Energy footprint of the Levenshtein distance computing algorithm

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`https://github.com/sallareznov/gc-levenshtein`

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Table of contents

Introduction

The Levenshtein distance (named after Vladimir Levenshtein) [1] between two words is the minimum number of single-character edits (i.e. insertions, deletions or substitutions) required to change one word into the other.

Chapter 1

Technical work

1.1 Goal

The goal of this project is to measure energy footprints of different programming languages through execution of programs executing the same task. The results of this experiment can be very beneficial for many people in specific domains, especially in two. First, developers who tend to favour energy-efficiency over performance will know how language to use to produce the most economical program possible. Second, language designers can analyse the metrics and reach conclusions on how a design of a language can be improved or rewritten.

DIAGRAM

1.2 Architecture and design

The design of the program is very simple. In we place ourselves in the context of object-oriented programming (since it is the most understandable form of design by a human), the program is composed of 5 classes (it could even be less than that). Those are depicted in the following UML diagram :

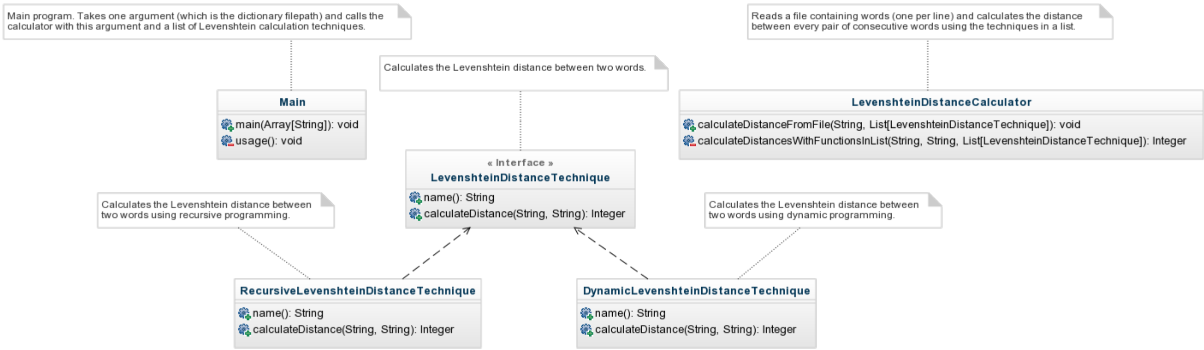


Figure 1.1: UML diagram of the algorithm in Scala

1.3 Algorithm

For the credibility of the measures made, the algorithm involves two I/O aspects : file reading, and printing. First, the algorithm performs file reading by retrieving words in a dictionary of words. File reading operations can be an important factor in energy consommation, as well as printing on the standard output.

The pathway of the algorithm is : opening a text file containing thousands of words, read every two consecutive word, print them and print the Levenshtein distances calculated with a recursive technique and a technique using dynamic programming (iterative).

The algorithm is summarized by the following flowchart :

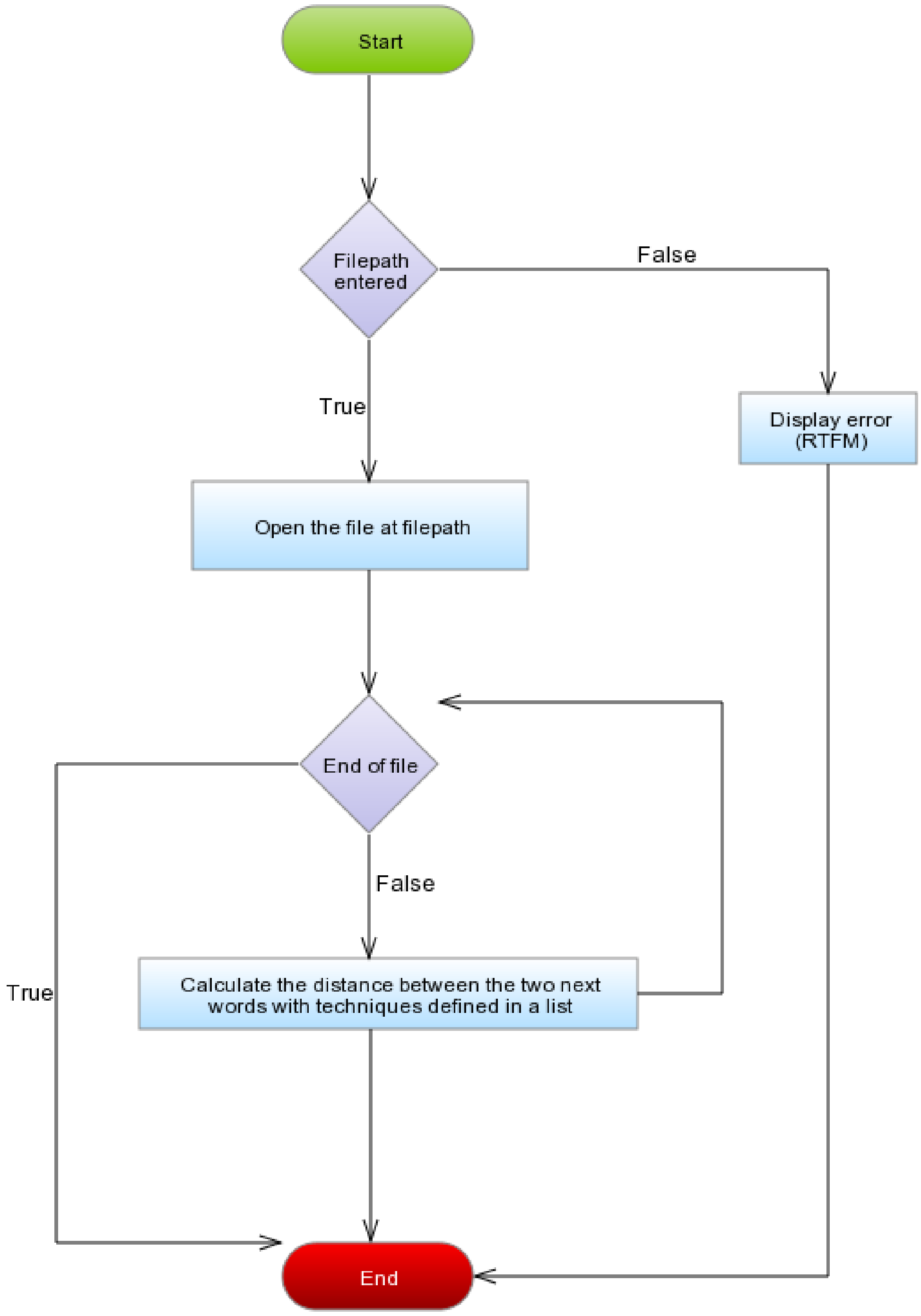


Figure 1.2: Flowchart of the algorithm

Two versions of the algorithm have been implemented : a recursive version and a version using dynamic programming (iterative).

Algorithm 1: The recursive version of the Levenshtein distance computing algorithm

```
Function recursiveLevenshteinDistance(word1 : String, word2 : String)
    if word1 == word2 then
        return 0
    lengthWord1 ← word1.length();
    lengthWord2 ← word2.length();
    if lengthWord1 == 0 then
        return lengthWord2
    if lengthWord2 == 0 then
        return lengthWord1
    firstLetterWord1 ← lengthWord1;
    firstLetterWord2 ← lengthWord2;
    subWord2 ← word2.substring(1);
    subWord2 ← word2.substring(1);
    if firstLetterWord1 == firstLetterWord2 then
        return recursiveLevenshteinDistance(subWord1, subWord2)
    else
        return 1 + min(recursiveLevenshteinDistance(subWord1, word2),
         recursiveLevenshteinDistance(word1, subWord2),
         recursiveLevenshteinDistance(subWord1, subWord2)
```

Algorithm 2: The dynamic version of the Levenshtein distance computing algorithm

```
Function dynamicLevenshteinDistance(word1 : String, word2 : String)
    if word1 == word2 then
        return 0
    lengthWord1 ← word1.length();
    lengthWord2 ← word2.length();
    table ← int[lengthWord1 + 1, lengthWord2 + 1];
    if lengthWord1 == 0 then
        return lengthWord2
    if lengthWord2 == 0 then
        return lengthWord1
    for i ← 0 to lengthWord1 do
        for j ← 0 to lengthWord2 do
            if i == 0 then
                table[i][j] = j
            else if j == 0 then
                table[i][j] = i
            else if word1[i - 1] == word2[j - 1] then
                table[i][j] = table[i - 1][j - 1]
            else
                table[i][j] = 1 + min(table[i - 1][j], table[i][j - 1], table[i - 1][j - 1]
    return table[lengthWord1][lengthWord2]
```

1.4 Implementation

The algorithm is implemented in the following languages (in alphabetical order) :

- C
- Go
- Java
- Ocaml
- Python
- Ruby
- Scala

The measurements of energy footprints is done thanks to PowerAPI [2][?], a middleware toolkit for software-defined power meters.

The GitHub repository containing the implementations in the different languages and the results (the files generated by PowerAPI) can be found at the following link : `https://github.`

`com/sallareznov/gc-levenshtein`.

In order to have relevant evaluations, the different program follow the same logic, down to the last semicolon.

1.5 Usage

The utilisation of the implemented programs is quite straightforward. No additional command needs to be entered, because every program has a build file. For example, with the implementation in the Go language, the initial arborescence (the one before compilation) is the following :

```
.
└── src
    ├── levenshtein
    │   ├── dynamic_levenshtein_distance_technique.go
    │   ├── levenshtein_distance_calculator.go
    │   ├── levenshtein_distance_technique.go
    │   └── recursive_levenshtein_distance_technique.go
    ├── levenshtein_test
    │   └── levenshtein_test.go
    └── main
        └── main.go
```

After setting the `$GOPATH` environment variable (needed by the Go compiler to find the module) to the project root folder (`gc-levenshtein/go/`), you have to compile the program by executing the command `go install main`.

Two new folders will be generated : one for the packages (`pkg/`) and another one for the binaries (`main`). In our context, the package is `levenshtein` and the binary is `main`.

```
.
├── bin
│   └── main
├── pkg
│   └── linux_amd64
│       └── levenshtein.a
└── src
    ├── levenshtein
    │   ├── dynamic_levenshtein_distance_technique.go
    │   ├── levenshtein_distance_calculator.go
    │   ├── levenshtein_distance_technique.go
    │   └── recursive_levenshtein_distance_technique.go
    ├── levenshtein_test
    │   └── levenshtein_test.go
    └── main
        └── main.go
```

To run the program, just launch the binary file with the name of the file containing the words as an argument. For example : `./bin/main ../dictionary_EN.txt`. The following output (truncated) will be produced in the standard output :

```
...

Word1 : micropipette
Word2 : microprocessing
Recursive distance : 8
Dynamic distance : 8

Word1 : microprocessor
Word2 : microprocessors
Recursive distance : 1
Dynamic distance : 1

Word1 : microprogram
Word2 : microprogrammed
Recursive distance : 3
Dynamic distance : 3

Word1 : microprogramming
Word2 : microradiographical
Recursive distance : 9
Dynamic distance : 9
```

```
Word1 : microradiographically
Word2 : microradiography
Recursive distance : 5
Dynamic distance : 5

Word1 : micros
Word2 : microscope
Recursive distance : 4
Dynamic distance : 4

...
```

Chapter 2

Evaluation

2.1 Performance

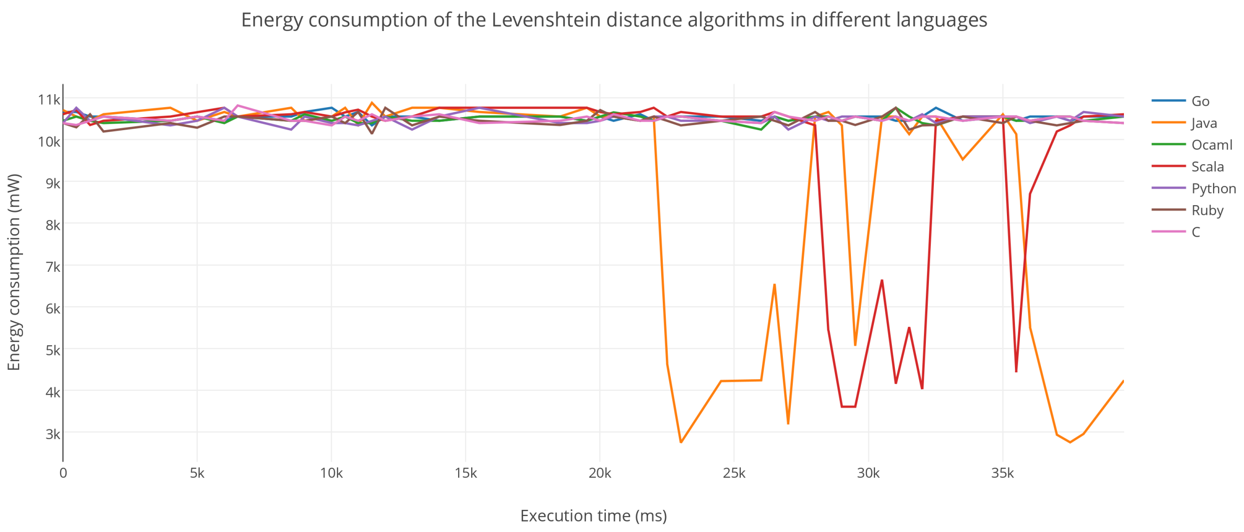
Language	Execution Time
C	1m32s
Go	1m9s
Java	47s
Ocaml	5m29s
Python	7m33s
Ruby	9m12s
Scala	45s

Figure 2.1: Execution time of the algorithm in the implemented languages

2.2 Validation

2.2.1 Time-dependent energy consumption

The measurements of the energy consumptions has been done on a 64-bits computer, with 6GB of RAM and running Intel(R) Core(TM) i5-4210H CPU @ 2.90GHz processor. Results generated by PowerAPI are entered in the following graph :



2.2.2 Total energy consumption

In our context, time-dependent energy consumption is not very relevant. This aspect doesn't really reflect the efficiency of one language over another. We need to include a crucial factor, which is the execution time.

If two languages have the same energy consumption, the one that takes a longer time to execute will be the least efficient. Therefore, a language is really more efficient than another if it has a smaller total energy consumption.

The total energy consumption is the energy consumption in Joule, the product of the mean of energy consumptions over time with the execution time of the program. [3]

$$TEC(J) = \frac{\sum_{EC}}{\#EC} \times ET$$

TEC = Total Energy Consumption, EC = Energy Consumption, ET = Execution Time

The total energy consumption of each algorithm can be found in the following figure :

Language	Execution Time (s)	Mean consumption (mW)	Total consumption (J)
C	1m32s	10504.77	966
Go	1m9s	9428.62	650
Java	47s	8890.39	418
Ocaml	5m29s	10358.25	3408
Python	7m33s	10493.72	4753
Ruby	9m12s	10468.74	5778
Scala	45s	9033.88	406

Figure 2.2: Total energy consumption of the algorithm in the implemented languages

Conclusion

Bibliography

[1] Wikipedia. Levenshtein distance. https://en.wikipedia.org/wiki/Levenshtein_distance.

[2] Inria Spirals Team. Powerapi, a middleware toolkit for software-defined power meters.
Official website : http://powerapi.org
GitHub : https://github.com/Spirals-Team/powerapi
GitHub Wiki : https://github.com/Spirals-Team/powerapi/wiki.

[3] Wikipedia. Joule. https://en.wikipedia.org/wiki/Joule.