

DEPARTMENT OF ELECTRICAL ENGINEERING  
INDIAN INSTITUTE OF TECHNOLOGY MADRAS  
CHENNAI – 600036

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## Classification of Vulnerability using NLP



*A Thesis*

*Submitted by*

**DIBYENDU MANDAL**

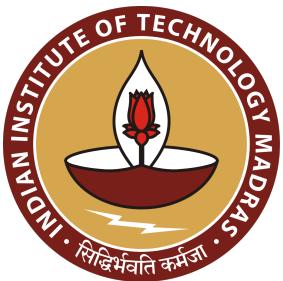
*For the award of the degree*

*Of*

**DUAL DEGREE**

June 2023





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## **THESIS CERTIFICATE**

This is to undertake that the Thesis titled **CLASSIFICATION OF VULNERABILITY USING NLP**, submitted by me to the Indian Institute of Technology Madras, for the award of **Dual Degree**, is a bona fide record of the research work done by me under the supervision of **Dr. Gaurav Raina**. The contents of this Thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

**Chennai 600036**

**Dibyendu Mandal**

**Date: June 2023**

**Dr. Gaurav Raina**  
Research advisor  
Professor  
Founder of Okarango  
Department of Electrical Engineering  
IIT Madras



# **LIST OF PUBLICATIONS**

## **I. REFEREED JOURNALS BASED ON THESIS**

whatever

## **II. REFEREED JOURNALS (OTHERS)**

whatever

## **III. PRESENTATIONS IN CONFERENCES**

whatever

## **IV. PUBLICATIONS IN CONFERENCE PROCEEDINGS**

whatever



## **ACKNOWLEDGEMENTS**

Here is where one would thank others for their assistance with the thesis, in whatever shape or form. While, this section is optional, almost all theses contain it.



## **ABSTRACT**

**KEYWORDS** L<sup>A</sup>T<sub>E</sub>X; template; dissertation; thesis; synopsis; here; is; a; long; list; of; keywords; one; can; have; as; many; as; desired

This is a minimal template to get one started. The abstract typically contains a brief gist of the thesis. Common guideslines to effective abstract writing are available on the internet.



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# GLOSSARY

<b>L<small>A</small>T<small>E</small>X</b>	L <small>A</small> T <small>E</small> X is a popular macro package for document preparation.
<b>Computer Science and Programming</b>	An art form that is commonly associated with bringing silicon to life.
<b>Engineering</b>	A popular scientific discipline.
<b>Mathematics</b>	A very versatile language.
<b>Physics</b>	Trying to understand the world by describing it using mathematics.



## **ABBREVIATIONS**

**DC** Doctoral Committee.

**GTC** General Test Committee.

**IITM** IIT Madras.

**MS** Master of Science.

**Ph.D** Doctor of Philosophy.



## NOTATION

$\epsilon_0$	the dielectric constant of free space
$\pi$	ratio of the circumference of a circle to its diameter
$\tau$	ratio of the circumference of a circle to its radius
$c$	the speed of light in vacuum



# **CHAPTER 1**

## **VULNERABILITIES IN CYBER SECURITY**

A vulnerability is a weakness or error in a system or device's code that, when exploited, can compromise the confidentiality, availability, and integrity of data stored in them through unauthorized access, elevation of privileges, or denial of service.

### **1.1 INTRODUCTION**

#### **1.1.1 Background and motivation**

Explain the significance of vulnerability classification in the context of natural language processing (NLP) and its relevance in various domains.

#### **1.1.2 Types**

There are 14 types of vulnerabilities being dealt with in this project.

### **1.2 PROBLEM STATEMENT**

Clearly define the research problem and the specific objectives of the thesis. Research question: State the main research question that the thesis aims to answer.

### **1.3 LITERATURE REVIEW**

Overview of vulnerability classification: Provide an overview of the existing methods and techniques used for vulnerability classification in the field of NLP.

### **1.4 NLP TECHNIQUES**

Discuss the fundamental concepts and techniques of NLP that are relevant to vulnerability classification.



# **CHAPTER 2**

## **LITERATURE REVIEW**

### **2.1 OVERVIEW OF VULNERABILITY CLASSIFICATION**

#### **2.1.1 Definition of vulnerability**

Provide a clear definition of vulnerability in the context of NLP and its importance in various domains such as cybersecurity, social media analysis, and sentiment analysis.

#### **2.1.2 Importance of vulnerability classification**

Discuss the significance of vulnerability classification in identifying and addressing potential risks and threats.

#### **2.1.3 Applications of vulnerability classification**

Explore the practical applications of vulnerability classification in different industries and sectors.

### **2.2 NLP TECHNIQUES FOR VULNERABILITY CLASSIFICATION**

#### **2.2.1 Text preprocessing**

Explain the preprocessing steps involved in cleaning and preparing textual data for vulnerability classification, including tasks such as tokenization, stop-word removal, stemming, and normalization.

#### **2.2.2 Feature extraction**

Discuss various NLP techniques used for feature extraction, such as bag-of-words, TF-IDF (Term Frequency-Inverse Document Frequency), word embeddings (e.g., Word2Vec, GloVe), and other advanced methods like BERT (Bidirectional Encoder Representations from Transformers).

### **2.2.3 Text representation**

Compare different text representation methods, including sparse vectors, dense vectors, and sequence models like recurrent neural networks (RNNs) and convolutional neural networks (CNNs).

## **2.3 EXISTING APPROACHES FOR VULNERABILITY CLASSIFICATION**

Rule-based methods: Provide an overview of rule-based approaches used for vulnerability classification, such as keyword matching and regular expressions.

Machine learning-based methods: Discuss traditional machine learning algorithms like Naive Bayes, support vector machines (SVM), decision trees, and random forests that have been applied to vulnerability classification tasks.

Deep learning-based methods: Explore the use of deep learning models, including recurrent neural networks (RNNs), convolutional neural networks (CNNs), and transformer models like BERT, for vulnerability classification.

Ensemble methods: Discuss ensemble techniques that combine multiple models to improve classification accuracy and robustness.

### **2.4 Related Work in Vulnerability Classification using NLP**

Summarize and analyze relevant research papers and studies on vulnerability classification using NLP techniques. Highlight the strengths and weaknesses of previous approaches, including the datasets used, evaluation metrics, and performance achieved. Identify the gaps in the existing literature and the research opportunities for further improvement in vulnerability classification using NLP.

Recapitulate the main points covered in the literature review chapter. Emphasize the significance of vulnerability classification in the context of NLP and its potential applications. Set the stage for the subsequent chapters by outlining the methodology and approach that will be employed in the thesis.

# **CHAPTER 3**

## **METHODOLOGY**

### **3.1 DATA COLLECTION AND PREPROCESSING**

#### **3.1.1 Data sources**

Describe the sources from which the vulnerability data was collected, such as vulnerability databases, security forums, or social media platforms.

#### **3.1.2 Data selection criteria**

Explain the criteria used to select the relevant data for vulnerability classification, considering factors such as data quality, diversity, and representativeness.

#### **3.1.3 Data preprocessing**

Detail the steps taken to preprocess the collected data, including text cleaning, removal of irrelevant information (e.g., URLs, special characters), and handling of noise or inconsistencies. 3.2 Feature Extraction

Feature selection: Explain the process of selecting relevant features for vulnerability classification from the preprocessed data. NLP techniques for feature extraction: Elaborate on the specific NLP techniques employed to extract meaningful features from the vulnerability data, such as n-grams, syntactic patterns, semantic embeddings, or domain-specific features. Feature engineering: Discuss any additional feature engineering techniques applied, such as feature scaling, dimensionality reduction, or feature combination. 3.3 Classification Models

Model selection: Describe the different classification algorithms or models chosen for vulnerability classification, explaining the reasons for their selection (e.g., suitability for text classification tasks, previous success in similar domains). Model architecture:

Provide a detailed description of the chosen models, including their structure, parameters, and any modifications or adaptations made for vulnerability classification. Training process: Explain the training procedure, including the use of training/validation splits, cross-validation techniques, and hyperparameter optimization.

### 3.4 Evaluation Metrics

Performance metrics: Define the evaluation metrics used to measure the performance of the vulnerability classification models, such as accuracy, precision, recall, F1-score, or area under the ROC curve (AUC-ROC). Experimental setup: Describe how the experiments were conducted, including the train-test split ratio, cross-validation folds, and any specific considerations for handling class imbalance or other challenges in the data.

### 3.5 Experimental Results and Analysis

Presentation of results: Report and analyze the performance results obtained from the experiments, including the evaluation metrics for each classification model. Comparative analysis: Compare the performance of different models, highlighting their strengths, weaknesses, and trade-offs. Interpretation of results: Provide insights and interpretations based on the experimental findings, identifying factors that contribute to the success or limitations of the classification models.

### 3.6 Summary

Summarize the methodology chapter, emphasizing the data collection and preprocessing steps, feature extraction techniques, classification models used, and the evaluation metrics employed. Discuss any challenges or limitations encountered during the methodology implementation and suggest possible ways to address them in future work.

## **CHAPTER 4**

# **CONCLUSION AND FUTURE WORK**

### **4.1 SUMMARY OF FINDINGS**

- Recapitulate the main objectives of the thesis and summarize the key findings and contributions.
- Discuss the effectiveness and performance of the vulnerability classification models developed using NLP techniques.
- Highlight any novel insights or advancements achieved in the field of vulnerability classification through the application of NLP.

### **4.2 CONTRIBUTIONS**

- Summarize the specific contributions of your research, including any new methodologies, techniques, or insights developed.
- Emphasize how your research addresses the existing gaps and contributes to the overall knowledge in vulnerability classification using NLP.

### **4.3 LIMITATIONS**

- Discuss the limitations and constraints encountered during the research process, such as data availability, data quality, or the assumptions made.
- Address any potential biases or shortcomings in the methodology or experimental design.

### **4.4 IMPLICATIONS AND APPLICATIONS**

- Discuss the practical implications of your research findings and how they can be applied in real-world scenarios.
- Explore potential applications of vulnerability classification in various domains, such as cybersecurity, social media monitoring, or threat intelligence.

## **4.5 FUTURE WORK**

- Identify potential areas for future research and improvement in vulnerability classification using NLP. - Propose research directions, methodologies, or techniques that could address the limitations identified in your work. - Suggest opportunities for incorporating other advanced NLP techniques, such as transformer models or deep reinforcement learning, into vulnerability classification tasks. - Consider exploring larger and more diverse datasets or extending the research to multi-class or hierarchical vulnerability classification.

## **4.6 CONCLUSION**

- Summarize the main points discussed in the chapter, highlighting the significance of your research and its potential impact. - Revisit the research question and objectives, reflecting on how they have been addressed and what has been accomplished. - Provide a concise and compelling conclusion to your thesis, leaving the reader with a clear understanding of the contributions made and the importance of the research in the broader context.

Remember to adapt the structure and content of the final chapter to reflect the specific findings and implications of your research. The conclusion and future work chapter should effectively summarize the main contributions, discuss the limitations, and provide a roadmap for future research in the field of vulnerability classification using NLP. Here are some references to terms in the glossary: L<sup>A</sup>T<sub>E</sub>X Mathematics Physics

# **CHAPTER 5**

## **ITEMIZED LISTS AND QUOTES**

Itemized lists work as one would expect. They are properly line-spaced. Refer to the tutorial for more details. In general, it is better to start a new paragraph (i.e. place a blank line in the source file) at the start of a new enumerate block. This ensures that the line-spacing options are activated correctly.

Line spacing of items in the list and the spacing of the list with respect to the surrounding textual matter is set as per the institute guidelines.

### **5.1 UNNUMBERED LISTS**

These are the standard “bulleted” lists that one is familiar with.

- this
- is
- a bulleted
- list

this is the next paragraph

- ◊ this
- ◊ is
- ◊ a dashed
- ◊ list

and this is the next paragraph

- this
- is

- a mixed

- list

and this is the next paragraph

- ★ this

- ★ is

- a mixed

- ★ list

and this is the next paragraph

- this

- is

- square

- list

and this is the next paragraph

- this

- is

- square

- list

## 5.2 NUMBERED LISTS

These are the standard numbered lists that one might be familiar with.

1. this

2. is a

3. numbered

4. list

this is the next paragraph

- i. this
- ii. is a
- iii. roman-numbered
- iv. list

this is the next paragraph

- I] this
- II] is a
- III] capitalized roman-numbered
- IV] list

this is the next paragraph

- a) this
- b) is an
- c) alphabetical
- d) list

this is the next paragraph

- A} this
- B} is the
- C} last
- D} This is what that author said and it is rather important. That is the reason I am quoting the entire passage here for reference and completeness
  - a) This is what that author said and it is rather important. That is the reason I am quoting the entire passage here for reference and completeness
  - b) This is what that author said and it is rather important. That is the reason I am quoting the entire passage here for reference and completeness

Note that one can nest lists as well as shown above

### **5.3 MORE COMPLEX LISTS MADE EASY**

Step i] reflect over the research done

Step ii] review ones notes, writings, lab journal and research articles

Step iii] stop overthinking and/or procrastinating

Step iv] start writing

Step v] realize that there is much to do

i} fear not

★ persevere

ii} continue writing

Step vi] success!

### **5.4 QUOTES**

Very useful for quoting text from other works. See the tutorial for more details and references.

An inline-quote, one that is along with the main material is placed like this “this is a quote”. Sometimes we want to mention the author as well “this is what that author wrote”  
(Author of the quote)

Sometimes, it is better to quote larger passages of text in the display mode like this

This is what that author said and it is rather important. That is the reason I am quoting the entire passage here for reference and completeness

this is the next paragraph. By specifying the optional argument, the author name can be set as well:

[Authorname] This is what that author said and it is rather important. That is the reason I am quoting the entire passage here for reference and completeness

## **5.5 FOOTNOTES**

One might find the need to include some relevant contextual information in the material but find it unnecessarily intrusive to do so in the running text matter itself. In such cases, or whenever else the author feels the need to do so, a footnote may be deployed thus <sup>1</sup>

---

<sup>1</sup>see, this is the footnote I was talking about. It is spaced appropriately. Best to use these sparingly since they detract from the general flow of the document. Some thoughtful restructuring of the material can help reduce the need for footnotes



# CHAPTER 6

## MATHEMATICS

$\text{\TeX}$  is unmatched when it comes to the precise rendering of complex mathematical material. Several handy tools and packages are available to the author from various packages offering mathematic facilities. Some of these are bundled-in by default. Refer to the relevant chapter of the tutorial for more details.

### 6.1 EQUATIONS

What follows below is an equation

$$e^{i\pi} + 1 = 0 \tag{6.1}$$

Notice that it is appropriately numbered. Notice that in the case of mathematics, appropriate spacing of the textual matter surrounding the equation (i.e., those portions of the material above and below the equation) are appropriately spaced only when there is no paragraph break before and after environment block. Therefore, the user must ensure that there are no blank line(s) before or after the mathematics block so that excess unwanted space is avoided. Shown below is a piece of display math, which are unnumbered by default. Therefore if equation numbering is desired, the equation environment is recommended

$$\lim_{x \rightarrow 0} \frac{\sin x}{x} = 1.$$

This is the next paragraph. Very often, one needs to write several equations in a sequence of steps aligned properly, one below the other. This is also easily achieved using the align environment:

$$\limsup_{n \rightarrow \infty} E_n = E_n \text{ i.o }^c \tag{6.2}$$

$$= \bigcup_{n \in \mathbb{N}} \bigcap_{m \geq n} E_m^c \quad (6.3)$$

$$= \lim_{n \rightarrow \infty} \bigcap_{m \geq n} E_m^c \quad (6.4)$$

$$= \lim_{n \rightarrow \infty} \prod_{m \geq n} E_n^c \quad (6.5)$$

$$= \lim_{n \rightarrow \infty} \prod_{m \geq n} 1 - E_n \quad (6.6)$$

$$\leq \lim_{n \rightarrow \infty} \prod_{m \geq n} \exp -E_n \quad (6.6)$$

$$= 0. \quad (6.7)$$

If equation numbers for certain steps are not required they may be avoided by using the `\nonumber` directive as has been done above.

Notice that the equations are line-spaced correctly as well. The surrounding text too is appropriately spaced from the `align` block. Here too, as with the equation environment, here too it is recommended to avoid blank lines (paragraph breaks) before and after the `align` environment so that unsightly white space before and after the block is avoided.

## 6.2 CONVENIENCES

Various other essential and convenient mathematical facilities are bundled with the package. For instance, automatically sized delimiters, common theorem and theorem-like environments, configured proof blocks and commonly used operators are all provided.

Refer to the tutorial for more information regarding these.

**Theorem 6.1.** *This is an insightful theorem.*

*Proof.* Here is the proof. ■

# CHAPTER 7

## FIGURES AND TABLES

Figures and tables are referred to as floats in the  $\text{\TeX}$  world. These are elements which cannot be broken across pages. For more details on these, refer to the relevant chapter of the tutorial.

### 7.1 FIGURES

A simple figure is shown below:



Figure 7.1: This is a photo of Tux. He is a very friendly penguin. We will meet his friends shortly.

As with almost all other elements in  $\text{\LaTeX}$  figures too can be cross-referenced using the labels. Make sure to provide these for all figures and choose a descriptive tag while doing so. That way, later on if one needs to refer to the figure, there is no need for hunting around to find where the image is. Instead, Overleaf will automatically suggest a list of tags to choose from while invoking the `\ref` command.

Since floats are complex, one does not have very fine-grained control over the location of its placement relative to surrounding text. While preparing a document, the author should not be too concerned about the placement unless it is severely out of place. Instead,



Figure 7.2: Tux with his various friends. Notice that captions of figures are placed below the figure and are properly line spaced as per the guidelines

once the document is near-complete, fine tuning can be done to precise measurements if desired/possible. Otherwise, some fine-tuning might go to waste as significant changes to the document (and hence the layout of the material) occurs.

The recommended way to place multiple figures is by use of the `subcaption` package. Make sure to include this. An example is shown in figure 7.2.

## 7.2 TABLES

Please refer to the tutorial for a slightly detailed note about tables. A simple table is shown below. Table captions are placed above the table. They are line-spaced as per the guidelines. It is not recommended to break paragraphs after a table unless absolutely necessary. Note that `\captionabove` (not `\caption`), is used to place captions in tables. Only then will the spacing around the captions of tables be appropriate. Make

Table 7.1: Shown below is a simple elegant table with a very long caption. Tables are quite helpful in organizing information in a presentable manner.

<b>Table Head</b>	
stuff	stuff

Table 7.2: A complex table is shown here. Careful use of the column specifiers along with thoughtful (re)organization of the material can yield great results

<b>Aspect</b>	<b>Value</b>		<b>Profit</b>	
	Before 2019	After 2019	Before 2020	After 2020
<b>Whatever</b>	30	40	20	2
<b>Aspect</b>	33	45	10	5
<b>Entries</b>	37	51	90	600
<b>Here</b>	33	67	97	52

note of this fact.

Far more complex table layouts are possible using `multicolumn` and/or specifying different column types for the `tabular` block. Refer to the tutorial for more details. An example is shown below:

Further, the `multirow` functionality offered by the `multirow` package is sometimes useful. The same example as above is repeated below with a slight change using the `multirow` functionality

Bear in mind that as in the case of figures, the tables too cannot always be precisely positioned as desired. Fine-tuning of the positioning by the use of position specifiers is best left to the final stages of the document preparation.

Finally, vertical rules in tables are not only unsightly, but also largely unnecessary (for

Table 7.3: A complex table is shown here. Sometimes, one might need to have cell entries which span more than a single row; this too is possible as shown below

Aspect	Value		Profit	
	Before 2019	After 2019	Before 2020	After 2020
<b>Whatever</b>	30	40	20	2
<b>Aspect</b>	33	45	10	5
<b>Entries</b>	37	51	90	600
<b>Here</b>	33	67	97	52

most cases). If one still wants properly positioned vertical rules in tables, refer to the tutorial file for more information.

### 7.3 BIBLIOGRAPHY REFERENCES

BibTeX is the only supported mechanism to manage bibliography and citations. For those unfamiliar with BibTeX, several useful tutorials are available on the internet.

In nutshell, one requires a `references.bib` file containing all the relevant details of the material to be referenced in the BibTeX format. Make sure to the `references.bib` file is free of any errors to ensure that the bibliography is typeset correctly. Many popular reference management tools support BibTeX export of libraries.

With that in place one simply uses the `\cite` command along with the tag of the entry to be referenced. For instance, this is a very nice paper Stroock and Varadhan (1971). While we are on the topic, let me recommend another classic: Nash (1951). Or perhaps, some other favorites might interest you if you work in related fields: see Chernoff (1972), Wald (2004), Zhang (2014) or Shannon (1948) for a nice selection. It is also worth mentioning that the work of Polyanskiy *et al.* (2010) is well regarded.

## **APPENDIX A**

### **GENERAL NOTES**

For any package, always consult the official package manual and/or reference for specific instructions on how to load them and the range of options available. If you run into strange issues, feel free to ask for send me an email or ask on the PhD or MS mailing lists.

Note: As is the case for many other programming languages, there are lot of L<sup>A</sup>T<sub>E</sub>X code snippets floating around at various forums on the internet. While using these code snippets may (or may not) alleviate issues, it is highly plausible that such code can have undesirable side effects, just from being placed in a document. Further, a single code snippet can, in general, have different effects depending on where it is placed in the document. Therefore, the user is urged to inspect an official manual and/or reference before inserting arbitrary code into the document. The code of `iitmthesis` largely conforms to the best practices and strictly abides by the documentation of the packages that it loads.

#### **A.1 SOURCE FILES**

The user must avoid editing the source files as far as possible. Commands do not always do what one expects of them unless of course they are invoked in the right context (and/or situation). `iitmthesis` has been extensively tested in many scenarios. However, it is very much possible that bugs exist. Most errors in compilation arise from incorrect use of packages and/or their facilities. Take care to ensure that you follow best practices while using external packages. If you encounter an insurmountable issue despite your best efforts, you are most welcome to contact the author for help.

Ensure that these files are not tampered with at any cost. The accompanying template will not compile (and produce a PDF) if even one of these is missing. These are as follows: `iitm.bst`, `iitmdissertation.cls`, `iitmdissertation.sty` and the folder `zz-imp`.

## A.2 SOME USEFUL PACKAGES

Quite a few packages are loaded by `iitmdissertation` which are very commonplace in a standard document. In the event that certain customization of one or more of the facilities offered by these packages is required, the user is urged to look at the respective package's documentation.

We hope this helps users to produce nicely formatted theses and simplifies his/her writing experience. Happy writing!

Table A.1: A list of commonly required (some of which are pre-loaded) packages along with links to their documentation

Package(s)	Note(s)
<code>enumitem</code>	handles all itemized lists and descriptions [López (2019)]
<code>booktabs &amp; array</code>	handle all facilities related to tables [Els (2020); Team and Mittelbach (2021)] Caution: Although, there are many table-related packages for L <sup>A</sup> T <sub>E</sub> X, use of booktabs and array is the recommended way to handle tabulation
<code>xcolor</code>	handles all color related facilities. This package is loaded with the usenames,svgnames option for a total of 170 color options. Consult page 43 of the xcolor manual for these color names [Team and Kern (2021)] Caution: Trying to load xcolor with other options might cause issues (i.e, option clashes in L <sup>A</sup> T <sub>E</sub> X parlance). If you really must have new color(s) you can define it using the definecolor command.
<code>subcaption</code>	This is the recommended package for handling sub-figures and sub-captions. This is not loaded by default but is highly recommended if the need for multiple figures with sub-captions arises [Sommerfeldt (2020)]
<code>multirow</code>	This is the recommended package for handling tabular-cells spanning multiple rows. This is not loaded by default, since it is not essential.[van Oostrum (2020)]
<code>glossaries</code>	This is the default package used to handle glossaries and the abbreviations in the prematter. <code>iitmthesis</code> provides defaults for a simple glossary customized to match the official guidelines of the institute as can be seen in the template. [Talbot (2021)]
<code>nomenc1</code>	This is the default package used to handle the notation chapter in the prematter. <code>iitmthesis</code> provides defaults for a simple notations chapter conforming to the guidelines. [Veytsman <i>et al.</i> (2021)]



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# CURRICULUM VITAE

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## EDUCATION QUALIFICATIONS

**1970**      **The first degree**  
Institution                  Wherever  
Specialization              Whatever

**2038**      **The previous degree**  
Institution                  Wherever  
Specialization              Whatever

**Dual Degree**  
Institution                  Wherever  
Specialization              Whatever  
Registration Date          Whenever



## DOCTORAL COMMITTEE

**Chairperson** Dr. Name

Whatever

Wherever

**Guide(s)** Dr. Name

Whatever

Wherever

Dr. Name

Whatever

Wherever

**Member(s)** Dr. Name

Whatever

Wherever

Dr. Name

Whatever

Wherever

Dr. Name

Whatever

Wherever