

# CAB401 Project

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October 25, 2024

## Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
<b>2</b>	<b>Original Application</b>	<b>1</b>
<b>3</b>	<b>Potential Parallelism</b>	<b>2</b>
3.1	Byte pair tokeniser transform . . . . .	2
3.2	Counting byte pairs . . . . .	3
3.3	The Clean Slate . . . . .	4
3.3.1	Dealing with data in chunks . . . . .	4
<b>4</b>	<b>Mapping computation to processors</b>	<b>4</b>
<b>5</b>	<b>Timing and profiling</b>	<b>4</b>
<b>6</b>	<b>Testing of logical equivalence</b>	<b>4</b>
<b>7</b>	<b>Tools used</b>	<b>4</b>
<b>8</b>	<b>Process and Problems encountered</b>	<b>4</b>
<b>9</b>	<b>Explanation of the code</b>	<b>4</b>
<b>10</b>	<b>Learnings</b>	<b>4</b>

## 1 Introduction

This report will detail the process of parallelising a serial application, and the results of this process. The original application is a C program that reads in any number of files and performs a byte pair encoding process.

## 2 Original Application

The application is a procedural program with a simple command line interface to control it. It has two modes, both train and status. The train mode takes a project name, target vocabulary size, output filepath, and a n-long list of filepaths to train on. The status mode can take a filepath to the output file and will print the vocabulary to stdout as JSON from which the status of the training can be determined.

The call graph of the application was generated by Doxygen and dot and is shown below.

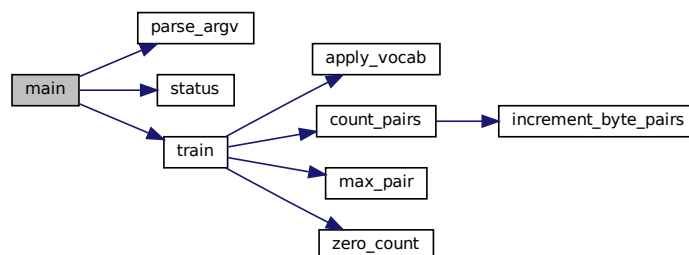


Figure 1: Call graph of the original application

The general algorithm of the original application is as follows

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**Algorithm 1** Original Application(mode, projectName, vocabSize, outputFilepath, inputFilepaths[..N])

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\\Input: String *mode* which is either train or vocab, String *projectName*, Natural number *vocabSize*  
 \\String *outputFilepath*, many strings *inputFilepaths* that is *N* long  
 \\Output: File *outputFilepath* with the vocabulary

```

1: vocabulary  $\leftarrow \{\}$ 
2: if mode == train then
3:   for i  $\leftarrow 0$  to vocabLength do
4:     pairCounts  $\leftarrow \{\}$ 
5:     for j  $\leftarrow 0$  to N do
6:       file  $\leftarrow$  inputFilepaths[j]
7:       buff  $\leftarrow$  Read(file)
8:       buff  $\leftarrow$  transform(vocabulary, buff)
9:       pairCounts  $\leftarrow$  pairCounts  $\cup$  countPairs(buff)
10:    end for
11:    vocabulary  $\leftarrow$  vocabulary  $\cup$  mostCommon(pairCounts)
12:    outputFilepath  $\leftarrow$  vocabulary
13:  end for
14: else if mode == status then
15:   stdout  $\leftarrow$  JSON(vocabulary)
16: end if
```

---

If called with the command `./train_vocab train project 260 output.vocab main.c` then the program will create a file called *output.vocab* that contains the vocabulary of the files *main.c*. There will be a list of four replacements which are the most common byte pairs where each is recursively replaced from the start of the list. As *main.c* is a C file it will contain common pairs found in C source code. You can expect that the first replacement made will be (32,32) to 256 as 32 is the ASCII code for a space character. If the author of the code used four spaces for the indentation then the next most common pair will be (256,256) which will be replaced with 257. as the four 32's will have been replaced with two 256's and then that will be replaced with a 257.

This vocabulary output can then be loaded at a later stage after being trained and used to encode some file you wish to feed into a language model.

A typical use case for this type of application is to take a large dataset, potentially multiple terrabytes of data and use it to train a vocabulary so some statistical model can be fitted on the encoded data. This technique allows for the model to see a more uniform distribution of token values as performing token level predictions on unencoded data would lead to it overfitting on the most common tokens.

### 3 Potential Parallelism

From the algorithm 1 it can be seen that how the vocabulary is used is a flow, output, and anti dependence with the loop from *i* to *vocabLength*. This is because the vocabulary starts empty and is built up on each iteration, this requires the previous iteration's value to be available so the files can be correctly transformed, This is a flow dependence. Then when the vocabulary is updated in each iteration it is an output dependence, and then in subsequent iterations the vocabulary is used to transform the files which is later overwritten when it is updated, this is an anti dependence.

As the nature of the algorithm is to build up the vocabulary in a loop, it is not possible to parallelise the outer loop. This makes the inner loop the first candidate for parallelisation. The inner loop is a loop over the files that are to be trained on. The original application is designed to preserve memory so on every iteration of the inner loop in algorithm 1 the file is read into memory, and then transformed. This makes sure it is in a state that matches the current point of training. These files could be processed in parallel, this would give too rough of a granularity which is not desirable. If parallelising at the file level the program could have to wait on very large files to be processed in a serial manner. This would lead to poor utilisation of the available compute if the files are imbalanced in size regardless of the data to compute map.

Given the predicted poor load balance of the file level parallelism the operations the loop performs were investigated.

#### 3.1 Byte pair tokeniser transform

To perform the tranformation there are two nested loops as per the following algorithm

---

**Algorithm 2** Transform(vocabulary, buff)

---

\\Input: Array of vocab *vocabulary*, Array of symbols *buff*

\\Output: Array of symbols *buff* with byte pairs replaced

```
1: for  $i \leftarrow 0$  to  $\text{len}(\text{vocabulary})$  do
2:   for  $j \leftarrow 0$  to  $\text{len}(\text{buff})$  do
3:     if  $\text{buff}[i] == \text{SKIP\_TOKEN}$  then
4:       continue
5:     end if
6:     if  $\text{buff}[i] == \text{vocabulary}[j].b1$  then
7:        $p \leftarrow 1$ 
8:       while  $j + p < \text{len}(\text{buff})$  do
9:         if  $\text{buff}[j + p] \neq \text{SKIP\_TOKEN}$  then
10:          break
11:        end if
12:         $p \leftarrow p + 1$ 
13:      end while
14:      if  $\text{buff}[i + 1] == \text{vocabulary}[j].b2$  then
15:         $\text{buff}[i] \leftarrow \text{vocabulary}[j].rep$ 
16:         $\text{buff}[i + 1] \leftarrow \text{SKIP\_TOKEN}$ 
17:      end if
18:       $j \leftarrow j + p$ 
19:    end if
20:  end for
21: end for
```

---

From the algorithm 2 it can be seen that the inner loop and outer loops both have flow and anti dependences. This makes the algorithm unsuitable for parallelisation. This means for this algorithm applying it to many files in parallel is the only suitable option.

### 3.2 Counting byte pairs

The algorithm for counting byte pairs is as follows

---

**Algorithm 3** CountPairs(buff)

---

\\Input: Array of symbols *buff*

\\Output: Array of array of numbers *pairCounts*

```
1:  $\text{pairCounts} \leftarrow \{\}$ 
2: for  $i \leftarrow 0$  to  $\text{len}(\text{buff})$  do
3:   if  $\text{buff}[i] == \text{SKIP\_TOKEN}$  then
4:     continue
5:   end if
6:    $p \leftarrow 1$ 
7:   while  $i + p < \text{len}(\text{buff})$  do
8:     if  $\text{buff}[i + p] \neq \text{SKIP\_TOKEN}$  then
9:       break
10:    end if
11:     $p \leftarrow p + 1$ 
12:  end while
13: if  $i + p == \text{len}(\text{buff})$  then
14:   return
15: end if
16:  $b_1 \leftarrow \text{buff}[i]$ 
17:  $b_2 \leftarrow \text{buff}[i + p]$ 
18:  $\text{pair}[b_1][b_2] \leftarrow \text{pair}[b_1][b_2] + 1$ 
19: end for
```

---

In the algorithm it can be seen that there is a flow and anti dependence in the loop. As the only dependence is the pair array though it is classed as a reduction operation. The reduction operation in this algorithm is non trivial as when indexing the pair there are possible branches and memory allocations that could be performed. This makes OpenMP's reduction clause unsuitable for this operation. This would require a custom reduction operation to be implemented.

### **3.3 The Clean Slate**

If the application is written from scratch and the parallelism available in the existing application is not binding then through significant refactoring the application could be made to be more parallelisable.

#### **3.3.1 Dealing with data in chunks**

It was discussed earlier that the file level parallelism would be too rough of a granularity to be useful. However if "files" were to be replaced with "chunks" then the granularity would be more fine grained. The chunk can have a size that is controlled by the programmer and can be adjusted to suit the data being processed.

If the ghost cell pattern is used then the dependence on the byte prior to a chunk can be handled. The chunks can also be created as a view to the original data so when the chunk is run through the transform the ghost cell pattern can be used to ensure that the chunk is transformed correctly. When creating the chunks the boundry must be checked to ensure that the chunk is not split in the middle of a byte pair that is to be replaced. This only works when one byte pair replacement transformation has to take place.

## **4 Mapping computation to processors**

OpenMP SIMD, and a manually managed thread pool created with POSIX pthreads

## **5 Timing and profiling**

## **6 Testing of logical equivalence**

## **7 Tools used**

## **8 Process and Problems encountered**

## **9 Explanation of the code**

## **10 Learnings**