, but expertise in Python is not necessary in order to understand the styles. In fact, one of the exercises in all of the chapters is to write the example program in another language. As such, the reader needs only to be able to *read* Python without needing to *write* in Python.

Python is relatively easy to read. There are, however, a few corners of the language that may confuse readers coming from other languages. I explain some of them here.

- **Lists.** In Python, a list is a primitive data type supported by dedicated syntax that is normally associated with arrays in C-like languages. Here is an example of a list: `mylist = [0, 1, 2, 3, 4, 5]`. Python doesn't have array as primitive data type[2], and most situations that would use an array in C-like languages use a list in Python.

- **Tuples.** A tuple is an immutable list. Tuples are also primitive data types supported by dedicated syntax that is normally associated with lists in Lisp-like languages. Here is an example of a tuple: `mytuple = (0, 1, 2, 3, 4)`. Tuples and lists are handled in similar ways, except for the fact that tuples are immutable, so the operations that change lists don't work on tuples.

- **List indexing.** List and tuple elements are accessed by index like this: `mylist[some_index]`. The lower bound of a list is index 0, like in C-like languages, and the list length is given by `len(mylist)`. Indexing a list can be much more expressive than this simple example suggests. Here are some more examples:

[2]There is an array data object, but it's not a primitive type of the language and it doesn't have any special syntax. It's not used as much as lists.

- `mylist[0]` – first element of the list
- `mylist[-1]` – last element of the list
- `mylist[-2]` – next-to-last element of the list
- `mylist[1:]` – a list starting at index 1 until the end of `mylist`
- `mylist[1:3]` – a list starting at index 1 and stoping before index 3 of `mylist`
- `mylist[::2]` – a list containing every other element of `mylist`
- `mylist[start:stop:step]` – a list containing every `step` element between `start` and `stop` indexes of `mylist`

- **Bounds.** Indexing an element beyond the length of a list results in an IndexError. For example, trying to access the 4th element of a list of 3 elements (e.g. [10, 20, 30][3]) results in an IndexError, as expected. However, many Python operations on lists (and collections in general) are constructivist with respect to indexing. For example, obtaining a list consisting of the range from 3 to 100 in a list with only 3 elements (e.g. [10, 20, 30][3:100]) results in an empty list (`[]`) rather than an IndexError. Similarly, any range that partially covers a list results in whatever part of the list is covered, with no IndexError (e.g. [10, 20, 30][2:10] results in [30]). This constructivist behavior may be puzzling at first for people used to more intolerant languages.

- **Dictionaries.** In Python, a dictionary, or map, is also a primitive data type supported by dedicated syntax. Here is an example of a dictionary: `mydict = {'a' : 1, 'b' : 2}`. This particular dictionary maps two string keys to two integer values; in general, keys and values can be of any type. In Java, these kinds of dictionaries can be found in the form of the `HashMap` class (among others), and in C++ they can be found in the form of the class template `map` (among others).

- **self.** In most Object-Oriented languages, the reference that an object has to itself is implicitly available through special syntax. For example, `this` in Java and C++, `$this` in PHP, or `@` in Ruby. Unlike these languages, Python has no special syntax for it. Moreover, instance methods are simply class methods that take an object as first parameter; this first parameter is called `self` by convention, but not by special mandate of the language. Here is an example of a class definition with two instance methods:

```
1  class Example:
2      def set_name(self, n):
3          self._name = n
4      def say_my_name(self):
5          print self._name
```


Both methods have a parameter named `self` in the first position, which is then accessed in their bodies. There is nothing special about the word `self`, and the methods could use any other name, for example `me` or `my` or even `this`, but any word other than `self` will be frowned upon by Python programmers. Calling instance methods, however, may be surprising, because the first parameter is omitted:

```
e = Example()
e.set_my_name(``Heisenberg'')
e.say_my_name()
```

This mismatch on the number of parameters is due to the fact that the dot-notation in Python ('.') is simply syntactic sugar for this other, more primitive form of calling the methods:

```
e = Example()
Example.set_my_name(e, ``Heisenberg'')
Example.say_my_name(e)
```

- **Constructors.** In Python, a constructor is a regular method with the name __init__ (two underscores on each side of the word). Methods with this exact name are called automatically by the Python runtime right after object creation. Here is one example of a class with a constructor, and its use:

```
1  class Example:
2      # This is the constructor of this class
3      def __init__(self, n):
4          self._name = n
5      def say_my_name(self):
6          print self._name
7
8  e = Example(``Heisenberg'')
9  e.say_my_name()
```

The Author

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Dr. Lopes has a PhD from Northeastern University, and MS and BS degrees from Instituto Superior Técnico in Portugal. She is the recipient of several National Science Foundation grants, including a prestigious CAREER Award. She claims to be the only person in the world who is both an ACM Distinguished Scientist and Ohloh Kudos Rank 9.

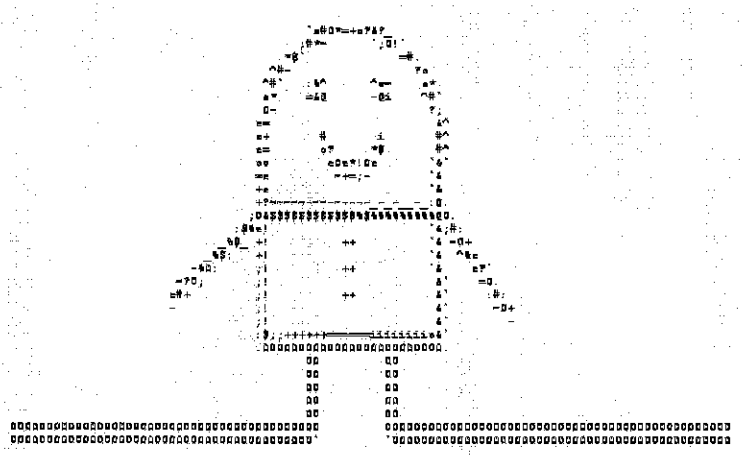
I

Historical

Computing systems are like an onion, with layers upon layers of abstraction developed over the years in order to facilitate the expression of intent. It is important to know what the inner layers really entail. The first two programming styles illustrate what programming was like several decades ago, and to some extent, what it still is in the inner layers of modern systems.

CHAPTER 1

Good Old Times



1.1 CONSTRAINTS

- ▷ Very small amount of primary memory, typically orders of magnitude smaller than the data that needs to be processed/generated.
- ▷ No identifiers – i.e. no variable names or tagged memory addresses. All we have is memory that is addressable with numbers.

1.2 A PROGRAM IN THIS STYLE

```
#!/usr/bin/env python

import sys, os, string

# Utility for handling the intermediate 'secondary memory'
def touchopen(filename, *args, **kwargs):
    try:
        os.remove(filename)
    except OSError:
        pass
    open(filename, "a").close() # "touch" file
    return open(filename, *args, **kwargs)

# The constrained memory should have no more than 1024 cells
data = []
# We're lucky:
# The stop words are only 556 characters and the lines are all
# less than 80 characters, so we can use that knowledge to
# simplify the problem: we can have the stop words loaded in
# memory while processing one line of the input at a time.
# If these two assumptions didn't hold, the algorithm would
# need to be changed considerably.

# Overall strategy: (PART 1) read the input file, count the
# words, increment/store counts in secondary memory (a file)
# (PART 2) find the 25 most frequent words in secondary memory

# PART 1:
# - read the input file one line at a time
# - filter the characters, normalize to lower case
# - identify words, increment corresponding counts in file

# Load the list of stop words
f = open('../stop_words.txt')
data = [f.read(1024).split(',')] # data[0] holds the stop words
f.close()

data.append([])     # data[1] is line (max 80 characters)
data.append(None)   # data[2] is index of the start_char of word
data.append(0)      # data[3] is index on characters, i = 0
data.append(False)  # data[4] is flag indicating if word was found
data.append('')     # data[5] is the word
data.append('')     # data[6] is word,NNNN
data.append(0)      # data[7] is frequency

# Open the secondary memory
word_freqs = touchopen('word_freqs', 'rb+')
# Open the input file
f = open(sys.argv[1])
# Loop over input file's lines
while True:
    data[1] = [f.readline()]
    if data[1] == ['']: # end of input file
        break
    if data[1][0][len(data[1][0])-1] != '\n': # If it does not end
        with \n
        data[1][0] = data[1][0] + '\n' # Add \n
    data[2] = None
    data[3] = 0
    # Loop over characters in the line
    for c in data[1][0]: # elimination of symbol c is exercise
        if data[2] == None:
            if c.isalnum():
                # We found the start of a word
                data[2] = data[3]
        else:
            if not c.isalnum():
                # We found the end of a word. Process it
                data[4] = False
                data[5] = data[1][0][data[2]:data[3]].lower()
                # Ignore words with len < 2, and stop words
                if len(data[5]) >= 2 and data[5] not in data[0]:
                    # Let's see if it already exists
                    while True:
                        data[6] = word_freqs.readline().strip()
                        if data[6] == '':
                            break;
                        data[7] = int(data[6].split(',')[1])
                        # word, no white space
                        data[6] = data[6].split(',')[0].strip()
                        if data[5] == data[6]:
                            data[7] += 1
                            data[4] = True
                            break
                    if not data[4]:
                        word_freqs.seek(0, 1) # Needed in Windows
                        word_freqs.writelines("%20s,%04d\n" % (
                            data[5], 1))
                    else:
                        word_freqs.seek(-26, 1)
                        word_freqs.writelines("%20s,%04d\n" % (
                            data[5], data[7]))
                    word_freqs.seek(0,0)
                # Let's reset
                data[2] = None
        data[3] += 1
# We're done with the input file
f.close()
word_freqs.flush()

# PART 2
# Now we need to find the 25 most frequently occuring words.
# We don't need anything from the previous values in memory
del data[:]

# Let's use the first 25 entries for the top 25 words
data = data + [[]]*(25 - len(data))
data.append('') # data[25] is word,freq from file
data.append(0)  # data[26] is freq

# Loop over secondary memory file
```

```
109 while True:
110     data[25] = word_freqs.readline().strip()
111     if data[25] == '': # EOF
112         break
113     data[26] = int(data[25].split(',')[1]) # Read it as integer
114     data[25] = data[25].split(',')[0].strip() # word
115     # Check if this word has more counts than the ones in memory
116     for i in range(25): # elimination of symbol i is exercise
117         if data[i] == [] or data[i][1] < data[26]:
118             data.insert(i, [data[25], data[26]])
119             del data[26] #  delete the last element
120             break
121
122 for tf in data[0:25]: # elimination of symbol tf is exercise
123     if len(tf) == 2:
124         print tf[0], ' - ', tf[1]
125 # We're done
126 word_freqs.close()
```

Note: If not familiar with Python, please refer to the Prologue (Pythonisms) for an explanation of lists, indexes and bounds.

1.3 COMMENTARY

IN THIS STYLE, the program reflects the constrained computing environment where it executes. The memory limitations force the programmer to come up with ways of rotating data through the available memory, adding complexity to the computational task at hand. Additionally, the absence of identifiers results in programs where the natural terminology of the problem is absent from the program text, and, instead, is added through comments and documentation. This is what programming was all about in the early 1950s. This style of programming, however, is not extinct; it is still in use today when dealing directly with hardware and when optimizing the use of memory.

The example program may look quite foreign to programmers not used to these kinds of constraints. While this is certainly a program that one doesn't associate with Python or with any of the modern programming languages, it embodies the theme of this book quite well: programming styles emerge from *constraints*. Very often, the constraints are imposed externally – maybe the hardware has limited memory, maybe the assembly language doesn't support identifiers, maybe performance is critical and one must deal directly with the machine, etc.; other times the constraints are self-imposed: the programmer, or the entire development team, decides to adhere to certain ways of thinking about the problems and of writing the code, for many different reasons – maintainability, readability, extensibility, adequacy for the problem domain, past experiences on the part of the developers; or simply, as is the case here, to teach what low-level programming looks like without having to learn new syntax. Indeed, it is possible to write low-level, Good Old Times style programs in just about any programming language!

Having explained the reason for this unusual implementation of term frequency, let's dive into this program. The memory limitations are such that we can't ignore the size of the data to be processed. In the example, we have self-imposed a size of 1024 memory cells (line #15). The term "memory cell" is used here in a somewhat fuzzy manner to denote, roughly, a piece of simple data, such as a character or a number. Given that books like *Pride and Prejudice* contain much more than 1024 characters, we need to come up with ways to read and process the data in small chunks, making heavy use of "secondary memory" (a file) to store the data that doesn't fit in primary memory. Before we start coding, we need to do some back-of-the-envelope calculations about the different options regarding what to hold in primary memory and what to dump to secondary memory, and when (see comments in lines #16 through #26). Then as now, access to primary memory is orders of magnitude faster than access to secondary memory, so these calculations are about optimizing for performance.

Many options could have been pursued, and the reader is encouraged to explore the solution space within this style. The example program is divided into two distinct parts: the first part (lines #28 through #98) processes the input file, counting word occurrences and writing that data into a word-frequency

file; the second part (lines #100 through #128) processes the intermediate word-frequency file in order to discover the 25 most frequently occurring words, printing them at the end.

The first part of the program works as follows:

- Hold the stop words, roughly 500 characters, in primary memory (lines #33 through #36)
- Read the input file one line at a time; each line is only 80 characters maximum (lines #50 through #95)
- For each line (lines #60 through #95), filter the characters, identify the words, and normalize them to lower case
- Retrieve/Write the words and their frequencies from/to secondary memory (lines #73 through #90)

After processing the entire input file like this, we then turn our attention to the word frequencies that have been accumulated in the intermediate file. We need a sorted list of the most frequently occurring words, so the program does the following:

- Keep an ordered list in memory holding the current 25 most frequently occurring words, and their frequencies (line #104)
- Read one line at a time from the file. Each line contains a word and its corresponding frequency (lines #108 through #120)
- If the new word has higher frequency than any of the words in memory, insert it at the appropriate place in the list and remove the word at the end of the list (lines #116 through #120)
- Finally, print the 25 top words and their frequencies (lines #122 through #124) and close the intermediate file (line #126)

As seen, the memory constraint has a strong effect on the algorithm employed, as we must be mindful of how much data there is in memory at any given point in time.

The second self-imposed constraint of this style is the absence of identifiers. This second constraint also has a strong effect on the program, but this effect is of a different nature: readability. There are no variables, as such; there is only a data memory that is accessed by indexing it with numbers. The problem's natural concepts (words, frequencies, counts, sorting, etc.) are completely absent from the program text, and are, instead, indirectly represented as indexes over memory. The only way we can bring those concepts back in is by adding comments that explain what kinds of data the memory cells hold (e.g. see comments in lines #38 through #44 and #103 through #106, among others). When reading through the program, we often need to go back to those comments to remind ourselves what high-level concept a certain memory index corresponds to.

1.4 THIS STYLE IN SYSTEMS DESIGN

In the age of computers with multi-gigabyte RAM, constrained memory such as that shown here is mostly a vague memory from the past. Nevertheless, with modern programming languages that encourage obliviousness with respect to memory management, and with the ever-growing amounts of data that modern programs handle, it is very easy to let memory consumption of programs run out of control, with negative consequences on run-time performance. A certain amount of awareness regarding the consequences that the different programming styles carry for memory usage is always a good thing.

Many applications these days – namely those falling in what's known as *Big Data* – have brought the complexities of dealing with small memory back to the center of attention. In this case, although memory is not scarce in absolute terms, it is much smaller than the size of the data to be processed. For example, if instead of just *Pride and Prejudice* we would apply term frequency to the entire Gutenberg Collection, we would likely not be able to hold all the books in memory at the same time; we might not even be able to hold the list of word frequencies all in memory either. Once the data can't fit in memory all at once, developers must devise smart schemes for (1) representing data so that more of it can fit in memory at any given time; and (2) rotating the data through primary and secondary memory. Programming with these constraints tends to make programs feel like the Good Old Times style.

Regarding the absence of names, one of the main drivers behind programming language evolution throughout the 1950s and 1960s was precisely the elimination of cognitive indirections such as those shown in the example: we want the program texts to reflect the high-level concepts of the domain as much as possible, instead of reflecting the low-level machine concepts and relying on external documentation to do the mapping between the two. But even though programming languages have provided for user-defined named abstractions for a long time, it is not unusual for programmers to fail to name their program elements, Application Programming Interfaces (APIs) and entire components appropriately, resulting in programs, libraries and systems as obscure as the one shown here.

Let this Good Old Times style be a reminder of how thankful we should be for being able to hold so much data in memory and for being able to give appropriate names to each and every one of our program elements!

1.5 HISTORICAL NOTES

This style of programming came directly from the first viable model of computation, the Turing Machine. A Turing Machine consists of an unbounded modifiable state "tape" (the data memory) and a state machine that reads and modifies that state. The Turing Machine had a tremendous influence in the development of computers and how they were programmed. Turing's ideas

influenced von Neumann's design of the first computer with stored programs. Turing himself also wrote the specifications of a computing machine known as the Automatic Computing Engine (ACE), which was, in many ways, more advanced than van Neumann's. Because that report was classified by the British government, and also because of the politics following the Second World War, Turing's design was not acted upon until several years later, and still in secrecy. Both von Neumann's architecture and Turing's machines led to the first programming languages in the 1950s, which enforced the concept of programming by reusing and changing state in memory over time.

1.6 FURTHER READING

Bashe, C., Johnson, L., Palmer, J. and Pugh, E. (1986). *IBM's Early Computers: A Technical History* (History of Computing), MIT Press, Cambridge, MA.
Synopsis: IBM was the major commercial player in the early days of computing machines. This book tells the story of IBM's transition from manufacturer of electromechanical machines to a powerhouse of computing machines.

Carpenter, B.E. and Doran, R.W. (1977). The other Turing Machine. *Computer Journal* 20(3): 269–279.
Synopsis: An account of one of Turing's technical reports describing a complete architecture for a computing machine based on von Neumann's, but including subroutines, stacks and much more. The original report can be found at
http://www.npl.co.uk/about/history/notable-individuals/turing/ace-proposal

Turing, A. (1936). On computable numbers, with an application to the Entscheidungs problem. *Proceedings of the London Mathematical Society* 2(42): 230–265.
Synopsis: The original "Turing Machine." In the context of this book, this paper is suggested not for its mathematics but for the programming model of a Turing Machine: a tape with symbols, a tape reader/writer that moves left and right, and the overwriting of symbols on the tape.

von Neumann, J. (1945). First draft of a report on the EDVAC. Reprinted in *IEEE Annals of the History of Computing* 15(4): 27–43, 1993.
Synopsis: The original "von Neumann's architecture." As with Turing's paper, suggested for the programming model.

1.7 GLOSSARY

Main memory: Often referred to simply as *memory*, this data storage is directly accessible by the CPU. Most data in this storage is volatile in the sense that it does not persist beyond the execution of the programs

that use it and also does not persist upon machine power downs. These days, the main memory is random access memory (RAM), meaning that the CPU can address any cell in it quickly, as opposed to having to scan sequentially.

Secondary memory: In contrast to primary memory, secondary memory refers to any storage facility that is not directly accessible by the CPU and that, instead, is indirectly accessed via input/output channels. Data in secondary memory persists in the device through power downs and until it is explicitly deleted. In modern computers, hard disk drives and "pen" drives are the most common secondary storage forms. Access to secondary memory is several orders of magnitude slower than access to primary memory.

1.8 EXERCISES

1.1 *Another language.* Implement the example program in another language, but preserve the style.

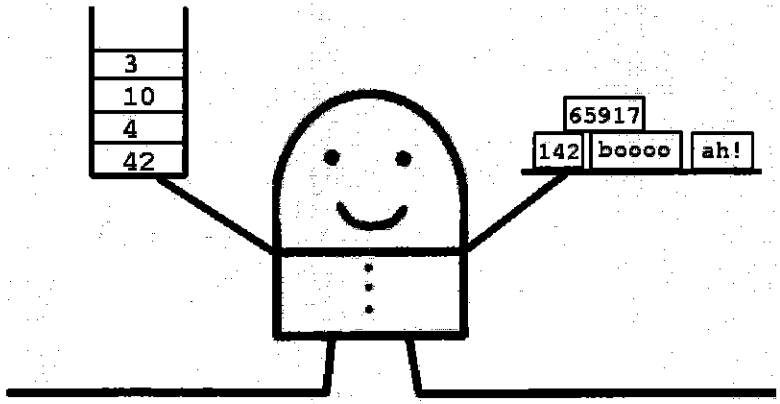
1.2 *No identifiers.* The example program still has a few identifiers left, namely in lines #60 (*c*), #116 (*i*) and #122 (*tf*). Change the program so that these identifiers are also eliminated.

1.3 *More lines.* The example program reads one line at a time into memory. In doing so it is underutilizing the main memory. Modify the program so that it loads as many lines as possible into memory without going over the established limit of 1024 memory cells. Justify the number of lines you chose. Check if your version runs faster than the original example program, and explain the result.

1.4 *A different task.* Write one of the tasks proposed in the Prologue using the Good Old Times style.

CHAPTER 2

Go Forth



2.1 CONSTRAINTS

- ▷ Existence of a data stack. All operations (conditionals, arithmetic, etc.) are done over data on the stack.
- ▷ Existence of a heap for storing data that's needed for later operations. The heap data can be associated with names (i.e. variables). As said above, all operations are done over data on the stack, so any heap data that needs to be operated upon needs to be moved first to the stack and eventually back to the heap.
- ▷ Abstraction in the form of user-defined "procedures" (i.e. names bound to a set of instructions), which may be called something else entirely.