Energy footprint of the Levenshtein distance computing algorithm

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

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Introduction

Information and Communications Technology devices usage is increasing, resulting in a growing complexity of modern processors [1]. Therefore, software power estimation is very important in this context, enabling architecture-agnostic solutions to leverage this power metric.

Even on the software side, when writing a program, the best choice is to be made (i.e the one with the best energy consumption). That is what this project tackles : energy consumption of languages executing the same algorithm.

In this project, a study consisting of a comparison of algorithms performance is presented. The algorithm is implemented and executed in 7 languages, and their energy consumption are measured and compared.

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 performing 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.

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 :

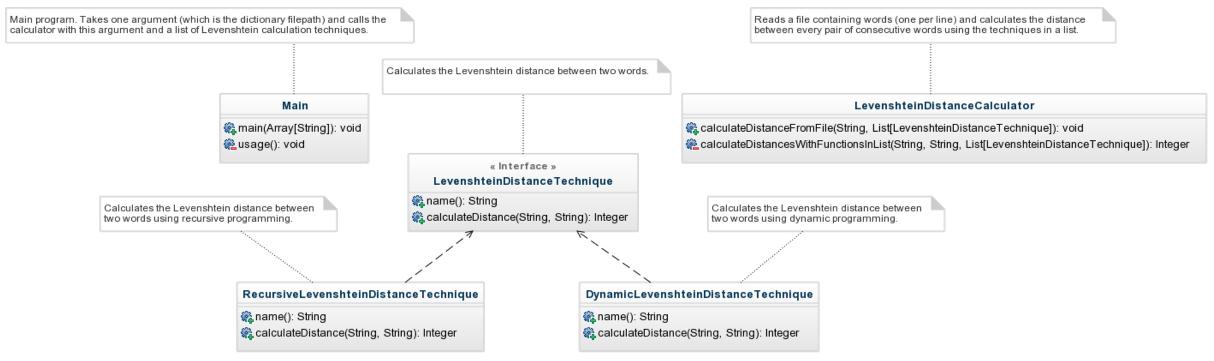

Main program. Takes one argument (which is the dictionary filepath) and calls the calculator with this argument and a list of Levenshtein calculation techniques.
Reads a file containing words (one per line) and calculates the distance between every pair of consecutive words using the techniques in a list.
Calculates the Levenshtein distance between two words.
Main
main(Array[String]): void
usage(): void
LevenshteinDistanceCalculator
calculateDistanceFromFile(String, List[LevenshteinDistanceTechnique]): void
calculateDistancesWithFunctionsInList(String, String, List[LevenshteinDistanceTechnique]): Integer
« Interface »
LevenshteinDistanceTechnique
name(): String
calculateDistance(String, String): Integer
Calculates the Levenshtein distance between two words using recursive programming.
Calculates the Levenshtein distance between two words using dynamic programming.
RecursiveLevenshteinDistanceTechnique
name(): String
calculateDistance(String, String): Integer
DynamicLevenshteinDistanceTechnique
name(): String
calculateDistance(String, String): Integer

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 Levenshtein distance (named after Vladimir Levenshtein) 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 [2].

The algorithm is summarized by the following flowchart :

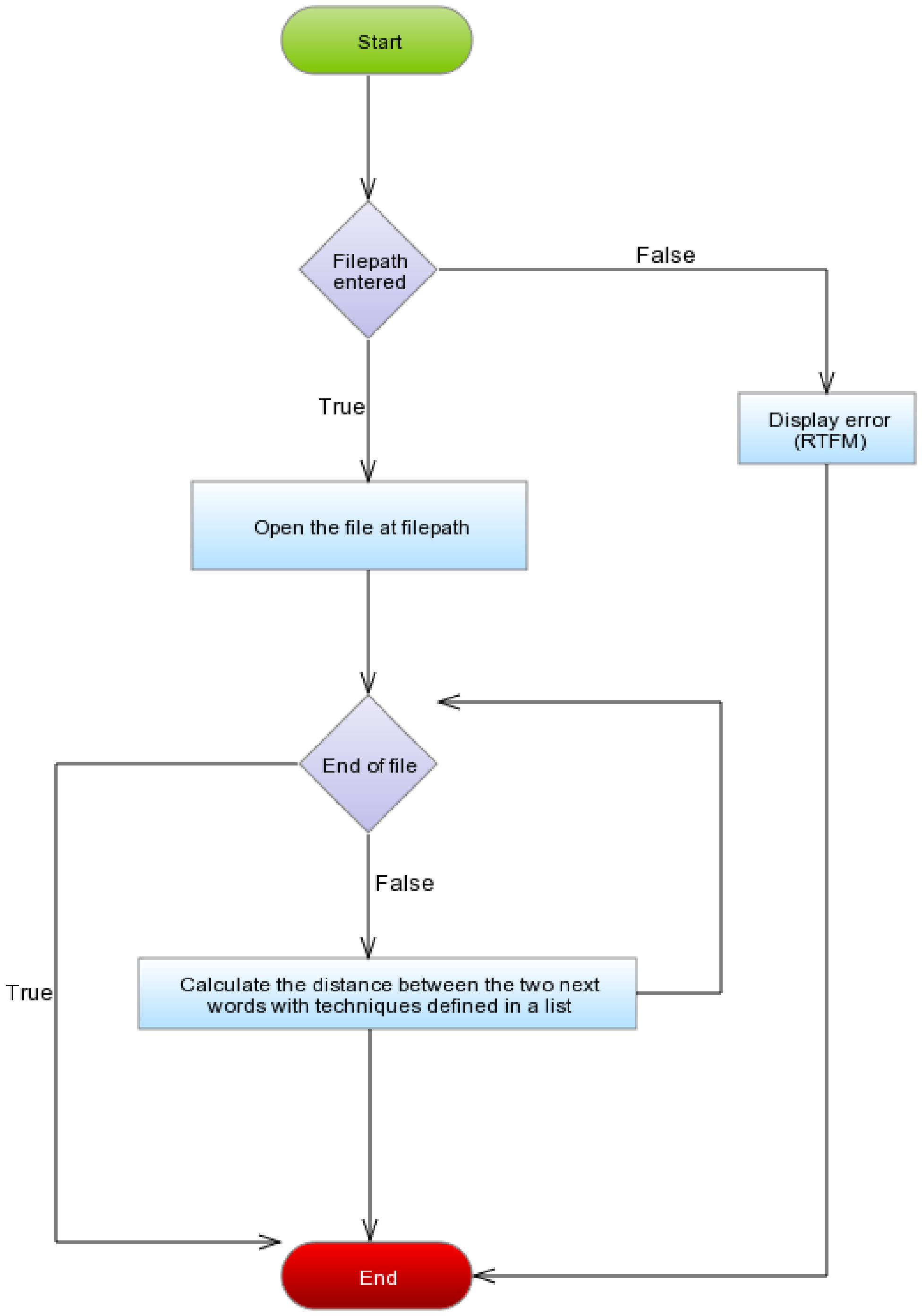

Start
Filepath entered
False
True
Display error (RTFM)
Open the file at filepath
End of file
False
True
Calculate the distance between the two next words with techniques defined in a list
End

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 (w. GCC v. 5.1)
- Go (v. 1.5.3)
- Java (v. 8u60)
- Ocaml (v. 4.02.3)
- Python (v. 3.3)
- Ruby (v. 2.3.0)
- Scala (v. 2.11.7)

The measurements of energy footprints are done thanks to PowerAPI, a middleware toolkit for software-defined power meters [3].

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/`), the program has to be compiled 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

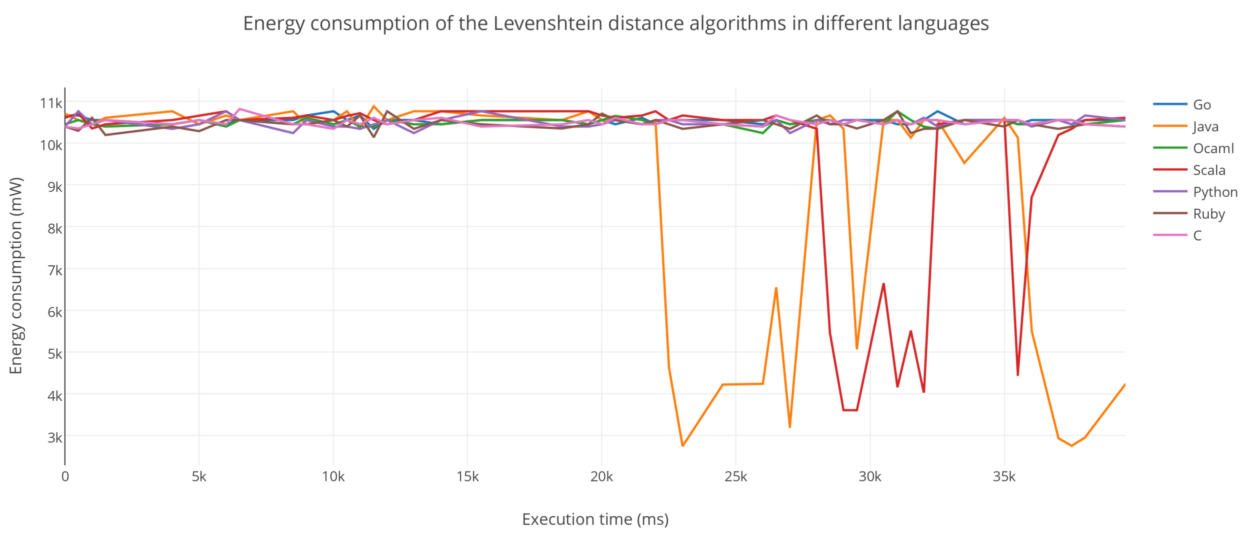
2.2 Validation

2.2.1 Context of the measurements

The measurements of the energy consumptions have been done on a 64-bits computer, with 6GB of RAM and running Intel(R) Core(TM) i5-4210H CPU @ 2.90GHz processor. The operating system monitoring the computer is Linux Mint 17, based on Debian.

2.2.2 Time-dependent energy consumption

Results generated by PowerAPI are entered in the following graph :



2.2.3 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 is 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 [4].

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

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)
Scala	45s	9033.88	406
Java	47s	8890.39	418
Go	1m9s	9428.62	650
C	1m32s	10504.77	966
Ocaml	5m29s	10358.25	3408
Python	7m33s	10493.72	4753
Ruby	9m12s	10468.74	5778

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

Among the languages, Scala and Java are the most efficient ones. It can be interpreted by the multiple optimizations that occure in the JVM (Java Virtual Machine) [5].

The Go and the C language come after, and the least efficient languages are Ocaml, Python, Ruby, which seem to have difficulties to handle recursivity.

Conclusion

In order to compare energy consumptions of different languages, the Levenshtein distance algorithm has been implemented in each, and results are measured and compared by PowerAPI, a middleware toolkit for software-defined power meters [3].

The result is the languages have slightly the same time-dependent energy consumption. But if the execution time of each program is taken into account, Scala and Java, JVM-based languages, are faster and consume less energy (respectively 406 and 418 Joules), and Ocaml, Python and Ruby are the greediest ones (the recursive version of the algorithm taking time to compute [respectively 3408, 4753 and 5778 Joules]).

Therefore, it is plausible to conclude that, unlike received ideas, the Java Virtual Machine, is very performant, at least on I/O intensive algorithms [6].

Bibliography

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