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The Performance of Red-Black Trees in Java

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Declaration

I, Derek Harter, of the Department of Computer Science, Texas A&M University - Commerce, confirm that this is my own work and figures, tables, equations, code snippets, artworks, and illustrations in this report are original and have not been taken from any other person's work, except where the works of others have been explicitly acknowledged, quoted, and referenced. I understand that if failing to do so will be considered a case of plagiarism. Plagiarism is a form of academic misconduct and will be penalised accordingly.

I give consent to a copy of my report being shared with future students as an exemplar.

I give consent for my work to be made available more widely to members of TAMUC and public with interest in teaching, learning and research.

Derek Harter
January 19, 2024

Abstract

This is a graduate project report template and instruction on how to write a report. It also has some useful examples to use \LaTeX . Do read this template carefully. The number of chapters and their titles may vary depending on the type of project and personal preference. Section titles in this template are illustrative and should be updated accordingly. For example, sections named “A section...” and “Example of ...” should be updated. The number of sections in each chapter may also vary. This template may or may not suit your project. Discuss the structure of your report with your supervisor.

Guidance on abstract writing: An abstract is a summary of a report in a single paragraph up to a maximum of 250 words. An abstract should be self-contained, and it should not refer to sections, figures, tables, equations, or references. An abstract typically consists of sentences describing the following four parts: (1) introduction (background and purpose of the project), (2) methods, (3) results and analysis, and (4) conclusions. The distribution of these four parts of the abstract should reflect the relative proportion of these parts in the report itself. An abstract starts with a few sentences describing the project’s general field, comprehensive background and context, the main purpose of the project; and the problem statement. A few sentences describe the methods, experiments, and implementation of the project. A few sentences describe the main results achieved and their significance. The final part of the abstract describes the conclusions and the implications of the results to the relevant field.

Keywords: a maximum of five keywords/keyphrase separated by commas

Report’s total word count: we expect a maximum of 10,000 words (excluding reference and appendices) and about 10 pages. [A good project report can also be written in approximately 5,000 words.]

Acknowledgements

An acknowledgements section is optional. You may like to acknowledge the support and help of your supervisor(s), friends, or any other person(s), department(s), institute(s), etc. If you have been provided specific facility from department/school acknowledged so.

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List of Abbreviations

SMPCS School of Mathematical, Physical and Computational Sciences

Chapter 1

Introduction

Guidance on introduction chapter writing: Introductions are written in the following parts:

- A brief description of the investigated problem.
- A summary of the scope and context of the project, i.e., what is the background of the topic/problem/application/system/algorithm/experiment/research question/hypothesis/etc. under investigation/implementation/development [whichever is applicable to your project].
- The aims and objectives of the project.
- A description of the problem and the methodological approach adopted to solve the problem.
- A summary of the most significant outcomes and their interpretations.
- Organization of the report.

Consult **your supervisor** to check the content of the introduction chapter. In this template, we only offer basic sections of an introduction chapter. It may not be complete and comprehensive. Writing a report is a subjective matter, and a report's style and structure depend on the "type of project" as well as an individual's preference. This template suits the following project paradigms:

1. software engineering and software/web application development;
2. algorithm implementation, analysis and/or application;
3. science lab (experiment); and
4. pure theoretical development (not mention extensively).

Use only a single **font** for the body text. We recommend using a clean and electronic document friendly font like **Arial** or **Calibri** for MS-word (If you create a report in MS word). If you use this template, DO NOT ALTER the template's default font "amsfont default computer modern". The default L^AT_EX font "computer modern" is also acceptable.

The recommended body text **font size** is minimum **11pt** and minimum one-half line spacing. The recommended figure/table caption font size is minimum 10pt. The footnote¹ font size is minimum 8pt. DO NOT ALTER the font setting of this template.

¹Example footnote: footnotes are useful for adding external sources such as links as well as extra information on a topic or word or sentence. Use command `\footnote{...}` next to a word to generate a footnote in L^AT_EX.

1.1 Background

Describe to a reader the context of your project. That is, what is your project and what its motivation. Briefly explain the major theories, applications, and/or products/systems/algorithms whichever is relevant to your project.

Cautions: Do not say you choose this project because of your interest, or your supervisor proposed/suggested this project, or you were assigned this project as your final year project. This all may be true, but it is not meant to be written here.

1.2 Problem statement

This section describes the investigated problem in detail. You can also have a separate chapter on “Problem articulation.” For some projects, you may have a section like “Research question(s)” or “Research Hypothesis” instead of a section on “Problem statement.”

1.3 Aims and objectives

Describe the “aims and objectives” of your project.

Aims: The aims tell a read what you want/hope to achieve at the end of the project. The aims define your intent/purpose in general terms.

Objectives: The objectives are a set of tasks you would perform in order to achieve the defined aims. The objective statements have to be specific and measurable through the results and outcome of the project.

1.4 Solution approach

Briefly describe the solution approach and the methodology applied in solving the set aims and objectives.

Depending on the project, you may like to alter the “heading” of this section. Check with you supervisor. Also, check what subsection or any other section that can be added in or removed from this template.

1.4.1 A subsection 1

You may or may not need subsections here. Depending on your project’s needs, add two or more subsection(s). A section takes at least two subsections.

1.4.2 A subsection 2

Depending on your project’s needs, add more section(s) and subsection(s).

A subsection 1 of a subsection

The command `\subsubsection{}` creates a paragraph heading in \LaTeX .

A subsection 2 of a subsection

Write your text here...

1.5 Summary of contributions and achievements

Describe clearly what you have done/created/achieved and what the major results and their implications are.

1.6 Organization of the report

Describe the outline of the rest of the report here. Let the reader know what to expect ahead in the report. Describe how you have organized your report.

Example: how to refer a chapter, section, subsection. This report is organised into seven chapters. Chapter 2 details the literature review of this project. In Section 3...

Note: Take care of the word like “Chapter,” “Section,” “Figure” etc. before the \LaTeX command `\ref{}`. Otherwise, a sentence will be confusing. For example, In 2 literature review is described. In this sentence, the word “Chapter” is missing. Therefore, a reader would not know whether 2 is for a Chapter or a Section or a Figure.

Chapter 2

Literature Review

A literature review chapter can be organized in a few sections with appropriate titles. A literature review chapter might contain the following:

1. A review of the state-of-the-art (include theories and solutions) of the field of research.
2. A description of the project in the context of existing literature and products/systems.
3. An analysis of how the review is relevant to the intended application/system/problem.
4. A critique of existing work compared with the intended work.

Note that your literature review should demonstrate the significance of the project.

2.1 Example of in-text citation of references in \LaTeX

The references in a report relate your content with the relevant sources, papers, and the works of others. To include references in a report, we *cite* them in the texts. In MS-Word, EndNote, or MS-Word references, or plain text as a list can be used. Similarly, in \LaTeX , you can use the “thebibliography” environment, which is similar to the plain text as a list arrangement like the MS word. However, In \LaTeX , the most convenient way is to use the BibTex, which takes the references in a particular format [see references.bib file of this template] and lists them in style [APA, Harvard, etc.] as we want with the help of proper packages.

These are the examples of how to *cite* external sources, seminal works, and research papers. In \LaTeX , if you use “**BibTex**” you do not have to worry much since the proper use of a bibliography style package like “agsm for the Harvard style” and little rectification of the content in a BiBText source file [In this template, BibTex are stored in the “references.bib” file], we can conveniently generate a reference style.

Take a note of the commands `\cite{}` and `\citep{}`. The command `\cite{}` will write like “Author et al. (2019)” style for Harvard, APA and Chicago style. The command `\citep{}` will write like “(Author et al., 2019).” Depending on how you construct a sentence, you need to use them smartly. Check the examples of **in-text citation** of sources listed here [This template recommends the **Harvard style** of referencing]:

- Lamport (1994) has written a comprehensive guide on writing in \LaTeX [Example of `\cite{}`].

- If \LaTeX is used efficiently and effectively, it helps in writing a very high-quality project report (Lamport, 1994) [Example of `\citep{}`].
- A detailed APA, Harvard, and Chicago referencing style guide are available in (University of Reading, 2019b).

Example of a numbered list:

1. Lamport (1994) has written a comprehensive guide on writing in \LaTeX .
2. If \LaTeX is used efficiently and effectively, it helps in writing a very high-quality project report (Lamport, 1994).

2.2 Example of “risk” of unintentional plagiarism

Using other sources, ideas, and material always bring with it a risk of unintentional plagiarism.

MUST: do read the university guidelines on the definition of plagiarism as well as the guidelines on how to avoid plagiarism (University of Reading, 2019a).

2.3 Critique of the review

Describe your main findings and evaluation of the literature.

2.4 Summary

Write a summary of this chapter

Chapter 3

Methodology

We mentioned in Chapter 1 that a project report's structure could follow a particular paradigm. Hence, the organization of a report (effectively the Table of Content of a report) can vary depending on the type of project you are doing. Check which of the given examples suit your project. Alternatively, follow your supervisor's advice.

3.1 Examples of the sections of a methodology chapter

A general report structure is summarised (suggested) in Table 3.1. Table 3.1 describes that, in general, a typical report structure has three main parts: (1) front matter, (2) main text, and (3) end matter. The structure of the front matter and end matter will remain the same for all the undergraduate final year project report. However, the main text varies as per the project's needs.

3.1.1 Example of a software/Web development main text structure

Notice that the “methodology” Chapter of Software/Web development in Table 3.2 takes a standard software engineering paradigm (approach). Alternatively, these suggested sections can be the chapters of their own. Also, notice that “Chapter 5” in Table 3.2 is “Testing and Validation” which is different from the general report template mentioned in Table 3.1. Check with your supervisor if in doubt.

3.1.2 Example of an algorithm analysis main text structure

Some project might involve the implementation of a state-of-the-art algorithm and its performance analysis and comparison with other algorithms. In that case, the suggestion in Table 3.3 may suit you the best.

3.1.3 Example of an application type main text structure

If you are applying some algorithms/tools/technologies on some problems/datasets/etc., you may use the methodology section prescribed in Table 3.4.

Table 3.1: Undergraduate report template structure

Frontmatter	Title Page
	Abstract
	Acknowledgements
	Table of Contents
	List of Figures
	List of Tables
	List of Abbreviations
Main text	Chapter 1 Introduction
	Chapter 2 Literature Review
	Chapter 3 Methodology
	Chapter 4 Results
	Chapter 5 Discussion and Analysis
	Chapter 6 Conclusions and Future Work
	Chapter 7 Refection
End matter	References
	Appendices (Optional)
	Index (Optional)

Table 3.2: Example of a software engineering-type report structure

Chapter 1	Introduction
Chapter 2	Literature Review
Chapter 3	Methodology
	Requirements specifications
	Analysis
	Design
	Implementations
Chapter 4	Testing and Validation
Chapter 5	Results and Discussion
Chapter 6	Conclusions and Future Work
Chapter 7	Reflection

3.1.4 Example of a science lab-type main text structure

If you are doing a science lab experiment type of project, you may use the methodology section suggested in Table 3.5. In this kind of project, you may refer to the “Methodology” section as “Materials and Methods.”

Table 3.3: Example of an algorithm analysis type report structure

Chapter 1	Introduction	
Chapter 2	Literature Review	
Chapter 3	Methodology	Algorithms descriptions Implementations Experiments design
Chapter 4	Results	
Chapter 5	Discussion and Analysis	
Chapter 6	Conclusion and Future Work	
Chapter 7	Reflection	

Table 3.4: Example of an application type report structure

Chapter 1	Introduction	
Chapter 2	Literature Review	
Chapter 3	Methodology	Problems (tasks) descriptions Algorithms/tools/technologies/etc. descriptions Implementations Experiments design and setup
Chapter 4	Results	
Chapter 5	Discussion and Analysis	
Chapter 6	Conclusion and Future Work	
Chapter 7	Reflection	

Table 3.5: Example of a science lab experiment-type report structure

Chapter 1	Introduction	
Chapter 2	Literature Review	
Chapter 3	Materials and Methods	Problems (tasks) description Materials Procedures Implementations Experiment set-up
Chapter 4	Results	
Chapter 5	Discussion and Analysis	
Chapter 6	Conclusion and Future Work	
Chapter 7	Reflection	

3.2 Example of an Equation in \LaTeX

Eq. 3.1 [note that this is an example of an equation’s in-text citation] is an example of an equation in \LaTeX . In Eq. (3.1), s is the mean of elements $x_i \in \mathbf{x}$:

$$s = \frac{1}{N} \sum_{i=1}^N x_i. \quad (3.1)$$

Have you noticed that all the variables of the equation are defined using the **in-text** maths command $\$$, and Eq. (3.1) is treated as a part of the sentence with proper punctuation? Always treat an equation or expression as a part of the sentence.

3.3 Example of a Figure in \LaTeX

Figure 3.1 is an example of a figure in \LaTeX . For more details, check the link:

wikibooks.org/wiki/LaTeX/Floats,_Figures_and_Captions.

Keep your artwork (graphics, figures, illustrations) clean and readable. At least 300dpi is a good resolution of a PNG format artwork. However, an SVG format artwork saved as a PDF will produce the best quality graphics. There are numerous tools out there that can produce vector graphics and let you save that as an SVG file and/or as a PDF file. One example of such a tool is the “Flow algorithm software”. Here is the link for that: flowgorithm.org.



Figure 3.1: Example figure in \LaTeX .

3.4 Example of an algorithm in \LaTeX

Algorithm 1 is a good example of an algorithm in \LaTeX .

Algorithm 1 Example caption: sum of all even numbers

Input: $\mathbf{x} = x_1, x_2, \dots, x_N$

Output: *EvenSum* (Sum of even numbers in \mathbf{x})

```

1: function EVENSUMMATION( $\mathbf{x}$ )
2:   EvenSum  $\leftarrow$  0
3:    $N \leftarrow \text{length}(\mathbf{x})$ 
4:   for  $i \leftarrow 1$  to  $N$  do
5:     if  $x_i \bmod 2 == 0$  then                                ▷ check if a number is even?
6:       EvenSum  $\leftarrow$  EvenSum +  $x_i$ 
7:     end if
8:   end for
9:   return EvenSum
10: end function

```

3.5 Example of code snippet in \LaTeX

Code Listing 3.1 is a good example of including a code snippet in a report. While using code snippets, take care of the following:

- do not paste your entire code (implementation) or everything you have coded. Add code snippets only.
- The algorithm shown in Algorithm 1 is usually preferred over code snippets in a technical/-scientific report.
- Make sure the entire code snippet or algorithm stays on a single page and does not overflow to another page(s).

Here are three examples of code snippets for three different languages (Python, Java, and CPP) illustrated in Listings 3.1, 3.2, and 3.3 respectively.

```

1 import numpy as np
2
3  $\mathbf{x}$  = [0, 1, 2, 3, 4, 5] # assign values to an array
4 evenSum = evenSummation( $\mathbf{x}$ ) # call a function
5
6 def evenSummation( $\mathbf{x}$ ):
7     evenSum = 0
8      $n = \text{len}(\mathbf{x})$ 
9     for  $i$  in  $\text{range}(n)$ :
10         if  $\text{np.mod}(\mathbf{x}[i], 2) == 0$ : # check if a number is even?
11             evenSum = evenSum +  $\mathbf{x}[i]$ 
12     return evenSum

```

Listing 3.1: Code snippet in \LaTeX and this is a Python code example

Here we used the “\clearpage” command and forced-out the second listing example onto the next page.

```

1 public class EvenSum{
2     public static int evenSummation(int[] x){
3         int evenSum = 0;
4         int n = x.length;
5         for(int i = 0; i < n; i++){
6             if(x[i]%2 == 0){ // check if a number is even?
7                 evenSum = evenSum + x[i];
8             }
9         }
10        return evenSum;
11    }
12    public static void main(String[] args){
13        int[] x = {0, 1, 2, 3, 4, 5}; // assign values to an array
14        int evenSum = evenSummation(x);
15        System.out.println(evenSum);
16    }
17 }

```

Listing 3.2: Code snippet in \LaTeX and this is a Java code example

```

1 int evenSummation(int x[]){
2     int evenSum = 0;
3     int n = sizeof(x);
4     for(int i = 0; i < n; i++){
5         if(x[i]%2 == 0){ // check if a number is even?
6             evenSum = evenSum + x[i];
7         }
8     }
9     return evenSum;
10 }
11
12 int main(){
13     int x[] = {0, 1, 2, 3, 4, 5}; // assign values to an array
14     int evenSum = evenSummation(x);
15     cout<<evenSum;
16     return 0;
17 }

```

Listing 3.3: Code snippet in \LaTeX and this is a C/C++ code example

3.6 Example of in-text citation style

3.6.1 Example of the equations and illustrations placement and reference in the text

Make sure whenever you refer to the equations, tables, figures, algorithms, and listings for the first time, they also appear (placed) somewhere on the same page or in the following page(s). Always make sure to refer to the equations, tables and figures used in the report. Do not leave them without an **in-text citation**. You can refer to equations, tables and figures more than once.

3.6.2 Example of the equations and illustrations style

Write **Eq.** with an uppercase “Eq” for an equation before using an equation number with (`\eqref{.}`). Use “Table” to refer to a table, “Figure” to refer to a figure, “Algorithm” to

refer to an algorithm and “Listing” to refer to listings (code snippets). Note that, we do not use the articles “a,” “an,” and “the” before the words Eq., Figure, Table, and Listing, but you may use an article for referring the words figure, table, etc. in general.

For example, the sentence “A report structure is shown in **the** Table 3.1” should be written as “A report structure is shown **in** Table 3.1.”

3.7 Summary

Write a summary of this chapter.

Note: In the case of **software engineering** project a Chapter “**Testing and Validation**” should precede the “Results” chapter. See Section 3.1.1 for report organization of such project.

Chapter 4

Results

The results chapter tells a reader about your findings based on the methodology you have used to solve the investigated problem. For example:

- If your project aims to develop a software/web application, the results may be the developed software/system/performance of the system, etc., obtained using a relevant methodological approach in software engineering.
- If your project aims to implement an algorithm for its analysis, the results may be the performance of the algorithm obtained using a relevant experiment design.
- If your project aims to solve some problems/research questions over a collected dataset, the results may be the findings obtained using the applied tools/algorithms/etc.

Arrange your results and findings in a logical sequence.

4.1 A section

...

4.2 Example of a Table in \LaTeX

Table 4.1 is an example of a table created using the package \LaTeX “booktabs.” do check the link: wikibooks.org/wiki/LaTeX/Tables for more details. A table should be clean and readable. Unnecessary horizontal lines and vertical lines in tables make them unreadable and messy. The example in Table 4.1 uses a minimum number of lines (only necessary ones). Make sure that the top rule and bottom rule (top and bottom horizontal lines) of a table are present.

Table 4.1: Example of a table in \LaTeX

Bike		
Type	Color	Price (£)
Electric	black	700
Hybrid	blue	500
Road	blue	300
Mountain	red	300
Folding	black	500

4.3 Example of captions style

- The **caption of a Figure (artwork)** goes **below** the artwork (Figure/Graphics/illustration). See example artwork in Figure 3.1.
- The **caption of a Table** goes **above** the table. See the example in Table 4.1.
- The **caption of an Algorithm** goes **above** the algorithm. See the example in Algorithm 1.
- The **caption of a Listing** goes **below** the Listing (Code snippet). See example listing in Listing 3.1.

4.4 Summary

Write a summary of this chapter.

Chapter 5

Discussion and Analysis

Depending on the type of project you are doing, this chapter can be merged with “Results” Chapter as “ Results and Discussion” as suggested by your supervisor.

In the case of software development and the standalone applications, describe the significance of the obtained results/performance of the system.

5.1 A section

Discussion and analysis chapter evaluates and analyses the results. It interprets the obtained results.

5.2 Significance of the findings

In this chapter, you should also try to discuss the significance of the results and key findings, in order to enhance the reader’s understanding of the investigated problem

5.3 Limitations

Discuss the key limitations and potential implications or improvements of the findings.

5.4 Summary

Write a summary of this chapter.

Chapter 6

Conclusions and Future Work

6.1 Conclusions

Typically a conclusions chapter first summarizes the investigated problem and its aims and objectives. It summarizes the critical/significant/major findings/results about the aims and objectives that have been obtained by applying the key methods/implementations/experiment set-ups. A conclusions chapter draws a picture/outline of your project's central and the most significant contributions and achievements.

A good conclusions summary could be approximately 300–500 words long, but this is just a recommendation.

A conclusions chapter followed by an abstract is the last things you write in your project report.

6.2 Future work

This section should refer to Chapter 4 where the author has reflected their criticality about their own solution. The future work is then sensibly proposed in this section.

Guidance on writing future work: While working on a project, you gain experience and learn the potential of your project and its future works. Discuss the future work of the project in technical terms. This has to be based on what has not been yet achieved in comparison to what you had initially planned and what you have learned from the project. Describe to a reader what future work(s) can be started from the things you have completed. This includes identifying what has not been achieved and what could be achieved.

A good future work summary could be approximately 300–500 words long, but this is just a recommendation.

Chapter 7

Reflection

Write a short paragraph on the substantial learning experience. This can include your decision-making approach in problem-solving.

Some hints: You obviously learned how to use different programming languages, write reports in \LaTeX and use other technical tools. In this section, we are more interested in what you thought about the experience. Take some time to think and reflect on your individual project as an experience, rather than just a list of technical skills and knowledge. You may describe things you have learned from the research approach and strategy, the process of identifying and solving a problem, the process research inquiry, and the understanding of the impact of the project on your learning experience and future work.

Also think in terms of:

- what knowledge and skills you have developed
- what challenges you faced, but was not able to overcome
- what you could do this project differently if the same or similar problem would come
- rationalize the divisions from your initial planned aims and objectives.

A good reflective summary could be approximately 300–500 words long, but this is just a recommendation.

Note: The next chapter is “**References**,” which will be automatically generated if you are using BibTeX referencing method. This template uses BibTeX referencing. Also, note that there is difference between “References” and “Bibliography.” The list of “References” strictly only contain the list of articles, paper, and content you have cited (i.e., refereed) in the report. Whereas Bibliography is a list that contains the list of articles, paper, and content you have cited in the report plus the list of articles, paper, and content you have read in order to gain knowledge from. We recommend to use only the list of “References.”

References

Lamport, L. (1994), *LATEX: a document preparation system: user's guide and reference manual*, Addison-wesley.

University of Reading (2019a), 'Avoiding unintentional plagiarism: Guidance on citing references for students at the university of reading: Styles of referencing'. (accessed October 26, 2019).
URL: <https://libguides.reading.ac.uk/citing-references/avoidingplagiarism>

University of Reading (2019b), 'Styles of referencing: Guidance on citing references for students at the university of reading'. (accessed October 26, 2019).
URL: <https://libguides.reading.ac.uk/citing-references/referencingstyles>

Appendix A

An Appendix Chapter (Optional)

Some lengthy tables, codes, raw data, length proofs, etc. which are **very important but not essential part** of the project report goes into an Appendix. An appendix is something a reader would consult if he/she needs extra information and a more comprehensive understating of the report. Also, note that you should use one appendix for one idea.

An appendix is optional. If you feel you do not need to include an appendix in your report, avoid including it. Sometime including irrelevant and unnecessary materials in the Appendices may unreasonably increase the total number of pages in your report and distract the reader.

Appendix B

An Appendix Chapter (Optional)

...