B.Sc. in Computer Science and Engineering Thesis

Optimization Techniques for Matrix Multiplication Algorithm

Submitted by

Arifur Rahman Sujon
201305014

Rezaul Huq
201305021

Md Faisal Uddin Sarker
201305056

Shadman Majid
201305068

Istiak Ahmed
201305082

Supervised by

Dr M Kaykobad

Department of Computer Science and Engineering
Bangladesh University of Engineering and Technology

Dhaka, Bangladesh

February 2017

CANDIDATES' DECLARATION

This is to certify that the work presented in this thesis, titled, "Optimization Techniques for Matrix Multiplication Algorithm", is the outcome of the investigation and research carried out by us under the supervision of Dr M Kaykobad.

It is also declared that neither this thesis nor any part thereof has been submitted anywhere else for the award of any degree, diploma or other qualifications.

Arifur Rahman Sujon
201305014

Rezaul Huq
201305021

Md Faisal Uddin Sarker
201305056

Shadman Majid
201305068

Istiak Ahmed
201305082

CERTIFICATION

This thesis titled, **"Optimization Techniques for Matrix Multiplication Algorithm"**, submitted by the group as mentioned below has been accepted as satisfactory in partial fulfillment of the requirements for the degree B.Sc. in Computer Science and Engineering in February 2017.

Group Members:

Arifur Rahman Sujon

Rezaul Huq

Md Faisal Uddin Sarker

Shadman Majid

Istiak Ahmed

Supervisor:

Dr M Kaykobad
Professor
Department of Computer Science and Engineering
Bangladesh University of Engineering and Technology

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Arifur Rahman Sujon

Rezaul Huq

Md Faisal Uddin Sarker

Shadman Majid

Istiak Ahmed

Contents

List of Figures

List of Tables

List of Algorithms

ABSTRACT

Thesis abstract

Chapter 1

Introduction

This chapter is for your Istiak introduction.

1.1 Cross Referencing

We have incorporated the Istiak `\cref` or `\Cref` command from `cleveref` package in this system. This will automatically insert words like Figure, Table etc. in your text.

See these examples:

- Figure 1.1 is a sample figure.
- Table 1.1 is a table.
- Section 3.1 in Chapter 3 shows some examples of citations.

1.2 How to Write a Section

This is for writing section.

1.3 How to Add Table and Figures

You should refer a figure as, "Figure 1.1 is a sample figure".

Then we applied same test cases to our modified algorithm i.e. the heuristic algorithm with our new operation *Block Reversal*. The performance is shown in Table 1.1.

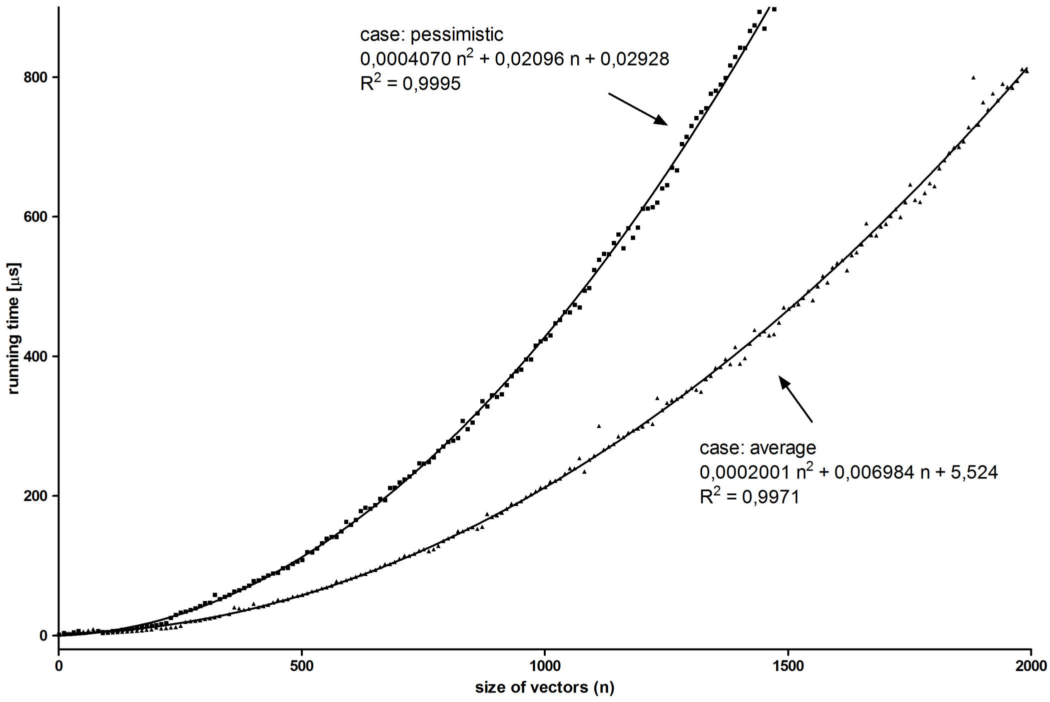

Figure 1.1: This is a sample figure.

Table 1.1: Performance table of *Block reversal* in a heuristic algorithm

α	αn	Test Cases											Average # of calculated operation
		1	2	3	4	5	6	7	8	9	10	11	
0.1	2	2	2	2	2	2	2	2	2	2	2	2	2
0.2	4	4	4	5	2	4	4	4	4	2	4	4	3.73
0.3	6	5	6	6	6	6	7	6	5	6	6	6	5.91
0.4	8	7	8	5	6	7	6	6	7	8	8	7	6.82
0.5	10	9	10	6	12	10	8	10	10	7	7	10	9
0.6	12	9	12	16	10	12	12	9	11	12	9	12	11.27
0.7	14	13	7	18	15	14	8	13	11	13	13	14	12.64
0.8	16	10	17	14	16	13	16	13	11	13	17	13	13.91
0.9	18	14	16	15	12	15	11	15	11	15	12	12	13.45
1	20	18	11	13	11	13	15	17	17	13	18	12	14.36

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Chapter 2

Multiplication of 2X3 and 3X2 matrices using 11 multiplications

In naive method, we already know that multiplication of two matrices having dimension 2X3 and 3X2 respectively requires 12 distinct multiplications. In this section, we will demonstrate how we can reduce the number of multiplications from 12 to 11. We have used Strassen's algorithm for this approach.

2.1 Algorithm

Suppose we have two matrices A and B where dimension of A is 2X3 and dimension of B is 3X2.

So,

$$A = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \end{bmatrix}$$

$$B = \begin{bmatrix} B_{11} & B_{12} \\ B_{21} & B_{22} \\ B_{31} & B_{32} \end{bmatrix}$$

Now, if we multiply the two matrices and get resultant matrix C, which is shown below:

$$C = \begin{bmatrix} A_{11}B_{11} + A_{12}B_{21} + A_{13}B_{31} & A_{11}B_{12} + A_{12}B_{22} + A_{13}B_{32} \\ A_{21}B_{11} + A_{22}B_{21} + A_{23}B_{31} & A_{21}B_{12} + A_{22}B_{22} + A_{23}B_{32} \end{bmatrix}$$

Let us also consider,

$$M_1 = A_{11}B_{11} + A_{12}B_{21}$$

$$M_2 = A_{11}B_{12} + A_{12}B_{22}$$

$$M_3 = A_{21}B_{11} + A_{22}B_{21}$$

$$M_4 = A_{21}B_{12} + A_{22}B_{22}$$

So, matrix C can be written as follows.

$$C = \begin{bmatrix} M_1 + A_{13}B_{31} & M_2 + A_{13}B_{32} \\ M_3 + A_{23}B_{31} & M_4 + A_{23}B_{32} \end{bmatrix}$$

Now, create two new sub-matrices of dimension 2 by 2 from the original matrices as follows

$$A_{2X2} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix}$$

$$B_{2X2} = \begin{bmatrix} B_{11} & B_{12} \\ B_{21} & B_{22} \end{bmatrix}$$

Using Strassen's matrix multiplication algorithm in the above two matrices, we get the following matrix using 7 multiplication.

$$X_{2X2} = \begin{bmatrix} A_{11}B_{11} + A_{12}B_{21} & A_{11}B_{12} + A_{12}B_{22} \\ A_{21}B_{11} + A_{22}B_{21} & A_{21}B_{12} + A_{22}B_{22} \end{bmatrix}$$

$$= \begin{bmatrix} M_1 & M_2 \\ M_3 & M_4 \end{bmatrix}$$

In order to compute matrix C, we need four additional multiplication $A_{13}B_{31}, A_{13}B_{32}, A_{23}B_{31}, A_{23}B_{32}$.

So, in total we need 11 multiplications.

Chapter 3

Citation Examples

In this chapter we show how we can cite the references.

3.1 See the Citations

As discussed by authors in [1–3] we can further show how this affects us. Moreover [4–11] can be examples for the previous works. Among these [10, 12–17] are the prominent ones. Also you can take a look at [18–25].

Chapter 4

Another Chapter

4.1 A Section

Some text.

4.1.1 This is a Subsection

And some more.

This is a Subsubsection

Yet some more.

4.2 And Another Section

Here are some dummy texts.

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Chapter 5

Index Creation

5.1 BUET

Bangladesh University of Engineering and Technology, abbreviated as BUET, is one of the most prestigious institutions for higher studies in the country. About 5500 students are pursuing undergraduate and postgraduate studies in engineering, architecture, planning and science in this institution. At present, BUET has sixteen teaching departments under five faculties and it has three institutes. Every year the intake of undergraduate students is around 900, while the intake of graduate students in Master's and PhD programs is around 1000. A total of about five hundred teachers are teaching in these departments and institutes. There are additional teaching posts like Dr. Rashid Professor, Professor Emeritus and Supernumerary Professors.

5.2 Campus

The BUET campus is in the heart of Dhaka — the capital city of Bangladesh. It has a compact campus with halls of residence within walking distances of the academic buildings. The physical expansion of the University over the last three decades has been impressive with construction of new academic buildings, auditorium complex, halls of residence, etc.

5.3 History

BUET is the oldest institution for the study of Engineering and Architecture in Bangladesh. The history of this institution dates back to the days of Dhaka Survey School which was established at Nalgola, in Old Dhaka in 1876 to train Surveyors for the then Government of Bengal of British India. As the years passed, the Survey School became the Ahsanullah School of Engineering offering three-year diploma courses in Civil, Electrical and Mechanical Engineering. In recognition of the generous financial contribution from the then Nawab of Dhaka, it was named after his father Khawja Ahsanullah. It moved to its present premises in 1912. In 1947, the School was upgraded to Ahsanullah Engineering College as a Faculty of Engineering under the University of Dhaka, offering four-year bachelor's courses in Civil, Electrical, Mechanical, Chemical and Metallurgical Engineering. In order to create facilities for postgraduate studies and research, Ahsanullah Engineering College was upgraded to the status of a University in 1962 and was named East Pakistan University of Engineering and Technology. After the War of Liberation in 1971, Bangladesh became an independent state and the university was renamed as the Bangladesh University of Engineering and Technology.

5.4 Students

Till today, it has produced around 25,000 graduates in different branches of engineering and architecture, and has established a good reputation all over the world for the quality of its graduates, many of whom have excelled in their profession in different parts of the globe. It was able to attract students from countries like India, Nepal, Iran, Jordan, Malaysia, Sri Lanka, Pakistan and Palestine.

5.5 Departments

Both Undergraduate and Postgraduate studies and research are now among the primary functions of the University. Eleven departments under five faculties offer Bachelor Degrees, while most of the departments and institutes offer Master's Degrees and some of the departments have Ph.D. programs. In addition to its own research programs, the university undertakes research programs sponsored by outside organizations like European Union, UNO, Commonwealth, UGC, etc. The expertise of the University teachers and the laboratory facilities of the University are also utilized to solve problems and to provide up-to-date engineering and technological knowledge to the various organizations of the country.

Chapter 6

k-safe Labeling of Petersen Graph

In 1898, Petersen produced a trivalent graph with no leaves, now called the Petersen graph [26]. In this chapter we study k-safe labeling for the Petersen graph. We also give upper bound for the span of the Petersen graph. We provide necessary proof for the upper bound.

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Index

Appendix A

Algorithms

A.1 Sample Algorithm

In Algorithm 1 we show how to calcute $y = x^n$.

Algorithm 1 Calculate $y = x^n$

Require: $n \geq 0 \vee x \neq 0$
Ensure: $y = x^n$
  $y \leftarrow 1$
  if $n < 0$ **then**
    $X \leftarrow 1/x$
    $N \leftarrow -n$
  else
    $X \leftarrow x$
    $N \leftarrow n$
  end if
  while $N \neq 0$ **do**
    if N is even **then**
      $X \leftarrow X \times X$
      $N \leftarrow N/2$
    else $\{N$ is odd$\}$
      $y \leftarrow y \times X$
      $N \leftarrow N - 1$
    end if
  end while

Appendix B

Codes

B.1 Sample Code

We use this code to find out…

```
#include <stdio.h>
int Fibonacci(int);

main()
{
  int n, i = 0, c;

  printf("Enter␣the␣value␣of␣n:␣");
  scanf("%d",&n);

  printf("\nFibonacci␣series\n");

  for (c = 1 ; c <= n ; c++)
    {
      printf("%d\n", Fibonacci(i));
      i++;
    }

  return 0;
}

int Fibonacci(int n)
{
```

```
  if (n == 0)
    return 0;
  else if (n == 1)
    return 1;
  else
    return (Fibonacci(n-1) + Fibonacci(n-2));
}
```

B.2 Another Sample Code

```
SELECT associations2.object_id, associations2.term_id,
       associations2.cat_ID, associations2.term_taxonomy_id
FROM (SELECT objects_tags.object_id, objects_tags.term_id,
     wp_cb_tags2cats.cat_ID, categories.term_taxonomy_id
FROM (SELECT wp_term_relationships.object_id,
     wp_term_taxonomy.term_id, wp_term_taxonomy.term_taxonomy_id
FROM wp_term_relationships
LEFT JOIN wp_term_taxonomy ON
     wp_term_relationships.term_taxonomy_id =
     wp_term_taxonomy.term_taxonomy_id
ORDER BY object_id ASC, term_id ASC)
AS objects_tags
LEFT JOIN wp_cb_tags2cats ON objects_tags.term_id =
     wp_cb_tags2cats.tag_ID
LEFT JOIN (SELECT wp_term_relationships.object_id,
     wp_term_taxonomy.term_id as cat_ID,
     wp_term_taxonomy.term_taxonomy_id
FROM wp_term_relationships
LEFT JOIN wp_term_taxonomy ON
     wp_term_relationships.term_taxonomy_id =
     wp_term_taxonomy.term_taxonomy_id
WHERE wp_term_taxonomy.taxonomy = 'category'
GROUP BY object_id, cat_ID, term_taxonomy_id
ORDER BY object_id, cat_ID, term_taxonomy_id)
AS categories on wp_cb_tags2cats.cat_ID = categories.term_id
WHERE objects_tags.term_id = wp_cb_tags2cats.tag_ID
GROUP BY object_id, term_id, cat_ID, term_taxonomy_id
ORDER BY object_id ASC, term_id ASC, cat_ID ASC)
AS associations2
LEFT JOIN categories ON associations2.object_id =
```

```
    categories.object_id
WHERE associations2.cat_ID <> categories.cat_ID
GROUP BY object_id, term_id, cat_ID, term_taxonomy_id
ORDER BY object_id, term_id, cat_ID, term_taxonomy_id
```

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