Warsaw University of Technology

FACULTY OF
MATHEMATICS AND INFORMATION SCIENCE

Bachelor's diploma thesis

in the field of study Computer Science and Information Systems

Thesis title

Author One

student record book number 123456

Author Two

student record book number 654321

thesis supervisor

title/degree Name Surname

consultation (optional)

academic title/degree Name and Surname

WARSAW 2022

Abstract

ENGLISH TITLE

Loremmmm ipsum dolor sit amet, consetetur sadipscing elitr, sed diam nonumyeirmod tempor invidunt ut labore et dolore magna aliquyam erat, sed diamvoluptua. At vero eos et accusam et justo duo dolores et ea rebum. Stet clita kasd gubergren, no sea takimata sanctus est Lorem ipsum dolor sit amet.

Lorem ipsum dolor sit amet, consetetur sadipscing elitr, sed diam nonumyeirmod tempor invidunt ut labore et dolore magna aliquyam erat, sed diamvoluptua. At vero eos et accusam et justo duo dolores et ea rebum. Stet clita kasd gubergren, no sea takimata sanctus est Lorem ipsum dolor sit amet.

Keywords: keyword1, keyword2, ...

Streszczenie

POLISH TITLE

Lorem ipsum dolor sit amet, consetetur sadipscing elitr, sed diam nonumyeirmod tempor invidunt ut labore et dolore magna aliquyam erat, sed diamvoluptua. At vero eos et accusam et justo duo dolores et ea rebum. Stet clita kasd gubergren, no sea takimata sanctus est Lorem ipsum dolor sit amet.

Lorem ipsum dolor sit amet, consetetur sadipscing elitr, sed diam nonumyeirmod tempor invidunt ut labore et dolore magna aliquyam erat, sed diamvoluptua. At vero eos et accusam et justo duo dolores et ea rebum. Stet clita kasd gubergren, no sea takimata sanctus est Lorem ipsum dolor sit amet.

Słowa kluczowe: slowo1, slowo2, ...

Contents

Introduction

What is the thesis about? What is the content of it? What is the Author's contribution to it?

WARNING! In a diploma thesis which is a team project: Description of the work division in the team, including the scope of each co-author's contribution to the practical part (Team Programming Project) and the descriptive part of the diploma thesis.

1. Foundations

1.1. Time series classification

Time series is an ordered collection of observations indexed by time.

$$X = (x_t)_{t \in T} = (x_1, ..., x_T),\ \ x_t \in R$$

The time index T can represent any collection with natural order. It can relate to point in time when the measurement was observed, or it can represent a point in space measured along X axis. We assume that indices are spaced evenly in the set T. The realisation or observation x_t in the times series is a numerical value describing the phenomena we observe, for example amplitude of a sound, stock price or y-coordinate. Time series classification is a problem of finding the optimal mapping between a set of time series and corresponding classes.

1.2. Transfer learning

2. Related works

In this chapter we would like to describe several algorithms used in time series classification. We will also recall theoretical definitions and distinctions used to describe transfer learning.

2.1. Dynamic Time Warping with k-Nearest Neighbour

The Dynamic Time Warping with k-Nearest Neighbour classifier uses a distance based algorithm with a specific distance measure. A DWT distance between time series X^1, X^2 of equal lengths is:

$$DTW(X^1, X^2) = \min\{\sum_{i=1}^{S} dist(x^1_{e_i}, x^2_{f_i}) : (e_i)_{i=1}^{S}, (f_i)_{i=1}^{S} \in 2^T\}$$

subject to:

- $e_1 = 1, f_1 = 1, e_S = N, f_S = N$
- $|e_{i+1} - e_i| \leq 1,\ |f_{i+1} - f_i| \leq 1$

The measure defined above, used in k-Nearest Neighbour classifier is often used as a benchmark classifier.

2.1.1. Multi Layer Perceptron

The Multi Layer Perceptron (MLP) is the first artificial neural network architecture proposed and can be used for time series classification task. The MLP network can be formally defined as a composition of *layer* functions. The output of the function is a vector that usually models the probability distribution over the set of classes.

$$MLP(X; \theta_1, \ldots, \theta_M, \beta_1, \ldots, \beta_M) = L_M(\ldots L_2(L_1(X; \theta_1, \beta_1); \theta_2, \beta_2); \theta_M, \beta_M)$$

Each layer $L_i : R^M \rightarrow R^N$ is a function that depends on the parameters $\theta \in r^{M \times N}, \beta in R^N$

$$L_i(X, ; \theta_i, \beta_i) = f_i(X\theta_i + \beta_i)$$

Function $f_i : R^N \to R^N$ is an arbitrary chosen non-linear function. The number of layers and dimensions of weights are also an arbitrary choice, except for the weights is last and first later. The weights is last and first later have to match the dimensionality of input time series (the length of time series) and number of classes.

The disadvantage of using Multi Layer Perceptrons for time series classification is that the input size is fixed. All time series is the training data must have the same length. In transfer learning, this means that if we want to reuse the source network (or a set of first layers from the network), the target dataset must consists of time series of the same length.

The MLP architecture fails at understanding the temporal dependencies. Each input values in the time series is treated separately, because it is multiplied by a separate row in the weight matrix.

2.2. Convolutional Neural Networks

Convolutional Neural Networks are widely used in image recognition. A convolution applied for a time series can be interpreted as sliding a filter over the time series. A convolutional layer is a set of functions called convolutions or filters. The filter is applied at a given point, taking into account values that surrounds the point.

In the first layer of convolutional neural networks used for univariate time series classification, the filter is one-dimensional. The output of the first for one time series layer has dimensions (length of time series - the length of the filter - 1, number of filters). Below we define the value of the output for filter i

$$y_{k,i} = f_i([\theta_1, \ldots, \theta_M] * [X_k, \ldots, X_{k+M-1}]$$

2.3. Example section

Definition 2.1 (Definition). A *definition* is a statement of the meaning of a term (a word, phrase, or other set of symbols).

2.3.1. Example subsection

It's the deepest deph of sectioning allowed by rector.

Definition 2.2 (Equation). In mathematics, an *equation* is a statement of an equality containing one or more variables.

Example 2.3. This is an example of an equation:

$$2 + 2 = 4. \tag{2.1}$$

Equation without a number:

$$2 + 2 = 4,$$

or:

$$2 + 2 = 4.$$

It is worthwhile to peruse other mathematical environments like *multline*, *align* and their versions with a star (, i.e. without numeration). The description of their use can be found at `https://texdoc.org/serve/amsldoc.pdf/0` starting from the end of the third page.

Equation (2.2) is false. References (and some other things) work properly after compliling TEX file twice.

$$\int_0^1 x\, dx = \frac{3}{2}. \tag{2.2}$$

Theorem 2.4 is a very interensting result.

Theorem 2.4 (Pythagoras' Theorem). Let c represent the length of the hypotenuse and a and b the lengths of the triangle's other two sides. Then:

$$a^2 + b^2 = c^2.$$

Proof. The proof has been presented in [1] and [2]. We can write then [1, 2]. □

Corollary 2.5. The use of the term *corollary*, rather than *proposition* or *theorem*, is intrinsically subjective.

Remark 2.6. You can find a rather comprehensive list of available symbols at `https://www3.nd.edu/~nmark/UsefulFacts/LaTeX_symbols.pdf`.

If you want to find a symbol by its shape, you can use the following site: `https://detexify.kirelabs.org/classify.html`.

Lemma 2.7 (Someone's Lemma). Ten lemat jest nie na temat.

Proof. Dowód przez indukcję. □

Table 2.1: Additional options

symbol	effect
`h`	Place the float here, i.e., approximately at the same point it occurs in the source text (however, not exactly at the spot)
`t`	Position at the top of the page
`b`	Position at the bottom of the page
`p`	Put on a special page for floats only
`!`	Override internal parameters LaTeX uses for determining "good" float positions
`H`	Places the float at precisely the location in the LaTeX code. Requires the float package,[1] i.e., `\usepackage{float}`. This is somewhat equivalent to !ht.

Lorem ipsum dolor sit amet, consetetur sadipscing elitr, sed diam nonumyeirmod tempor invidunt ut labore et dolore magna aliquyam erat, sed diamvoluptua. At vero eos et accusam et justo duo dolores et ea rebum. Stet clita kasd gubergren, no sea takimata sanctus est Lorem ipsum dolor sit amet.Lorem ipsum dolor sit amet, consetetur sadipscing elitr, sed diam nonumyeirmod tempor invidunt ut labore et dolore magna aliquyam erat, sed diamvoluptua. At vero eos et accusam et justo duo dolores et ea rebum. Stet clita kasd gubergren, no sea takimata sanctus est Lorem ipsum dolor sit amet.

2.4. Floats – tables and figures

Place labels after captions or you get the wrong labelling.

In Table 2.1 there are additional options for `table` and `figure` environments.

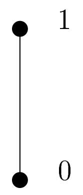

Figure 2.1: Example figure – it has been drawn by LaTeX default tools

Lorem ipsum dolor sit amet, consetetur sadipscing elit, sed diam nonumyeirmod tempor invidunt ut labore et dolore magna aliquyam erat, sed diamvoluptua. At vero eos et accusam et justo duo dolores et ea rebum. Stet clita kasd gubergren, no sea takimata sanctus est Lorem ipsum dolor sit amet.Lorem ipsum dolor sit amet, consetetur sadipscing elitr, sed diam nonumyeirmod tempor invidunt ut labore et dolore magna aliquyam erat, sed diamvoluptua. At vero eos et accusam et justo duo dolores et ea rebum. Stet clita kasd gubergren, no sea takimata sanctus est Lorem ipsum dolor sit amet.

3. The next chapter

Lorem ipsum dolor sit amet, consetetur sadipscing elit, sed diam nonumyeirmod tempor invidunt ut labore et dolore magna aliquyam erat, sed diamvoluptua. At vero eos et accusam et justo duo dolores et ea rebum. Stet clita kasd gubergren, no sea takimata sanctus est Lorem ipsum dolor sit amet.Lorem ipsum dolor sit amet, consetetur sadipscing elitr, sed diam nonumyeirmod tempor invidunt ut labore et dolore magna aliquyam erat, sed diamvoluptua. At vero eos et accusam et justo duo dolores et ea rebum. Stet clita kasd gubergren, no sea takimata sanctus est Lorem ipsum dolor sit amet.

3.1. Matrices

Simple matrix:

$$\begin{matrix} a & b & c & d \\ d & e & f & g \\ 1 & 1 & 1 & 1 \end{matrix}$$

Matrix with parentheses:

$$A = \begin{pmatrix} a & b & c & d \\ d & e & f & g \\ 1 & 1 & 1 & 1 \end{pmatrix}$$

Matrix with brackets:

$$\begin{bmatrix} a & b & c & d \\ d & e & f & g \\ 1 & 1 & 1 & 1 \end{bmatrix}$$

You can also use more general environment:

$$\begin{array}{ccc} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{array}$$

Matrix with braces:

$$\left\{\begin{matrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{matrix}\right\}$$

Definition 3.1. Let $A \neq \emptyset$, $n \in \mathbb{N}$. Every function $f\colon A^n \to A$ is called an *n-ary operation* or *działaniem* określonym na A. 0-ary operations are constant functions.

Definition 3.2 (Algebra). The ordered pair (A, F), where $A \neq \emptyset$ is a set and F is a family of operations defined on A, shall be called an *algebra* (or *F-algebra*). The set A is called *the set of elements*, *support* or *universe* of an algebra (A, F) and F is called *the set of elementary operations.*

Proposition 3.3. I state that, having passed to the limit, the only thing left me me is to camp at said limit or return, or, maybe, search for a pass or an exit to other areas.

Bibliography

[1] A. Author, *Title of a book*, Publisher, year, page–page.

[2] J. Bobkowski, S. Dobkowski, Title of an article, *Magazine X, No. 7*, year, PAGE–PAGE.

[3] C. Brink, Power structures, *Algebra Universalis 30(2)*, 1993, 177–216.

[4] F. Burris, H. P. Sankappanavar, *A Course of Universal Algebra*, Springer-Verlag, New York, 1981.

List of symbols and abbreviations

nzw.	nadzwyczajny
*	star operator
~	tilde

If you don't need it, delete it.

List of Figures

If you don't need it, delete it.

Spis tabel

If you don't need it, delete it.

List of appendices

1. Appendix 1
2. Appendix 2
3. In case of no appendices, delete this part.