**Visualizing Uncertainty with Chromatic Aberration**

By

Md Rashidul Islam  
md313724@dal.ca

Supervised by

Dr. Stephen Brooks

Professor

Faculty of Computer Science, Dalhousie University

Submitted in partial fulfilment of the requirements

for the degree of Master of Computer Science

at

Dalhousie University

Faculty of Computer Science, Dalhousie University

Halifax, Nova Scotia

© Dalhousie University 2020. All rights reserved.

**Table of Contents**

List of Tables ………………………………………………………………………………….. vii

List of Figures …………………………………………………………………………………. viii

List of Algorithms …………………………………………………………………………….. x

Abstract ………………………………………………………………………………………... xi

List of abbreviations …………………………………………………………………………... xi

Acknowledgements …………………………………………………………………………... xii

**Chapter 1 Introduction** …………………………………………………………………... 1

1.1 Background and Motivation ……………………………………………………….... 1

1.2 Background Concepts ……………………..………………………………………… 2

1.2.1 Machine Learning (Predictive Models) …………………………………... 2

1.2.2 D3.js ……………………………………………………………................. 3

1.2.3 Uncertainty …………………………………………………...…………… 3

1.2.4 Streamgraph ……………………………………………………………….. 4

1.2.5 Texture …………………………………………………………………….. 5

1.2.6 Chromatic Aberration …………………………….……………………….. 5

1.3 Problem Statement …………………………………………………………………. 7

1.4 Approach ……………………………………………………………………………. 8

1.5 Thesis Outline ……………………………………………………………………….. 9

**Chapter 2 Literature Review** …………………………………………………………… 10

2.1 Introduction ………………………………………………………………………… 10

2.2 Prior works related to prediction in Machine Learning Models …………………… 10

2.3 Uncertainty related prior works ……………………………………………………. 11

2.4 Chromatic Aberration related prior works …………………………………………. 19

2.5 Texture related prior works ………………………………………………………… 21

2.6 Limitations of related works ……………………………………………………….. 23

**Chapter 3 Data Collection, Processing, and Introduction of Models** ……………… 25

3.1 Introduction ……………………………………………………………………….. 25

3.2 Data ……………………………………………………………………………….. 25

3.2.1 Data Collection …………………………………………………………. 25

3.2.2 Sample Data ……………………………………………………………. 27

3.3 Machine Learning Algorithms …………………………………………………… 27

3.3.1 Predictive/Forecasting Models …………………………………………. 28

3.3.2 Time Series Analysis vs Forecasting …………………………………… 28

3.3.3 Concerns of Forecasting ………………………………………………… 29

3.3.4 Example of Forecasting …………………………………………………. 30

3.4 MLP ……………………………………………………………………………….. 30

3.5 CNN ……………………………………………………………………………….. 34

3.6 LSTM ……………………………………………………………………………… 36

3.7 ARIMA ……………………………………………………………………………. 37

3.7.1 Auto ARIMA ……………………………………………………………. 38

3.8 Uncertainty Data Generation ……………………………………………………… 39

3.8.1 Uncertainty Data Scaling ………………………………………………... 40

3.8.2 Snapshot of uncertainty data ……………………………………………. 41

3.8.3 Top 10 uncertainty countries using MLP model ………………………… 41

3.8.4 Lowest 10 uncertainty countries using MLP model …………………….. 41

3.8.5 Uncertainty Comparison among Models ………………………………… 42

**Chapter 4 Visualization Method** ……………..………………………………………. 43

4.1 Introduction ………………………………………………………………………. 43

4.2 Background Architecture ………………………………………………………… 43

4.3 Examples of CA in Shapes ………………………………………………………. 44

4.4 Texture Pattern Generation ………………………………………………………. 45

4.4.1 Slicing Plot …………………………………………………………….. 47

4.4.2 Pattern Generation ……………………………………………………… 48

4.4.3 Texture Generation …………………………………………………….. 50

**Chapter 5 Application of Chromatic Aberration** ……………..…………………… 51

5.1 Introduction ………………………………………………………………………. 51

5.2 Web Interface ……………………………………………………………………. 51

5.3 Filtering ………………………………………………………………………….. 53

5.3.1 Bubble Selection Mode ……………………………………………….. 53

5.3.2 Bubble Removal Mode ……………………………………………….. 54

5.4 Legend ……………………………………………………………………………. 54

5.5 Reshuffling Streamgraph …………………………………………………………. 54

5.6 Drill-down All Model Predictions ……………………………………………….. 56

5.7 Star Fish Inspired Design …………………………………………………………. 57

5.8 Parallel Coordinate Chart …………………………………………………………. 59

5.9 Bubble Grid Chart ………………………………………………………………… 60

5.10 Horizontal Chart …………………………………………………………………. 61

5.11 Square Grid Chart ……………………………………………………………….. 63

5.12 World Map ………………………………………………………………………. 64

**Chapter 6 Evaluation: Numerical Analysis** …….…………………………………….

6.1 Introduction ………………………………………………………………………….

**Chapter 7 Results and Discussion**………………………….…………………………..

7.1 Introduction …………………………………………………………………………

**Chapter 8 Conclusion and Future Work** ………………………….…………………..

8.1 Introduction ………………………………………………………………………….

**References** ………………………….………………………………………………………..

**Bibliography** ……………………………………………………………………………………  
Appendix A REB Application Form ………………………………………………………….

Appendix B Letter of REB Approval …………………………………………………………

Appendix C Consent Form ……………………………………………………………………..

Appendix D Examples and Questionnaire …………………………………………………….

D.1 Questionnaire Setup and Arrangement ……………………………………………

D.2 Example of CA + Bubble …………………………………………………………

D.3 Questionnaire on CA + Bubble ……………………………………………………

D.4 Example of VSUP + Bubble ………………………………………………………

D.5 Questionnaire on VSUP + Bubble …………………………………………………

D.6 Example of CA + Grid ……………………………………………………………. D.7 Questionnaire on CA + Grid ………………………………………………………

D.8 Example of VSUP + Grid …………………………………………………………

D.9 Questionnaire on VSUP + Grid ……………………………………………………

D.10 Questions on System Usability Scale (SUS) …………………………………..

D.11 Questions on NASA TLX ……………………………………………………..

Appendix E Ishihara Color Blindness Test Plates ……………………………………………

**List of Tables**

Table 3.1 COVID Data property list ……………………………………………

Table 3.2 Screenshot of sample data ……………………………………………

Table 3.3Top uncertainty countries ………………….…………………………

Table 3.4 Lowest Uncertainty countries ………………………………………..

Table 3.5 Uncertainty Comparisons of Models ………………………………...

**List of Figures**

Figure 1.1 Streamgraph Prototype ……………………………………………….

Figure 1.2 Example of Chromatic Aberration ……………………………………

Figure 3.1 Predictive modelling workflow to generate uncertainty ……………...

Figure 3.2 Example of daily covid forecasting for 200 days …………………….

Figure 3.3 Basic Architecture of MLP network ………………………………….

Figure 3.4 Basic Architecture of CNN network ………………………………….

Figure 3.5 Basic Architecture of LSTM network …………………………………

Figure 4.1 Underlying Geometry of Chromatic Aberration ………………………

Figure 4.2 Example CA on Bubbles and Rectangles ……………………………..

Figure 4.3 Streamgraph Color Filled (left), Texture Filled (right) ……………….

Figure 4.4 Sliced Streamgraph ……………………………………………………

Figure 5.1 Initial Web Interface …………………………………………………..

Figure 5.2 Filter by selected countries of interest …………………………………

Figure 5.3 Removal of countries of interest ……………………………………….

Figure 5.4 Reshuffling Main Streamgraph ………………………………………..

Figure 5.5 Streamgraphs for all models for Brazil ………………………………..

Figure 5.6 Uncertainty presentation on stream by texture …………………………

Figure 5.7 Multi Country Stream Graphs filled by color ………………………….

Figure 5.8 Multi Country Stream Graphs filled by Texture of CA ………………..

Figure 5.9 Parallel coordinates chart ………………………………………………

Figure 5.10 Bubble Grid chart with CA textures ……………………………………

Figure 5.11 Horizontal chart (Color filled) ………………………………………….

Figure 5.12 Horizontal chart (Texture filled) ………………………………………

Figure 5.13 Charts of Daily Counts for different countries …………………………

Figure 5.14 Uncertainty in World view …………………………………………….

Figure 5.15 Zoomed World Map centering Nigeria ………………………………..

Figure D.1 Balanced Latin Squares ………………………………………………..

Figure D.2 Questionnaire Email Screen ……………………………………………

Figure D.3 Layout of Questionnaire View …………………………………………

Figure D.4 Module Starter View………………………………………………….

Figure D.5 Sample Question ……………………………………………………..

Figure D.6 Question-Answer Identification on CA + Bubble …………………..

Figure D.7 CA + Bubble Questionnaire UI ……………………………………..

Figure D.8 Questions on CA + Bubble ………………………………………….

Figure D.9 Question-Answer Identification on VSUP + Bubble ……………….

Figure D.10 VSUP + Bubble Questionnaire UI …………………………………..

Figure D.11 Questions on VSUP + Bubble ……………………………………….

Figure D.12 Question-Answer Identification on CA + Grid ………………………

Figure D.13 CA + Grid Questionnaire UI …………………………………………

Figure D.14 Questions on CA + Grid ……………………………………………..

Figure D.15 Question-Answer Identification on VSUP + Grid …………………..

Figure D.16 VSUP + Grid Questionnaire UI ……………………………………..

Figure D.17 Questions on VSUP + Grid ………………………………………….

**List of Algorithms**

Algorithm 3.1 MLP Model …………………………………………………………

Algorithm 3.2 CNN Model …………………………………………………………

Algorithm 3.3 LSTM Model ………………………………………………………..

Algorithm 3.4 ARIMA Model ………………………………………………………

Algorithm 3.5 Calculate uncertainty ………………………………………………..

Algorithm 3.6 Data scaling ………………………………………………………….

Algorithm 4.1 CA Construction Formula ……………………………………………

Algorithm 4.2 Pattern Generation ……………………………………………………

Algorithm 4.3 Texture Generation …………………………………………………….