Ohio State College of Engineering MS/PhD/Candidacy Dissertation Template

Dissertation

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of The Ohio State University

By

Firstname Midname Lastname, B.S., M.S.

Graduate Program in Nuclear Engineering

The Ohio State University

2023

Dissertation Committee:

Richard Vasques, Advisor

Someone 1, Co-Advisor

Someone 2

Maybe Someone 3

Abstract

This is your abstract. Fill it accordingly.

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Nam dui ligula, fringilla a, euismod sodales, sollicitudin vel, wisi. Morbi auctor lorem non justo. Nam lacus libero, pretium at, lobortis vitae, ultricies et, tellus. Donec aliquet, tortor sed accumsan bibendum, erat ligula aliquet magna, vitae ornare odio metus a mi. Morbi ac orci et nisl hendrerit mollis. Suspendisse ut massa. Cras nec ante. Pellentesque a nulla. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Aliquam tincidunt urna. Nulla ullamcorper vestibulum turpis. Pellentesque cursus luctus mauris.

Nulla malesuada porttitor diam. Donec felis erat, congue non, volutpat at, tincidunt tristique, libero. Vivamus viverra fermentum felis. Donec nonummy pellentesque ante. Phasellus adipiscing semper elit. Proin fermentum massa ac quam. Sed diam turpis, molestie vitae, placerat a, molestie nec, leo. Maecenas lacinia. Nam ipsum ligula, eleifend at, accumsan nec, suscipit a, ipsum. Morbi blandit ligula feugiat magna. Nunc eleifend consequat lorem. Sed lacinia nulla vitae enim. Pellentesque tincidunt purus vel magna. Integer non enim. Praesent euismod nunc eu purus. Donec bibendum quam in tellus. Nullam cursus pulvinar lectus. Donec et mi. Nam vulputate metus eu enim. Vestibulum pellentesque felis eu massa.

Dedicated to elevators for always lifting people up and being helpful on so many levels.

Acknowledgments

I thank my friends and family, without whom this work would have been completed two years earlier.

In reality, this is the only page of the dissertation of which the author has full control. You can write anything you want here, and no one can tell you it is wrong (except if the margins don't line up!!!!).

<div align="center">

Vita

</div>

August 2016 . . . . B.S. in something, The Ohio State University

Some date . . . . Some degree, Some place

September 2016 to present . . . . Graduate Research Associate,
The Ohio State University

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Publications

</div>

Research Publications

F.M. Lastname, J. Doe, and R. Vasques, "Some Cool Title for a Paper," Journal Name, vol. 99, pp. 11-22, 2018.

<div align="center">

Fields of Study

</div>

Major Field: Nuclear Engineering

Table of Contents

List of Tables

List of Figures

List of Symbols

ψ . . . . Angular Flux

ϕ . . . . Scalar Flux

Chapter 1: Introduction

This is your introduction chapter. You are allowed to make sections and subsections.

1.1 Something Basic

This is a section.

1.1.1 Something even more basic

This is a subsection.

1.2 Another Section

This is another section.

Chapter 2: Neutron Spectrum Unfolding

This Chapter will contain all of the current neutron spectrum unfolding techniques, including the strengths and weaknesses of each.

2.1   Radiation Interaction with Matter

Radiation interacts with stuff

2.2   Spectrum Unfolding

Spectrum unfolding requires math.

2.2.1   Detector Response Matrix

2.3   MAXED

An introduction about MAXED and the reasons it was developed will go here.

2.3.1   Description of the math of detector response unfolding

Talk about dual annealing, the maximum entropy method, χ^2 method.

2.3.2   Passive Neutron Spectrometer Response

The Passive Neutron Spectrometer provides similar capabilities to multisphere neutron spectrometers (like Bonner spheres), albeit in a single sphere of material. With the 55 TLDs

arranged along the three Cartesian axes, each detector has a different thickness of material separating it from a potential neutron source. This arrangement effects a different response in each of the TLDs, which can be utilized in unfolding techniques.

A typical depth-averaged (I'll have described this in an earlier chapter/section) detector response from the PNS is shown in Figure 2.1.
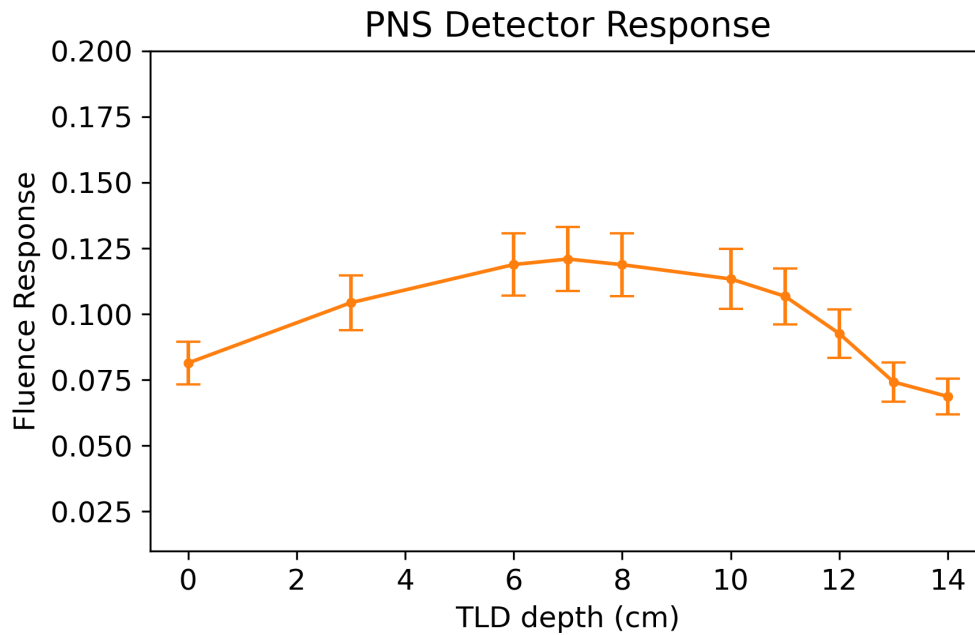

Figure 2.1: A depth-averaged detector response from the PNS in the presence of a Cf-252 neutron source.

2.3.3   Unfolding the Detector Response

(The math will be described in Section 2.3.1) The detector response from Figure 2.1 was used to unfold the neutron spectrum. As mentioned earlier, this detector response was achieved in the presence of a Cf-252 source. Knowing the correct spectrum allows for a

good measurement of the accuracy of the algorithm. The inputs needed for MAXED to unfold the spectrum is a detector response, an initial guess at what the spectrum should be, and, as mentioned in Section 2.2.1, a detector response matrix. The following sections will show the accuracy of MAXED when the guess spectrum is varied and showcases the extreme sensitivity to the initial guess.

Because the true spectrum is known, the accuracy of the output of MAXED can be calculated and compared using the modal assurance criterion (MAC). (Put more information about it here) It gives a range (0 1], 1 being an exact match between two sets of data and anything lower is less similar.

$$MAC = \frac{|(Spectrum_{unfolded})^T(Spectrum_{true})|^2}{((Spectrum_{unfolded})^T(Spectrum_{unfolded}))((Spectrum_{true})^T(Spectrum_{true}))}.$$

(2.1)

Using the true spectrum

An initial point to check for the accuracy of MAXED is by using the true spectrum as the initial guess. The values for this spectrum were taken from the IAEA document Compendium of Neutron Spectra and Detector Responses for Radiation Protection Purposes [**iaea_spec**]. Barring any other interactions, the MAXED code should get 100% accuracy on this example, but because the environment surrounding the PNS will reflect neutrons and affect the detector response, there will still be error. The results of this unfolding is shown in 2.2.

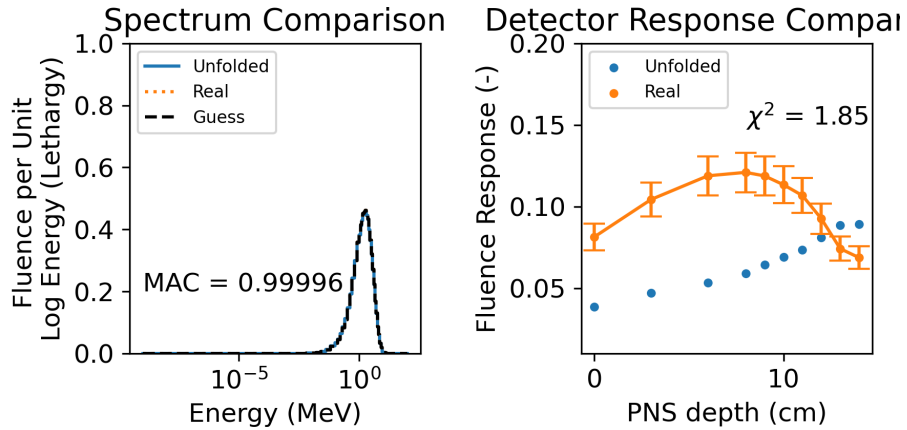- DRM: Plane source DRM

- Guess Spectrum: Cf-252 spectrum

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Figure 2.2: The results of the MAXED algorithm using a Cf-252 guess spectrum.

Using the true spectrum with a different DRM

Following the above example but with a DRM developing using a spherical source surrounding the PNS and directing neutrons inward. Both are very accurate, with MAC numbers very close to 1. Results are in Figure 2.3

- DRM: Sphere source DRM

- Guess Spectrum: Cf-252 spectrum

Using the true spectrum multiplied by 0.9

Running MAXED with the plane-source DRM and using a modified Cf-252 spectrum as the input guess spectrum. The modification was performed by multiplying the spectrum by 0.9. Results are in Figure 2.4

MAXED Unfolding Spectra Results
DRM: Spherical_Source_DRM_avg_GSmod100percent
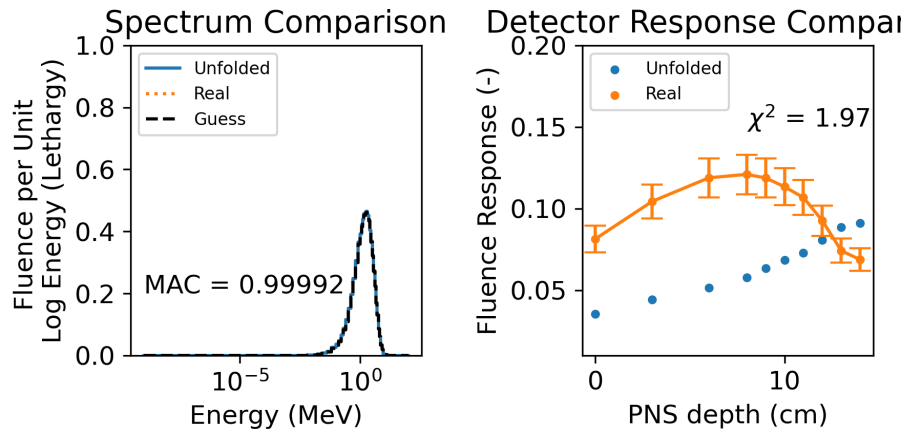### Guess Spectrum: IAEA Cf-252 Spectrum*1

Figure 2.3: The results of the MAXED algorithm using a Cf-252 guess spectrum.

- DRM: Plane source DRM

- Guess Spectrum: Cf-252 spectrum * 0.9

Using the true spectrum multiplied by 0.5

Running MAXED with the plane-source DRM and using a modified Cf-252 spectrum as the input guess spectrum. The modification was performed by multiplying the spectrum by 0.5. Results are in Figure 2.5

- DRM: Plane source DRM

- Guess Spectrum: Cf-252 spectrum * 0.5

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MAXED Unfolding Spectra Results
DRM: Planar_Source_DRM_avg_GSmod90percent
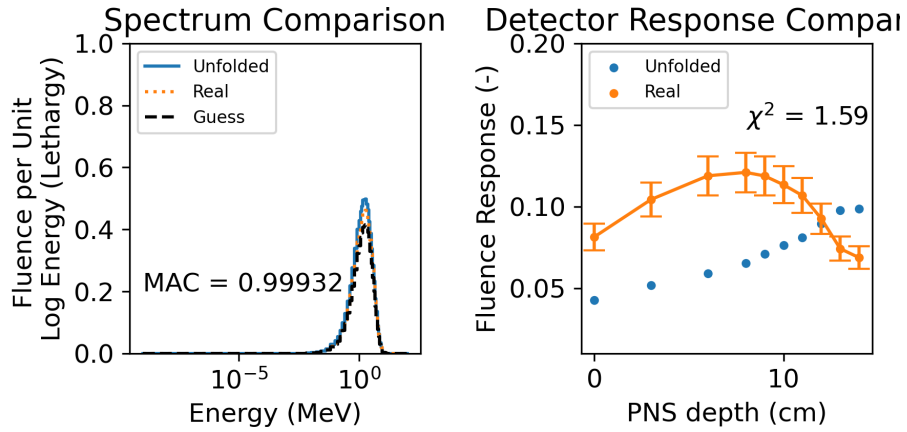Guess Spectrum: IAEA Cf-252 Spectrum*0.9

Figure 2.4: The results of the MAXED algorithm using a modified Cf-252 guess spectrum.

Using a D2O moderated Cf-252 spectrum

Running MAXED with the plane-source DRM and using a D2O moderated Cf-252 spectrum. Notice that the MAC number is much smaller than 1. Results are in Figure 2.6

- DRM: Plane source DRM

- Guess Spectrum: D20 moderated Cf-252 spectrum

Using a H2O moderated PuBe spectrum

Running MAXED with the plane-source DRM and using a H2O moderated PuBe spectrum. Notice that the MAC number is much smaller than 1. Results are in Figure 2.7

- DRM: Plane source DRM

- Guess Spectrum: H2O moderated PuBe spectrum

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MAXED Unfolding Spectra Results
DRM: Planar_Source_DRM_avg_GSmod50percent
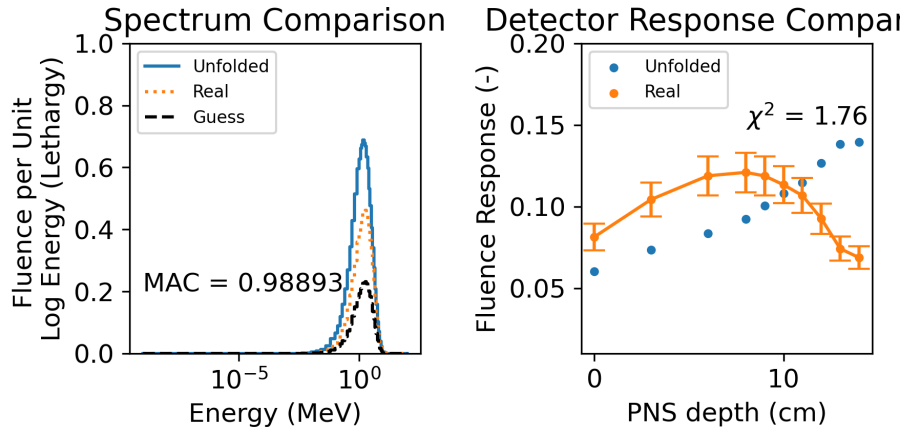**Guess Spectrum: IAEA Cf-252 Spectrum*0.5**

Figure 2.5: The results of the MAXED algorithm using a modified Cf-252 guess spectrum.

Using a randomly generated DRM

Once a different spectrum is used for input, the output of MAXED becomes highly inaccurate. Another test of the robustness is to try using a randomly generated DRM. The results are in Figure 2.8.

- DRM: Random DRM

- Guess Spectrum: Cf-252

Using a randomly generated DRM and modified guess spectrum

The effects of the random DRM are even more visible when the true spectrum is modified like above. In this case, the Cf-252 spectrum is multiplied by 0.5 and the results are in Figure 2.9.

MAXED Unfolding Spectra Results
DRM: Planar_Source_DRM_avg_GSmod100percent
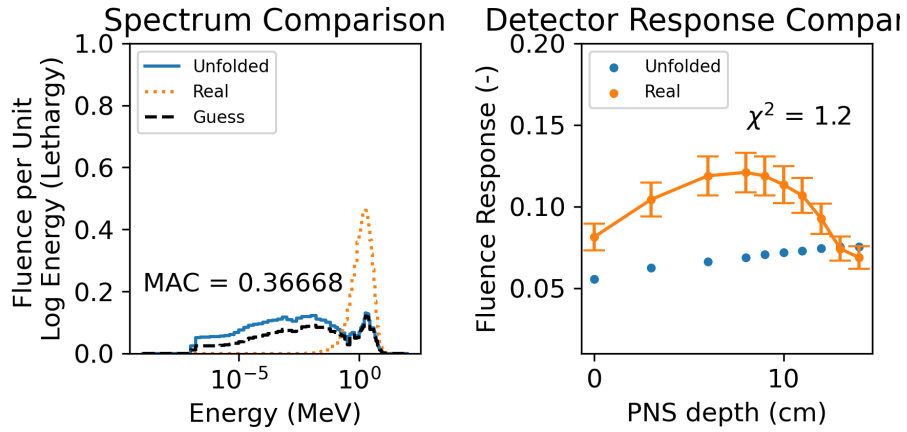Guess Spectrum: IAEA D2O Moderated Cf Spectrum*1

Figure 2.6: The results of the MAXED algorithm using a D20 moderated Cf-252 guess spectrum.

- DRM: Random DRM

- Guess Spectrum: Cf-252 * 0.5

Thoughts on MAXED

When given very good information, the MAXED algorithm can perform neutron spectrum unfolding. This is highly dependent on the operator who provides the information to the algorithm. As shown in the examples above, the results of MAXED do not depart greatly from the initial guess spectrum.

At first, it appears that a randomly generated DRM performs well, but I think this is an artifact of the limitations of the MAXED algorithm. I believe that there are a great many local minima and the initial guess makes a very big impact. Additionally, when the

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MAXED Unfolding Spectra Results
DRM: Planar_Source_DRM_avg_GSmod100percent
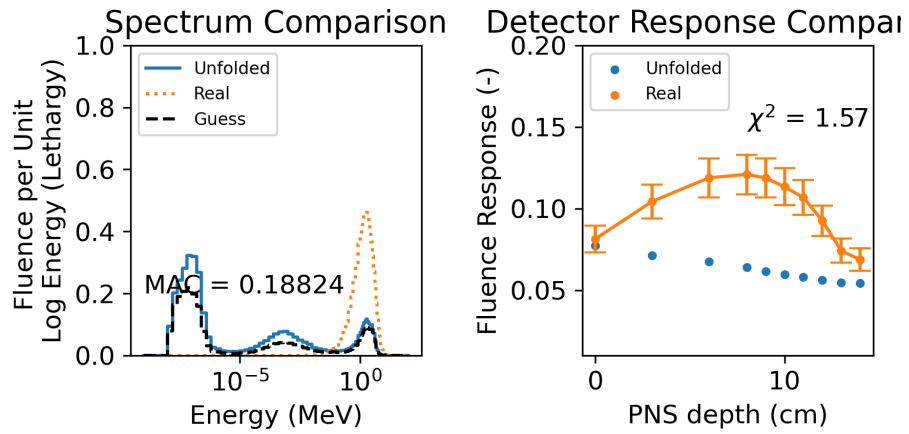Guess Spectrum: IAEA H2O Moderated PuBe Spectrum*1

Figure 2.7: The results of the MAXED algorithm using a H2O moderated PuBe guess spectrum.

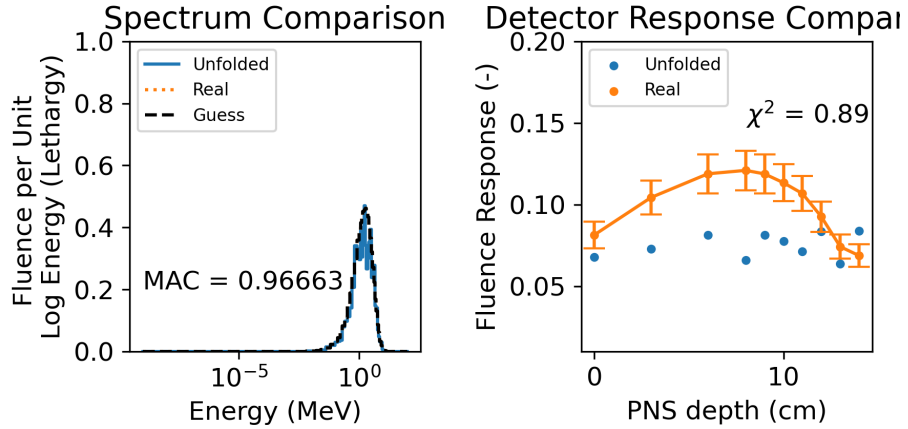guess spectrum is modified like in earlier examples, the effects of the randomness are more

pronounced.

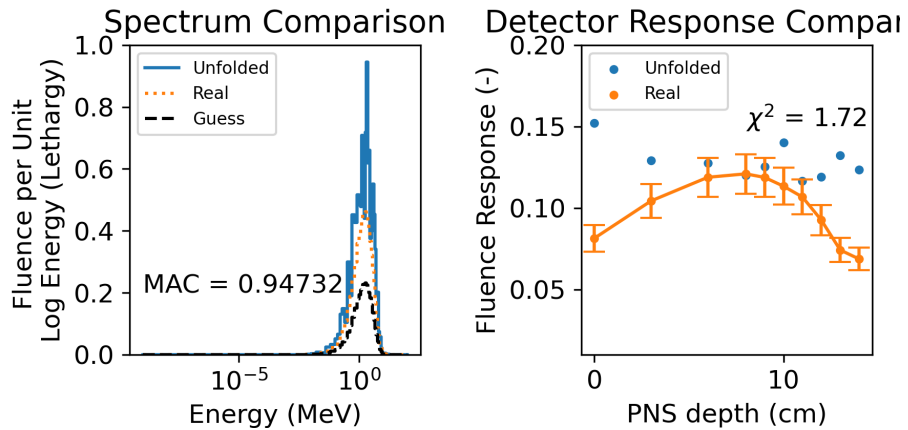Figure 2.8: The results of the MAXED algorithm using a Cf-252 guess spectrum and a randomly generated DRM.

Figure 2.9: The results of the MAXED algorithm using a modified Cf-252 guess spectrum and a randomly generated DRM.

Chapter 3: This is Another Chapter

You can use any equation environment. I suggest the "align" environment. Like this:

$$1 + 1 = 2.\tag{3.1}$$

This is because this environment allows you to break your equations easily. If an equation is broken, always number its first line only:

$$(x + y + z + a + b + c + d + e + f + g + h) + (w + r + t + y + u) =\tag{3.2}$$
$$(x + y + z + a + b + c + d + e + f + g + h + w + r + t + y + u)$$

You can also also use the "subequations" environment. Identify a list of subequations by [pluraleq], like this:

$$1 + 2 = 3,\tag{3.3a}$$

$$2 + 3 + 5 = 10,\tag{3.3b}$$

$$1 + 2 + 2 + 3 + 5 = 3 + 10.\tag{3.3c}$$

You can even add text between the list of equations.

$$13 = 13.\tag{3.3d}$$

Now you can use the "cleverref" package to refer to equations, tables, chapters, sections, figures, etc. Just enter Eq. (3.1) or Equation (3.1) if you do not want abbreviations. Also,

the list of equations is done automatically: Eqs. (3.3). Or you can do Eqs. (3.1) and (3.3b) to (3.3d).

The same package will refer to figures and tables, and these will be entered automatically in your index.

3.1 Figures and Tables

This is an example of a basic table:

Table 3.1: Example of a table

Set	ℓ_1	ℓ_2	Σ_{t1}	q_1	Set	ℓ_1	ℓ_2	Σ_{t1}	q_1
A_1	0.5	1.0	1.0	1.0	B_1	20/3	40/3	1.5	1.5
A_2	1.0	1.0	1.0	1.0	B_2	10	10	1.0	1.0
A_3	1.0	0.5	1.0	1.0	B_3	40/3	20/3	0.75	0.75

This is an example of a basic figure: As you can see, "cleverref" allows you to refer to

Figure 3.1: Example of a figure

more than just equations: you can refer to Chapter 3, or Section 3.1, or Table 3.1, or Fig. 3.1. Tables and figures are indexed automatically (see index).

Chapter 4: Machine Learning/Neural Networks

This Chapter will contain all of the current machine learning and neural networks techniques.

Chapter 5: Unfolding Neutron Spectra with Neural Networks

This Chapter will contain all of the process of developing a neural network to unfold neutron spectra.

Chapter 6: Validation of Unfolding Neutron Spectrum Using a Neural Network

This Chapter will contain all of the work done validating the neural network for unfolding spectra.

Chapter 7: Comparing Neutron Spectrum Unfolding Techniques

This Chapter will compare the neural network unfolding method with other unfolding techniques.

Chapter 8: Unfolding the Spectrum with New Data

This Chapter will showcase the results of using the neural network to unfold data from a new real world detection using the PNS.

Chapter 9: Conclusions

This is your final chapter. It does not have to be titled "Conclusions"; it could be "Discussion", or whatever else you prefer.

I am going to use this chapter to talk about references. All your references should be in the references.bib file, in the same folder as this source file. Only entries that are actually referenced in the text will show up, so you do not have to delete entries from the references.bib file. References will appear in the order they are cited in the text. You can look at the references.bib file to see how to enter each of the references in the following examples.

For papers in proceedings you need: authors' names, title of paper, title of proceedings, location [city, state (if in the US), or city, country (if abroad)], dates (month, days, year). See examples in [**proc1**, **proc2**, **proc3**].

For papers in journals you need: authors' names, title of paper, full name of journal, volume, number (if exists), pages, year. See examples in [**artic1**, **artic2**, **artic3**].

For book chapters or papers in books you need: authors' names, title of chapter or paper, title of book, name of editors, name of publisher, pages, year. See examples in [**chapter1**, **chapter2**, **chapter3**].

For books you need: authors' names, title of book, name of publisher, year. See examples in [**book1**, **book2**, **book3**].

Appendix A: This is an Appendix

You can have as many appendices as needed.