

ARIEL UNIVERSITY OF SAMARIA

MASTERS THESIS

Multidimensional Interpolated Discretized for Objects and Object Pairs Embedding

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*A thesis submitted in fulfillment of the requirements
for the degree of Master of Science*

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electrical engineering

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Declaration of Authorship

I, Yakir BEN-ALIZ, declare that this thesis titled, “Multidimensional Interpolated Discretized for Objects and Object Pairs Embedding” and the work presented in it are my own. I confirm that:

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- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
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“Thanks to my solid academic training, today I can write hundreds of words on virtually any topic without possessing a shred of information, which is how I got a good job in journalism.”

Dave Barry

ARIEL UNIVERSITY OF SAMARIA

Abstract

Faculty of Engineering
electrical engineering

Master of Science

Multidimensional Interpolated Discretized for Objects and Object Pairs Embedding

by Yakir BEN-ALIZ

Distance functions are at the core of numerous scientific areas. One can choose a distance function based on prior knowledge or learn it from data, metric learning. The most commonly used and learned distance function is the Euclidean distance. In metric learning, most of the works learn a Mahalanobis distance. These methods [1-12] learn a linear transform that is applied on the vector and then apply the squared Euclidean distance (thus these methods are actually semimetric learning). Kernel metric learning applies embedding separably on each vector before learning the linear transform. Deep learning methods [13] learn an embedding using a deep network and then apply the Euclidean distance on the embedded vectors (the output of the network). Thus, even kernel and deep metric learning can only learn a Euclidean distance. Some works [14, 15, 16, 17] have suggested learning other families of distances. However, these methods are restricted to the suggested pre-chosen families of distances (e.g. Earth Mover's Distance and χ). Finally, multi-metric learning methods [1, 18] learn separate local Mahalanobis metrics around keypoints. However, they do not learn a global metric. An exception is [19] which shows how to combine information from several local metrics into one global metric. However, again it is only able to model Euclidean metrics.

We propose a new embedding method for a single vector and for a pair of vectors. This embedding method enables:

- efficient classification and regression of functions of single vectors
- efficient approximation of distance functions
- general, non-Euclidean, semimetric learning

To the best of our prior knowledge, this is the first work that enables learning any general, non-Euclidean, semimetrics. That is, our method is a universal semimetric learning and approximation method that can approximate any distance function with as high accuracy and/or without semimetric constraints. The main difference between our model and previous models is that our model embeds object pairs jointly and not separably. Distance between objects is the embedded vector dot product with a learned parameters vector. Thus, most of the learning objectives are convex in our model. Additionally, we can enforce constraints on the vector of parameters such that the resulting distance will be a continuous semimetric. This work enables learning and approximation of arbitrary distance functions or arbitrary semimetrics.

Acknowledgements

The acknowledgments and the people to thank go here, don't forget to include your project advisor...

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List of Abbreviations

ID	Interpolized Discretized
NDIDD	n-Dimension Interpolized Discretized Distance
BCC	Bary centric coordinates

Physical Constants

Speed of Light $c_0 = 2.997\,924\,58 \times 10^8 \text{ m s}^{-1}$ (exact)

List of Symbols

a	distance	m
P	power	W (J s ⁻¹)
ω	angular frequency	rad

/Dedicated to/To my...

Chapter 1

Introduction

Distance functions are at the core of numerous scientific areas, such as classification, regression, clustering challenges etc. it can be based either on strict, constant formulation, such as norms[] (such as L_2 norm, representing the euclidean distance []), or can be learned from datasets - metric learning.

In metric learning, most of the works learn a Mahalanobis distance. These methods [1-12] learn a linear transformation that is applied on the vector and then apply the squared Euclidean distance (thus these methods are actually semimetric learning). Kernel metric learning applies embedding separably on each vector before learning the linear transformation. Deep learning methods [13] learn an embedding using a deep network and then apply the Euclidean distance on the embedded vectors (the output of the network). Thus, even kernel and deep metric learning can only learn a Euclidean distance. Some works [14, 15, 16, 17] have suggested learning other families of distances. However, these methods are restricted to the suggested pre-chosen families of distances (e.g. Earth Mover's Distance and χ). Finally, multi-metric learning methods [1, 18] learn separate local Mahalanobis metrics around keypoints. However, they do not learn a global metric. An exception is [19] which shows how to combine information from several local metrics into one global metric. However, again it is only able to model Euclidean metrics.

Our work is handling the following use case: let us say there is a given dataset, which does not own any euclidean properties, and cannot be embedded separately in order to perform various classification tasks. Ofir's work [] treats this particular matter, by interpolating and embedding pairs of data as a unified objects, by performing bin to bin semi-metric pairing.

We propose a new embedding method for a single vector and for a pair of vectors. This embedding method enables:

- efficient classification and regression of functions of single vectors
- efficient approximation of distance functions
- general, non-Euclidean, semimetric learning

Bin to bin comparison between pairs of data samples is beneficial when the data is not dimensionally correlated, and has no relations between one dimension in the first vector, to another. For example, when performing SIFT analysis to compare between two images for pattern recognition, there might be relations between one element to its own neighbors, but also to its paired - candidate neighbor. For this and other purposes we may consider a cross-bin comparison method.

Let us now address describing the theories behind our method.

1.1 Metrics

1.1.1 Definition

Metric space is a set for which distances between all members of the set are defined. Distances applied on every pair of objects on a given set called **metric**. A metric d is defined as:

$$d : q_1 \times q_2 \rightarrow \mathbb{R} \quad (1.1)$$

where q_i are objects in a given set

1.1.2 Metrics Properties

Any metrics must obey the following properties:

1.1.2.1 Non-negativity

any metric on a pair of objects must be non-negative

$$d(q_1, q_2) \geq 0 \quad (1.2)$$

1.1.2.2 Identity of Indiscernibles

$$d(q_1, q_2) = 0 \iff q_1 = q_2 \quad (1.3)$$

for every pair of objects q_1, q_2 , d metric function provides zero if and only if those objects are identical. Identity of indiscernibles is an ontological principle that states there cannot be separate objects or entities that have all their properties in common.

1.1.2.3 Symmetry

$$d(q_1, q_2) = d(q_2, q_1) \quad (1.4)$$

A symmetric function of a pair of objects is one whose value at any pair of objects is the same as its value at any permutation of that pair.

1.1.2.4 Sub-additivity (Triangle Inequality)

$$d(q_1, q_3) \leq d(q_1, q_2) + d(q_2, q_3) \quad (1.5)$$

Evaluating the function for the sum of two elements of the domain always returns something less than or equal to the sum of the function's values at each element.

There are two useful generalizations for metric definition:

1.1.3 Semi-metrics

Semi metric is a generalization of the metric definition, which basically excludes 1.1.2.4, and remains the rest.

1.1.4 Pseudo-metrics

Pseudometrics supports all metrics properties except the identity of indiscernibles property 1.1.2.2, which is modified as follows:

$$q_1 = q_2 \Rightarrow d(q_1, q_2) = 0 \quad (1.6)$$

1.2 Metric Learning

Metric learning study refers to learning a distance function from data objects, while still applying the basic properties of metrics.

Most of the works learn a Mahalanobis distance[]. These methods [1-12] learn a linear transform that is applied on the vector and then apply the squared Euclidean distance (thus these methods are actually semimetric learning).

Kernel metric learning applies embedding separably on each vector before learning the linear transform.

Deep learning methods such [13] learn an embedding using a deep network and then apply the Euclidean (or any known) distance on the embedded vectors (the output of the network). Thus, even kernel and deep metric learning can only learn a Euclidean distance. Some works [14-17] have suggested learning other families of distances. However, these methods are restricted to the suggested pre-chosen families of distances (e.g. Earth Mover's Distance[] and χ^2 []).

Finally, multi-metric learning methods [1, 18] learn separate local Mahalanobis metrics around keypoints. However, they do not learn a global metric. An exception is [19] which shows how to combine information from several local metrics into one global metric. However, again it is only able to model Euclidean metrics.

1.3 Bin-to-Bin & Cross-Bin Metrics

Bin-to-Bin distance functions such as L_2, L_1 and χ^2 compare only corresponding bin's of a vector to its exact corresponding bin in the second vector. The assumption when using these distances is that the histogram domains are aligned. However this assumption is violated in many cases due to quantization, shape deformation, light changes, etc. Bin-to-bin distances depend on the number of bins. If it is low, the distance is robust, but not discriminative, if it is high, the distance is discriminative, but not robust. Distances that take into account cross-bin relationships (cross-bin distances) can be both robust and discriminative.

1.4 Mahalanobis Distance

Let $A \in \Re^{N \times N}$ be a bin-similarity matrix, so that a_{ij} encodes how much bin i is similar to bin j .

The Quadratic-Form (QF) distance [21] is defined as :

$$QF^A(P, Q) = \sqrt{(P - Q)^T \times A(P - Q)} \quad (1.7)$$

Where the bin-similarity matrix A is the inverse of the covariance matrix, the QF distance is called the Mahalanobis distance [22]. If the bin-similarity matrix is positive-semidefinite (PSD), A matrix can be expressed as $A = LL^T$ for some real matrix L . Thus, the distance can be computed as the Euclidean norm between linearly transformed vectors:

$$QF^A(P, Q) = \|LP - LQ\|_2 \quad (1.8)$$

In this case the QF distance is a **psuedo-metric**

1.5 Related Work

Our method builds in a novel direction on the success of previous metric learning approaches. As Weinberger and Saul [1] conjectured, more adaptive transformations of the input space can lead to improved performance. Our method allows to enlarge the number of the learned parameters, while the computation of the distance between two never-seen examples is only linear in the dimension.

Chopra et al. [3] proposed to learn a convolutional neural net as a non-linear transformation before applying the 2 norm. They showed excellent results on image data. Babenko et al. [12] suggested a boosting framework for learning non-Mahalanobis metrics. They also presented excellent results on image data. These methods are non-convex and thus they might suffer from local minimas and training is sensitive to parameters.

Kernel methods were also proposed in order to learn a Mahalanobis distance over non-linear transformations of the data [1, 7, 9]. Computing such a distance between two vectors scales linear in the number of training examples, which makes it impractical for large datasets. Computing our ID distances does not depend on the number of training examples.

A family of non-Mahalanobis distances recently proposed is the Quadratic-Chi (QC) [15]. The QC family generalizes both the Mahalanobis distance and the ℓ_2 distance. A QC distance have parameters that can be learned. However, a serious limitation is that it can only model ℓ_2 -like distances. In addition, it is applicable only to non-negative vectors. Finally, it is non-convex with respect to its parameters, so learning them is hard.

Rosales and Fung [5] also propose learning metrics via linear programming. However, while we learn a non-Mahalanobis distance, their method learns a subfamily of Mahalanobis distance. That is, their method is restricted to learning a Mahalanobis distance which is parameterized with a diagonal dominant matrix.

Danfeng et al. [3] displays a Quantized Kernels metrics learning methods concludes additive and block-wise kernels learning. Our method refers to any multi-dimensional distance learning problem, not only blocks of objects (such as SIFT descriptor maps around any interest point of an image)

1.6 Contribution

In this novel work, we present an efficient method for embedding either single object or pairs of objects. This method applies a semi-metric learning for a given data space. This method is a generalization of the single-dimensional Interpolated-Discretized (ID) distance, presented by Dr. Ofir Pele[]. In this work we embed pairs of objects jointly, which for our best of knowledge is the debut embedding method for such purpose. In this work a novel attitude for upgrading IDD embedding procedure to n-dimensional IDD, while maintaining its basic semi-metric, non-euclidean properties, and also contributes the ability of applying “physical” constraints during the embedding process to maintain our method continuous and linearly computed.

Chapter 2

ID Embedding

We now describe the general embedding process for both single objects and object pairs. This is the core process applied on several tasks in our work, such classification, regression, pairs matching etc. Our embedding method is assembled from three main phases:

- Discretization
- Interpolation
- Assigning

let us describe each part in the ID sequence:

2.1 Discretization

Discretization phase is performed in order to downgrade complexity of a given machine/metric learning problem. Let us assume we have a very high ordered vectors to classify, for example a 1G ordered vectors dataset $\vec{v} \in \mathbb{R}^{10^9}$ would cause struggled learning process due to high memory resources required.

For that reason we downscale problems' dimensions by discretizing the dataset in the following **dimension-wise** method: Each dimension in dataset is clustered and sorted into C_i - dimensional $\vec{v} \in \mathbb{R}^{C_i}$ vector.

Any common clustering method may benefit in this, with one exception: The extremum points of the sorted discretized vector must surround the extremum values of the dataset.

2.2 Interpolation

As described above, our IDD function should delivers continuous output for any given valid object/pair of objects. For this purpose we perform interpolation of the given data sample features, where each element among data sample is interpolated by its closest boundaries in the proper discretization vector space. By the following algorithm:

1. For each element find closest bounds among discretization vector
2. Compute coefficients - this will be described further for every scenario, where this phase is actually performs a multidimensional interpolation

2.3 Assigning

This phase assigns the coefficients computed in the last phase, in their proper locations among the embedded (sparsed) vector.

In the following sections we describe specifically each nuance of each sub-domain of the method. Please notice that the most detailed sub-method in this work is the multidimensional IDD pairs embedding, since it is the most innovative section in this work in our opinion.

Algorithm 1 Embedding Method - General

Input: L sized, vectorized n -dimensional dataset

Input: number of centers per dimension - C

Output: $\vec{\phi}$: L sized set, embedded, sparse vectors

Find centers vectors

V shall be a set of centers vectors

for all dim in n **do**

$V_{dim} \leftarrow centers \text{ vector per } dim$

end for

Find embedded coefficients for all dataset

$\vec{\phi} = C^n$ length empty $\vec{\phi}$ embedded vectors

for all vec in L **do**

find vec bounding hypercube

find vec bounding simplex (permutation method)

$\vec{\lambda} \leftarrow$ find vec barycentric coefficients

$\hat{\lambda} \leftarrow$ normalize($\vec{\lambda}$)

end for

Assign

for all \vec{vec} in $emb - set$ **do**

$inds \leftarrow$ find vertices from hypercube and simplex locations

for all i in $inds$ **do**

$\vec{vec}(i) \leftarrow \hat{\lambda}(j(i)) - j$ is the assigning function between the coef. vector and embedding vector

end for

end for

return $\vec{\phi}$

Chapter 3

Interpolated Discretized object pairs embedding

We now describe the Interpolated Discretized Distances (IDD) embedding method. As mentioned above, this method uniqueness is applying an embedding method that treats each pair as a **joint** object in its problem. This method may fit any two-objects task such similarity/matching problems etc. Let us initiate by presenting the original single dimensional (IDD-1D) work[], then the expansion of this work into multidimensional (IDD-ND) scenario - general distance embedding is described.

3.1 1D case

Our method's objective is to find an embedding function such:

$$ID : \mathbb{R}^n \times \mathbb{R}^m \rightarrow \mathbb{R}^d \quad (3.1)$$

, which applies the following distance function by multiplying with a learned weights vector \vec{w} (learned vector)

$$d(\vec{x}_1, \vec{x}_2) = ID(\vec{x}_1, \vec{x}_2) \times \vec{w} \quad (3.2)$$

this embedding shall obtain semimetric constraints applied.

$$W = \begin{pmatrix} c_{1(1)} & \dots & \dots & \dots & c_{1(n)} \\ c_{2(1)} \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ c_{2(m)} \end{pmatrix} \begin{pmatrix} s_{1,1} & \dots & \dots & \dots & s_{1,m} \\ \vdots & \ddots & & & \vdots \\ \vdots & & \ddots & & \vdots \\ \vdots & & & \ddots & \vdots \\ \vdots & & & & \ddots & \vdots \\ s_{n,1} & \dots & \dots & \dots & s_{n,m} \end{pmatrix}$$

FIGURE 3.1: discretization matrix W as built from 2 vectors c_1, c_2 . this matrix is 2D as it is an outcome of 2 - 1D vectors discretization processes

3.1.1 Discretization

as described in 2 1D-IDD describes bin-to-bin distance between two samples from single dimensional spaces. Each dimension is clustered and sorted into C_i - dimensional: $\vec{c} \in \mathbb{R}^{C_i}$ vector. The vector's pair defines the shape of a distance matrix $W \in \mathbb{R}^{C_i \times C_j}$, where each element $W_{i,j}$ describes the distance between two cluster centers form vectors - v_a, v_b

3.1.2 Interpolation

As described above, our *IDD* function provides continuous output for any given valid object/pair of objects. For this purpose we perform interpolation of the given data sample features within the W matrix space for each data sample by the following process:

- extract the closest vertices from W matrix to the feature sample.
- calculate four (2 per feature) coefficients per sample, each represented by the normalized surface of the opposite triangle to a vertex (1D coefficients calculation will be described in section).
- 1D-IDD is computed by applying inner product between the sparse coefficient vector and their corresponding vertices vector:

$$1DIDD = \sum_{t=1}^3 \alpha_{a(t),b(t)} \times W_{a(t),b(t)} \quad (3.3)$$

where:

α is the coefficients sparse vector, representing the interpolation result per feature vector a, b are parametrization function for both α, W
 t is the scanning index for all arguments among this expression

Please notice that there are only 4 elements different than zero at α , so this expression represents the non-zero elements only provides value to 1DIDD expression

a, b parameterizations are described as:

- $$a_{(1)} = a_{(2)} = \operatorname{argmax}_{(c_i)} \{v_{c_i} \leq x_i\} \quad (3.4)$$

- $$a_{(3)} = a_{(4)} = \operatorname{argmin}_{(c_i)} \{v_{c_i} \geq x_i\} \quad (3.5)$$

- $$b_{(1)} = b_{(3)} = \operatorname{argmax}_{(c_j)} \{v_{c_j} \leq x_j\} \quad (3.6)$$

- $$b_{(2)} = b_{(4)} = \operatorname{argmin}_{(c_j)} \{v_{c_j} \geq x_j\} \quad (3.7)$$

3.1.2.1 Interpolation Coefficients extraction - 1D

Let us describe how does coefficients vectors are calculated from a data sample (assembled from a pair of samples) and a discretization matrix.

For a given data pair, bounding square (2D-cube) is assembled from the clusters vectors per feature. this square is divided into 2 triangles (simplices) along its main diagonal, as described in figure ??.

The containing triangle of the data sample is divided to 3 sub-triangles by applying direct lines between the data sample and each vertex of the relevant triangle. Each sub-triangle relative surface represents the coefficient of the opposite vertex ??.

In the 1D case, there would be just 3 non-zero elements in the ID coef. vector, since there are 3 affecting sub-triangles (the forth vertex of the cell is zeroed like any other vertex in the output ID vector) .

Single dimensional formation *IDD* applies semi-metrics properties as described back in 1

3.1.3 Assigning

Now that we have ID coefficients (sparse) vector, we may assign it to the ID output vector shape. ID output vector is sized by the flatten vector of the discretization matrix W , which may be flatten row-wise/column-wise. Each vertex in the output vector receives the value calculated for its equivalent index at the opposite triangles surfaces phase.

3.2 multidimensional case

We now address describing the generalization of the single dimension IDD method to n-dimensional object pairs embedding.

For this we should adapt a different embedding attitude, since it should obtain multi-dimensional embedding, unlike the triangles relative surfaces process performed in the 1d scenario.

The selected coefficients calculation process for our embedding is the Barycentric (center of mass) Coordinates [] of a given vector in a $2n$ dimensional space ($2n$ since we embed pairs of objects for distance/similarity calculation).

3.2.1 Definition

The general expression of *NDIDD* would appear to be:

$$NDIDD = \sum_{t=1}^{2n!} \alpha_{a(t),b(t)} \times W_{a(t),b(t)} \quad (3.8)$$

In this scenario, a, b are the multi-dimensional parametrization functions, which correlates between the coefficients vector and the learned weights vector.

3.2.2 Discretization

Given a n-dimensional vectors dataset, we first discrete the data range/space of each dimension, into C discretization values. C may vary among dimensions. This step is equivalent to the 1D scenario. At the 1D scenario, a 2D matrix was generated, which represents the distance between a pair of elements.

Now we address the n -dimensional scenario, by obtaining a $2n$ dimensional tensor, representing the distance between a pair of n dimensional vectors.

3.2.3 Interpolation

Next phase is interpolating every dataset sample, or any tested sample, in order to embed it using our method.

let us assign a pair of n -dimensional vectors $x_1, x_2 \in \mathbb{R}^n$.

NDIDD embedding handles this pair as a **joint $2n$ dimensional vector**, flatten in the following order:

$$\vec{p} = [x_1^1, x_2^1, \dots, x_1^n, x_2^n], \quad \vec{p} \in \mathbb{R}^{2n} \quad (3.9)$$

for the further process description we will treat \vec{p} as our data object

3.2.3.1 find bounding hypercube

First, we place the sampled vector \vec{p} within its bounding $2n$ -hypercube, same as performed in the single dimensional scenario 3.1.2.

3.2.3.2 find bounding simplex

Next stage is discover the simplex (equivalent to triangle in 1d scenario) containing point \vec{p} . A $2n$ -dimensional hypercube is assembled from $(2n)!$ vertices. Assuming the vertices values are normalized to a “unit hypercube” - containing only 0/1 values in elements, any vertex applies a permutation as follows:

$$0 \leq p_{t(1)} \leq p_{t(1)} \leq \dots \leq p_{t(2n-1)} \leq p_{t(2n)} \leq 1 \quad (3.10)$$

<http://www.mathpages.com/home/kmath664/kmath664.htm>

where:

$t_{(i)}$ is a permutation function.

so how we select the right simplex (and permutation) for a given point p ? Each point \vec{p} obeys a unique permutation. A certain permutation defines the right simplex vertices. For each set of correct vertices that obeys a certain permutation, the extreme vertices, all zeros/all ones values, always included in the right vertices account.

3.2.3.3 calculate sub-volumes of all simplices involved

Next phase is calculating the relative volumes (equivalent to 1 dimensional relative surfaces) of all sub simplices.

Given a simplex assembled from $T = 2n + 1$ set of vertices, which bounds a point \vec{p} , we calculate the volumes of T sub-simplices, so every simplex is assembled from $T - 1$ vertices plus \vec{p} .

These normalized volumes represents the coefficients of the missing (or counter in the T space) vertex.

3.2.3.4 Simplex Volume Calculation

Given $T = 2n + 1$ simplices of $N = 2n$ dimension, a general expression for the volume contained between its vertices would be:

$$V_{[r^1, r^2, r^3, \dots, r^T]} = \frac{1}{(2n)!} \times \begin{vmatrix} 1 & r_1^1 & r_2^1 & \dots & r_{2n}^1 \\ 1 & r_1^2 & \ddots & \ddots & r_{2n}^2 \\ \vdots & \ddots & \ddots & \ddots & \vdots \\ \vdots & \ddots & \ddots & \ddots & \vdots \\ 1 & r_1^T & \dots & \dots & r_{2n}^T \end{vmatrix} \quad (3.11)$$

We calculate the volume for every vertex in the simplex as follows: Given a point \vec{p} and a set of vertices $r^1, r^2, r^3, \dots, r^T$, the volume correspond to every vertex r^i is:

$$\lambda_i = V_{[r^1, r^2, p, \dots, r^T]} = \frac{1}{(2n)!} \times \begin{vmatrix} 1 & r_1^1 & r_2^1 & \dots & r_{2n}^1 \\ 1 & r_1^2 & \ddots & \ddots & r_{2n}^2 \\ \vdots & p_1 & p_2 & \ddots & p_{2n} \\ \vdots & \ddots & \ddots & \ddots & \vdots \\ 1 & r_1^T & \dots & \dots & r_{2n}^T \end{vmatrix} \quad (3.12)$$

3.2.3.5 Efficient method - calculating Barycentric Coordinates (BCC)

A more efficient way (time complexity $O(n)$) providing the coefficients to a given point is by using barycentric coordinates of a point \vec{p} . Given a point $\vec{p} \in \mathbb{R}^{2n}$, the following formulation applies under the assumption the hypercube bounding the point is mapped to a unit hypercube, the bounding simplex of the point may be:

$$\begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \\ 1 \end{bmatrix}, \dots, \begin{bmatrix} 0 \\ 1 \\ \vdots \\ 1 \\ 1 \end{bmatrix}, \begin{bmatrix} 1 \\ 1 \\ \vdots \\ 1 \\ 1 \end{bmatrix}$$

so the equation we shall use is this:

$$\begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \\ 0 \end{bmatrix} \lambda_0 + \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \\ 1 \end{bmatrix} \lambda_1 + \dots + \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \\ 0 \end{bmatrix} \lambda_{2n-1} + \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \\ 0 \end{bmatrix} \lambda_{2n} = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \\ 0 \end{bmatrix}, \quad \sum_{i=0}^{2n} \lambda_i = 1 \quad (3.13)$$

notice that number of both vertices and barycentric coordinates are $T = 2n + 1$.

3.2.3.6 $O(n)$ solution

We solve this equation by using the gradation of the vertices along the left side of the equation.

Let $i = 2n, \dots, 2, 1$. The recursive formulation for the solution of the equation would be the follows:

$$\lambda_i = p_{2n-i+1} - \sum_{j=i+1}^{2n} \lambda_j \quad (3.14)$$

and the remained coefficient extracted from the final step:

$$\lambda_0 = 1 - \sum_{j=1}^{2n} \lambda_j \quad (3.15)$$

3.2.3.7 Methods identity for n=2

Let us demonstrate the identity of BCC calculation methods for $n = 2$ dimensions:

3.2.3.8 Volumes method

let our sample be $\vec{p} = [p_1, p_2, p_3, p_4]$, and let us assume permutation:

$$p_1 \leq p_2 \leq p_3 \leq p_4.$$

the vertices obeys to the given permutation are:

- $r_0 = [0, 0, 0, 0]$
- $r_1 = [0, 0, 0, 1]$
- $r_2 = [0, 0, 1, 1]$
- $r_3 = [0, 1, 1, 1]$
- $r_4 = [1, 1, 1, 1]$

We begin with λ_4 calculation, since it is straightforward from matrix's gradation

$$\lambda_4 = V_{[r^0, r^1, r^2, r^3, p]} = \begin{vmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 1 & 1 \\ 1 & 0 & 1 & 1 & 1 \\ 1 & p_1 & p_2 & p_3 & p_4 \end{vmatrix} = p_1 \quad (3.16)$$

for λ_3 we use the proceed the algorithm:

$$\lambda_3 = V_{[r^0, r^1, r^2, p, r^4]} = \begin{vmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 1 & 1 \\ 1 & p_1 & p_2 & p_3 & p_4 \\ 1 & 0 & 1 & 1 & 1 \end{vmatrix} = p_2 - p_1 = p_2 - \lambda_4 \quad (3.17)$$

λ_2 :

$$\lambda_2 = V_{[r^0, r^1, p, r^3, r^4]} = \begin{vmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 \\ 1 & p_1 & p_2 & p_3 & p_4 \\ 1 & 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 & 1 \end{vmatrix} = p_3 - p_2 = p_3 - (\lambda_3 + \lambda_4) \quad (3.18)$$

λ_1 :

$$\begin{aligned} \lambda_1 &= V_{[r^0, p, r^2, r^3, r^4]} = \begin{vmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & p_1 & p_2 & p_3 & p_4 \\ 1 & 0 & 0 & 1 & 1 \\ 1 & 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 & 1 \end{vmatrix} \\ &= p_1 \cdot \begin{vmatrix} 0 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{vmatrix} - p_2 \cdot \begin{vmatrix} 0 & 1 & 1 \\ 0 & 1 & 1 \\ 1 & 1 & 1 \end{vmatrix} + p_3 \cdot \begin{vmatrix} 0 & 0 & 1 \\ 0 & 1 & 1 \\ 1 & 1 & 1 \end{vmatrix} - p_4 \cdot \begin{vmatrix} 0 & 0 & 1 \\ 0 & 1 & 1 \\ 1 & 1 & 1 \end{vmatrix} \\ &= p_4 - p_3 = p_4 - (\lambda_2 + \lambda_3 + \lambda_4) \end{aligned}$$

(3.19)

for λ_0 we apply the final step expression:

$$\begin{aligned} \lambda_0 &= V_{[p, r^1, r^2, r^3, r^4]} = \begin{vmatrix} 1 & p_1 & p_2 & p_3 & p_4 \\ 1 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 1 & 1 \\ 1 & 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 & 1 \end{vmatrix} \\ &= 1 - p_1 \cdot \begin{vmatrix} 1 & 0 & 0 & 1 \\ 1 & 0 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{vmatrix} + p_2 \cdot \begin{vmatrix} 1 & 0 & 0 & 1 \\ 1 & 0 & 1 & 1 \\ 1 & 0 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{vmatrix} - p_3 \cdot \begin{vmatrix} 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 1 \\ 1 & 0 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{vmatrix} + p_4 \cdot \begin{vmatrix} 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 1 \\ 1 & 0 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{vmatrix} \\ &= 1 - p_4 - p_3 = 1 - (\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4) \end{aligned}$$

(3.20)

final coefficient vector produced by volumes method would be:

vectors dimension[n]	vertices [(2n)!]	simplex vertices [2n+1]	simplices
1	4 (exceptional private case)	3	2
2	24	5	4
3	720	7	6
4	40320	9	8
n	(2n)!	2n+1	2n

TABLE 3.1: higher dimensions' number of simplices and vertices

$$\begin{bmatrix} \lambda_0 \\ \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \lambda_4 \end{bmatrix} = \begin{bmatrix} 1 - (\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4) \\ p_4 - (\lambda_2 + \lambda_3 + \lambda_4) \\ p_3 - (\lambda_3 + \lambda_4) \\ p_2 - \lambda_4 \\ p_1 \end{bmatrix} \quad (3.21)$$

3.2.3.9 Recursive method

based on the formulation developed above 3.14, we extract the now extract the λ coefficients:

$$\lambda_4 = p_1$$

$$\lambda_3 = p_2 - \lambda_4$$

$$\lambda_2 = p_3 - \lambda_3 - \lambda_4$$

$$\lambda_1 = p_4 - \lambda_2 - \lambda_3 - \lambda_4$$

and for λ_0 simply apply the final step which provides **identical** result to the volume method:

$$\lambda_0 = 1 - \lambda_1 - \lambda_2 - \lambda_3 - \lambda_4$$

3.2.4 Assigning

After calculating coefficients vector for $2n + 1$ related vertices (from bounding simplex) of a data sample p , we now address embedding those coefficients into a single, flatten, sparse vector $\alpha \in c^{2n}$, where c is the number of means per dimension, and n is the dimension of a single object from an object pair.

The only non-zero values in the embedded vector would be the ones related to the bounding simplex of the sample \vec{p} .

–insert figure Fig - embedding from matrix to sparse vector

The embedding process could be easily generalized if c is vectorized to values - set, then the dimension of α would be:

$\prod_{i=1}^{2n} c_i$, which equivalent to the number of vertices in the “discretized” space of the problem. In order to finally receive a distance/similarity/dissimilarity function, we apply inner product between α vector and a learned weights vector (equivalent to the W matrix from the 1D scenario).

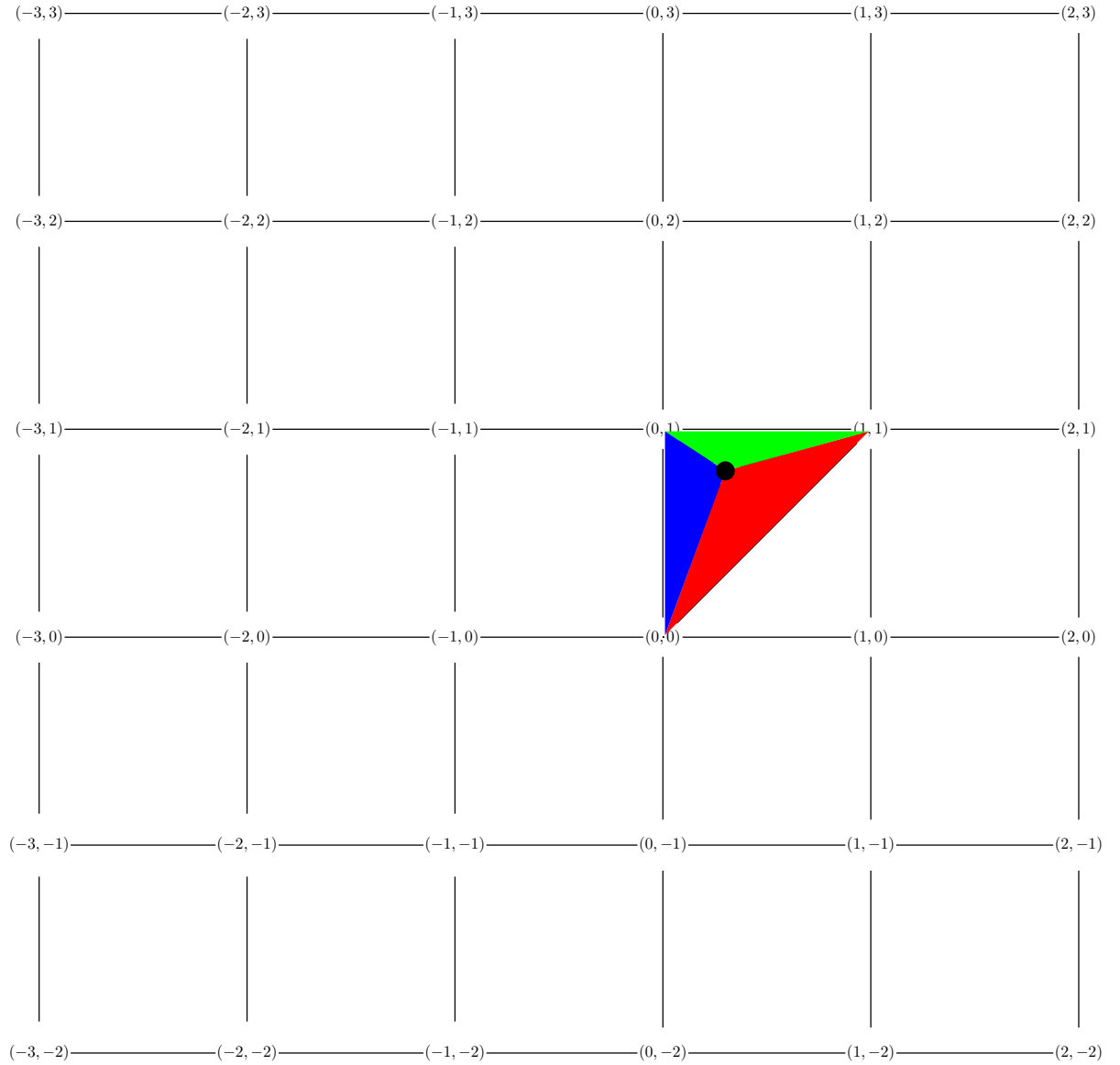


FIGURE 3.2: this matrix scheme describes a given data sample coefficients calculation according to its containing hypercube and simplex. The examined data sample is $(0.3, 0.8)$, so its containing hypercube would be the cell between $[0, 1]$. In this hypercube we search the containing simplex (triangle in 1D case), which occurs to be the upper triangle among the 2 main diagonal triangles. By assembling 3 sub-triangles using the data sample and the vertices we may extract the proper coefficients for the ID vector. Each normalized sub-triangle surface represents the contrary vertex's coefficients. For example the blue triangle surface represents the $(1, 1)$ vertex's coefficient

Chapter 4

Interpolated Discretized Single objects Embedding

4.1 Welcome and Thank You

Welcome to this L^AT_EX Thesis Template, a beautiful and easy to use template for writing a thesis using the L^AT_EX typesetting system.

If you are writing a thesis (or will be in the future) and its subject is technical or mathematical (though it doesn't have to be), then creating it in L^AT_EX is highly recommended as a way to make sure you can just get down to the essential writing without having to worry over formatting or wasting time arguing with your word processor.

L^AT_EX is easily able to professionally typeset documents that run to hundreds or thousands of pages long. With simple mark-up commands, it automatically sets out the table of contents, margins, page headers and footers and keeps the formatting consistent and beautiful. One of its main strengths is the way it can easily typeset mathematics, even *heavy* mathematics. Even if those equations are the most horribly twisted and most difficult mathematical problems that can only be solved on a super-computer, you can at least count on L^AT_EX to make them look stunning.

4.2 Learning algebra ··· ψ

L^AT_EX is not a WYSIWYG (What You See is What You Get) program, unlike word processors such as Microsoft Word or Apple's Pages. Instead, a document written for L^AT_EX is actually a simple, plain text file that contains *no formatting*. You tell L^AT_EX how you want the formatting in the finished document by writing in simple commands amongst the text, for example, if I want to use *italic text for emphasis*, I write the `\emph{text}` command and put the text I want in italics in between the curly braces. This means that L^AT_EX is a "mark-up" language, very much like HTML.

4.2.1 A (not so short) Introduction to L^AT_EX_d

If you are new to L^AT_EX, there is a very good eBook – freely available online as a PDF file – called, "The Not So Short Introduction to L^AT_EX". The book's title is typically shortened to just *lshort*. You can download the latest version (as it is occasionally updated) from here: <http://www.ctan.org/tex-archive/info/lshort/english/lshort.pdf>

It is also available in several other languages. Find yours from the list on this page: <http://www.ctan.org/tex-archive/info/lshort/>

It is recommended to take a little time out to learn how to use \LaTeX by creating several, small ‘test’ documents, or having a close look at several templates on:

<http://www.LaTeXTemplates.com>

Making the effort now means you’re not stuck learning the system when what you *really* need to be doing is writing your thesis.

4.2.2 A Short Math Guide for \LaTeX

If you are writing a technical or mathematical thesis, then you may want to read the document by the AMS (American Mathematical Society) called, “A Short Math Guide for \LaTeX ”. It can be found online here: <http://www.ams.org/tex/amslatex.html> under the “Additional Documentation” section towards the bottom of the page.

4.2.3 Common \LaTeX Math Symbols

There are a multitude of mathematical symbols available for \LaTeX and it would take a great effort to learn the commands for them all. The most common ones you are likely to use are shown on this page: <http://www.sunilpatel.co.uk/latex-type/latex-math-symbols/>

You can use this page as a reference or crib sheet, the symbols are rendered as large, high quality images so you can quickly find the \LaTeX command for the symbol you need.

4.2.4 \LaTeX on a Mac

The \LaTeX distribution is available for many systems including Windows, Linux and Mac OS X. The package for OS X is called MacTeX and it contains all the applications you need – bundled together and pre-customized – for a fully working \LaTeX environment and work flow.

MacTeX includes a custom dedicated \LaTeX editor called TeXShop for writing your ‘.tex’ files and BibDesk: a program to manage your references and create your bibliography section just as easily as managing songs and creating playlists in iTunes.

4.3 Getting Started with this Template

If you are familiar with \LaTeX , then you should explore the directory structure of the template and then proceed to place your own information into the *THESIS INFORMATION* block of the `main.tex` file. You can then modify the rest of this file to your unique specifications based on your degree/university. Section 9.5 on page 83 will help you do this. Make sure you also read section 9.7 about thesis conventions to get the most out of this template.

If you are new to \LaTeX it is recommended that you carry on reading through the rest of the information in this document.

Before you begin using this template you should ensure that its style complies with the thesis style guidelines imposed by your institution. In most cases this template style and layout will be suitable. If it is not, it may only require a small change to bring the template in line with your

Algorithm 2 Embedding Procedure - General

Input: L sized, vectorized n -dimensional dataset

Input: number of centers per dimension - C

Output: $emb - set$: L sized set, embedded, sparsed vectors

```

1: Find centers vectors
2:  $V$  shall be a set of centers vectors
3: for all  $dim$  in  $n$  do
4:    $V_{dim} \leftarrow centers \ vector \ per \ dim$ 
5: end for
6: Find embedded coefficients for all dataset
7:  $\vec{\phi} = C^n$  length empty  $emb - set$  embedded vectors
8: for all  $vec$  in  $L$  do
9:   find  $vec$  bounding hypercube
10:  find  $vec$  bounding simplex (permutation method)
11:   $\vec{\lambda} \leftarrow$  find  $vec$  barycentric coefficients
12:   $\vec{\lambda} \leftarrow$  normalize( $\vec{\lambda}$ )
13: end for
14: Assign
15: for all  $\vec{eve\ell}$  in  $emb - set$  do
16:   $inds \leftarrow$  find vertices from hypercube and simplex locations
17:  for all  $i$  in  $inds$  do
18:     $\vec{eve\ell}(i) \leftarrow \vec{\lambda}(j(i))$  -  $j$  is the assigning function between the coef.
      vector and embedding vector
19:  end for
20: end for
21: return  $\vec{\phi}$ 

```

institution's recommendations. These modifications will need to be done on the `MastersDoctoralThesis.cls` file.

4.3.1 About this Template

This L^AT_EX Thesis Template is originally based and created around a L^AT_EX style file created by Steve R. Gunn from the University of Southampton (UK), department of Electronics and Computer Science. You can find his original thesis style file at his site, here: <http://www.ecs.soton.ac.uk/~srg/softwaretools/document/templates/>

Steve's `ecsthesis.cls` was then taken by Sunil Patel who modified it by creating a skeleton framework and folder structure to place the thesis files in. The resulting template can be found on Sunil's site here: <http://www.sunilpatel.co.uk/thesis-template>

Sunil's template was made available through <http://www.LaTeXTemplates.com> where it was modified many times based on user requests and questions. Version 2.0 and onwards of this template represents a major modification to Sunil's template and is, in fact, hardly recognisable. The work to make version 2.0 possible was carried out by Vel and Johannes Böttcher.

4.4 What this Template Includes

4.4.1 Folders

This template comes as a single zip file that expands out to several files and folders. The folder names are mostly self-explanatory:

Appendices – this is the folder where you put the appendices. Each appendix should go into its own separate `.tex` file. An example and template are included in the directory.

Chapters – this is the folder where you put the thesis chapters. A thesis usually has about six chapters, though there is no hard rule on this. Each chapter should go in its own separate `.tex` file and they can be split as:

- Chapter 1: Introduction to the thesis topic
- Chapter 2: Background information and theory
- Chapter 3: (Laboratory) experimental setup
- Chapter 4: Details of experiment 1
- Chapter 5: Details of experiment 2
- Chapter 6: Discussion of the experimental results
- Chapter 7: Conclusion and future directions

This chapter layout is specialised for the experimental sciences.

Figures – this folder contains all figures for the thesis. These are the final images that will go into the thesis document.

4.4.2 Files

Included are also several files, most of them are plain text and you can see their contents in a text editor. After initial compilation, you will see that more auxiliary files are created by \LaTeX or BibTeX and which you don't need to delete or worry about:

example.bib – this is an important file that contains all the bibliographic information and references that you will be citing in the thesis for use with BibTeX. You can write it manually, but there are reference manager programs available that will create and manage it for you. Bibliographies in \LaTeX are a large subject and you may need to read about BibTeX before starting with this. Many modern reference managers will allow you to export your references in BibTeX format which greatly eases the amount of work you have to do.

MastersDoctoralThesis.cls – this is an important file. It is the class file that tells \LaTeX how to format the thesis.

main.pdf – this is your beautifully typeset thesis (in the PDF file format) created by \LaTeX . It is supplied in the PDF with the template and after you compile the template you should get an identical version.

main.tex – this is an important file. This is the file that you tell \LaTeX to compile to produce your thesis as a PDF file. It contains the framework and constructs that tell \LaTeX how to layout the thesis. It is heavily commented so you can read exactly what each line of code does and why it is there. After you put your own information into the *THESIS INFORMATION* block – you have now started your thesis!

Files that are *not* included, but are created by \LaTeX as auxiliary files include:

main.aux – this is an auxiliary file generated by \LaTeX , if it is deleted \LaTeX simply regenerates it when you run the main **.tex** file.

main.bbl – this is an auxiliary file generated by BibTeX, if it is deleted, BibTeX simply regenerates it when you run the **main.aux** file. Whereas the **.bib** file contains all the references you have, this **.bbl** file contains the references you have actually cited in the thesis and is used to build the bibliography section of the thesis.

main.blg – this is an auxiliary file generated by BibTeX, if it is deleted BibTeX simply regenerates it when you run the main **.aux** file.

main.lof – this is an auxiliary file generated by \LaTeX , if it is deleted \LaTeX simply regenerates it when you run the main **.tex** file. It tells \LaTeX how to build the *List of Figures* section.

main.log – this is an auxiliary file generated by \LaTeX , if it is deleted \LaTeX simply regenerates it when you run the main **.tex** file. It contains messages from \LaTeX , if you receive errors and warnings from \LaTeX , they will be in this **.log** file.

main.lot – this is an auxiliary file generated by \LaTeX , if it is deleted \LaTeX simply regenerates it when you run the main **.tex** file. It tells \LaTeX how to build the *List of Tables* section.

main.out – this is an auxiliary file generated by \LaTeX , if it is deleted \LaTeX simply regenerates it when you run the main **.tex** file.

So from this long list, only the files with the **.bib**, **.cls** and **.tex** extensions are the most important ones. The other auxiliary files can be ignored or deleted as \LaTeX and BibTeX will regenerate them.

4.5 Filling in Your Information in the `main.tex` File

You will need to personalise the thesis template and make it your own by filling in your own information. This is done by editing the `main.tex` file in a text editor or your favourite LaTeX environment.

Open the file and scroll down to the second large block titled *THESIS INFORMATION* where you can see the entries for *University Name*, *Department Name*, etc ...

Fill out the information about yourself, your group and institution. You can also insert web links, if you do, make sure you use the full URL, including the `http://` for this. If you don't want these to be linked, simply remove the `\href{url}{name}` and only leave the name.

When you have done this, save the file and recompile `main.tex`. All the information you filled in should now be in the PDF, complete with web links. You can now begin your thesis proper!

4.6 The `main.tex` File Explained

The `main.tex` file contains the structure of the thesis. There are plenty of written comments that explain what pages, sections and formatting the LaTeX code is creating. Each major document element is divided into commented blocks with titles in all capitals to make it obvious what the following bit of code is doing. Initially there seems to be a lot of LaTeX code, but this is all formatting, and it has all been taken care of so you don't have to do it.

Begin by checking that your information on the title page is correct. For the thesis declaration, your institution may insist on something different than the text given. If this is the case, just replace what you see with what is required in the *DECLARATION PAGE* block.

Then comes a page which contains a funny quote. You can put your own, or quote your favourite scientist, author, person, and so on. Make sure to put the name of the person who you took the quote from.

Following this is the abstract page which summarises your work in a condensed way and can almost be used as a standalone document to describe what you have done. The text you write will cause the heading to move up so don't worry about running out of space.

Next come the acknowledgements. On this page, write about all the people who you wish to thank (not forgetting parents, partners and your advisor/supervisor).

The contents pages, list of figures and tables are all taken care of for you and do not need to be manually created or edited. The next set of pages are more likely to be optional and can be deleted since they are for a more technical thesis: insert a list of abbreviations you have used in the thesis, then a list of the physical constants and numbers you refer to and finally, a list of mathematical symbols used in any formulae. Making the effort to fill these tables means the reader has a one-stop place to refer to instead of searching the internet and references to try and find out what you meant by certain abbreviations or symbols.

The list of symbols is split into the Roman and Greek alphabets. Whereas the abbreviations and symbols ought to be listed in alphabetical order (and

this is *not* done automatically for you) the list of physical constants should be grouped into similar themes.

The next page contains a one line dedication. Who will you dedicate your thesis to?

Finally, there is the block where the chapters are included. Uncomment the lines (delete the % character) as you write the chapters. Each chapter should be written in its own file and put into the *Chapters* folder and named **Chapter1**, **Chapter2**, etc. . . Similarly for the appendices, uncomment the lines as you need them. Each appendix should go into its own file and placed in the *Appendices* folder.

After the preamble, chapters and appendices finally comes the bibliography. The bibliography style (called *authoryear*) is used for the bibliography and is a fully featured style that will even include links to where the referenced paper can be found online. Do not underestimate how grateful your reader will be to find that a reference to a paper is just a click away. Of course, this relies on you putting the URL information into the BibTeX file in the first place.

4.7 Thesis Features and Conventions

To get the best out of this template, there are a few conventions that you may want to follow.

One of the most important (and most difficult) things to keep track of in such a long document as a thesis is consistency. Using certain conventions and ways of doing things (such as using a Todo list) makes the job easier. Of course, all of these are optional and you can adopt your own method.

4.7.1 Printing Format

This thesis template is designed for double sided printing (i.e. content on the front and back of pages) as most theses are printed and bound this way. Switching to one sided printing is as simple as uncommenting the *oneside* option of the `documentclass` command at the top of the **main.tex** file. You may then wish to adjust the margins to suit specifications from your institution.

The headers for the pages contain the page number on the outer side (so it is easy to flick through to the page you want) and the chapter name on the inner side.

The text is set to 11 point by default with single line spacing, again, you can tune the text size and spacing should you want or need to using the options at the very start of **main.tex**. The spacing can be changed similarly by replacing the *singlespacing* with *onehalfspacing* or *doublespacing*.

4.7.2 Using US Letter Paper

The paper size used in the template is A4, which is the standard size in Europe. If you are using this thesis template elsewhere and particularly in the United States, then you may have to change the A4 paper size to the US Letter size. This can be done in the margins settings section in **main.tex**.

Due to the differences in the paper size, the resulting margins may be different to what you like or require (as it is common for institutions to

dictate certain margin sizes). If this is the case, then the margin sizes can be tweaked by modifying the values in the same block as where you set the paper size. Now your document should be set up for US Letter paper size with suitable margins.

4.7.3 References

The `biblatex` package is used to format the bibliography and inserts references such as this one (**Reference1**). The options used in the `main.tex` file mean that the in-text citations of references are formatted with the author(s) listed with the date of the publication. Multiple references are separated by semicolons (e.g. (**Reference2**; **Reference1**)) and references with more than three authors only show the first author with *et al.* indicating there are more authors (e.g. (**Reference3**)). This is done automatically for you. To see how you use references, have a look at the `Chapter1.tex` source file. Many reference managers allow you to simply drag the reference into the document as you type.

Scientific references should come *before* the punctuation mark if there is one (such as a comma or period). The same goes for footnotes¹. You can change this but the most important thing is to keep the convention consistent throughout the thesis. Footnotes themselves should be full, descriptive sentences (beginning with a capital letter and ending with a full stop). The APA6 states: “Footnote numbers should be superscripted, [...], following any punctuation mark except a dash.” The Chicago manual of style states: “A note number should be placed at the end of a sentence or clause. The number follows any punctuation mark except the dash, which it precedes. It follows a closing parenthesis.”

The bibliography is typeset with references listed in alphabetical order by the first author’s last name. This is similar to the APA referencing style. To see how \LaTeX typesets the bibliography, have a look at the very end of this document (or just click on the reference number links in in-text citations).

4.7.3.1 A Note on bibtex

The `bibtex` backend used in the template by default does not correctly handle unicode character encoding (i.e. “international” characters). You may see a warning about this in the compilation log and, if your references contain unicode characters, they may not show up correctly or at all. The solution to this is to use the `biber` backend instead of the outdated `bibtex` backend. This is done by finding this in `main.tex`: `backend=bibtex` and changing it to `backend=biber`. You will then need to delete all auxiliary BibTeX files and navigate to the template directory in your terminal (command prompt). Once there, simply type `biber main` and `biber` will compile your bibliography. You can then compile `main.tex` as normal and your bibliography will be updated. An alternative is to set up your LaTeX editor to compile with `biber` instead of `bibtex`, see [here](#) for how to do this for various editors.

¹Such as this footnote, here down at the bottom of the page.

TABLE 4.1: The effects of treatments X and Y on the four groups studied.

Groups	Treatment X	Treatment Y
1	0.2	0.8
2	0.17	0.7
3	0.24	0.75
4	0.68	0.3

4.7.4 Tables

Tables are an important way of displaying your results, below is an example table which was generated with this code:

```
\begin{table}
\caption{The effects of treatments X and Y on the four groups studied.}
\label{tab:treatments}
\centering
\begin{tabular}{l l l}
\toprule
\thead{Groups} & \thead{Treatment X} & \thead{Treatment Y} \\
\midrule
1 & 0.2 & 0.8 \\
2 & 0.17 & 0.7 \\
3 & 0.24 & 0.75 \\
4 & 0.68 & 0.3 \\
\bottomrule
\end{tabular}
\end{table}
```

You can reference tables with `\ref{<label>}` where the label is defined within the table environment. See **Chapter1.tex** for an example of the label and citation (e.g. Table 9.1).

4.7.5 Figures

There will hopefully be many figures in your thesis (that should be placed in the *Figures* folder). The way to insert figures into your thesis is to use a code template like this:

```
\begin{figure}
\centering
\includegraphics{Figures/Electron}
\decoRule
\caption[An Electron]{An electron (artist's impression).}
\label{fig:Electron}
\end{figure}
```

Also look in the source file. Putting this code into the source file produces the picture of the electron that you can see in the figure below.

Sometimes figures don't always appear where you write them in the source. The placement depends on how much space there is on the page for the figure. Sometimes there is not enough room to fit a figure directly



FIGURE 4.1: An electron (artist's impression).

where it should go (in relation to the text) and so \LaTeX puts it at the top of the next page. Positioning figures is the job of \LaTeX and so you should only worry about making them look good!

Figures usually should have captions just in case you need to refer to them (such as in Figure 9.1). The `\caption` command contains two parts, the first part, inside the square brackets is the title that will appear in the *List of Figures*, and so should be short. The second part in the curly brackets should contain the longer and more descriptive caption text.

The `\decoRule` command is optional and simply puts an aesthetic horizontal line below the image. If you do this for one image, do it for all of them.

\LaTeX is capable of using images in pdf, jpg and png format.

4.7.6 Typesetting mathematics

If your thesis is going to contain heavy mathematical content, be sure that \LaTeX will make it look beautiful, even though it won't be able to solve the equations for you.

The "Not So Short Introduction to \LaTeX " (available on [CTAN](http://www.ctan.org)) should tell you everything you need to know for most cases of typesetting mathematics. If you need more information, a much more thorough mathematical guide is available from the AMS called, "A Short Math Guide to \LaTeX " and can be downloaded from: [ftp://ftp.ams.org/pub/tex/doc/amsmath/short-math-guide.pdf](http://ftp.ams.org/pub/tex/doc/amsmath/short-math-guide.pdf)

There are many different \LaTeX symbols to remember, luckily you can find the most common symbols in [The Comprehensive \$\text{\LaTeX}\$ Symbol List](#).

You can write an equation, which is automatically given an equation number by \LaTeX like this:

```
\begin{equation}
E = mc^{2}
\label{eqn:Einstein}
\end{equation}
```

This will produce Einstein's famous energy-matter equivalence equation:

$$E = mc^2 \quad (4.1)$$

All equations you write (which are not in the middle of paragraph text) are automatically given equation numbers by \LaTeX . If you don't want a particular equation numbered, use the unnumbered form:

```
\[ a^{2}=4 \]
```

4.8 Sectioning and Subsectioning

You should break your thesis up into nice, bite-sized sections and subsections. \LaTeX automatically builds a table of Contents by looking at all the `\chapter{}`, `\section{}` and `\subsection{}` commands you write in the source.

The Table of Contents should only list the sections to three (3) levels. A `chapter{}` is level zero (0). A `\section{}` is level one (1) and so a `\subsection{}` is level two (2). In your thesis it is likely that you will even use a `subsubsection{}`, which is level three (3). The depth to which the Table of Contents is formatted is set within **MastersDoctoralThesis.cls**. If you need this changed, you can do it in **main.tex**.

4.9 In Closing

You have reached the end of this mini-guide. You can now rename or overwrite this pdf file and begin writing your own **Chapter1.tex** and the rest of your thesis. The easy work of setting up the structure and framework has been taken care of for you. It's now your job to fill it out!

Good luck and have lots of fun!

Guide written by —
Sunil Patel: www.sunilpatel.co.uk
Vel: LaTeXTemplates.com

Chapter 5

Time Complexity

5.1 Welcome and Thank You

Welcome to this L^AT_EX Thesis Template, a beautiful and easy to use template for writing a thesis using the L^AT_EX typesetting system.

If you are writing a thesis (or will be in the future) and its subject is technical or mathematical (though it doesn't have to be), then creating it in L^AT_EX is highly recommended as a way to make sure you can just get down to the essential writing without having to worry over formatting or wasting time arguing with your word processor.

L^AT_EX is easily able to professionally typeset documents that run to hundreds or thousands of pages long. With simple mark-up commands, it automatically sets out the table of contents, margins, page headers and footers and keeps the formatting consistent and beautiful. One of its main strengths is the way it can easily typeset mathematics, even *heavy* mathematics. Even if those equations are the most horribly twisted and most difficult mathematical problems that can only be solved on a super-computer, you can at least count on L^AT_EX to make them look stunning.

5.2 Learning algebra ··· ψ

L^AT_EX is not a WYSIWYG (What You See is What You Get) program, unlike word processors such as Microsoft Word or Apple's Pages. Instead, a document written for L^AT_EX is actually a simple, plain text file that contains *no formatting*. You tell L^AT_EX how you want the formatting in the finished document by writing in simple commands amongst the text, for example, if I want to use *italic text for emphasis*, I write the `\emph{text}` command and put the text I want in italics in between the curly braces. This means that L^AT_EX is a "mark-up" language, very much like HTML.

5.2.1 A (not so short) Introduction to L^AT_EX_d

If you are new to L^AT_EX, there is a very good eBook – freely available online as a PDF file – called, "The Not So Short Introduction to L^AT_EX". The book's title is typically shortened to just *lshort*. You can download the latest version (as it is occasionally updated) from here: <http://www.ctan.org/tex-archive/info/lshort/english/lshort.pdf>

It is also available in several other languages. Find yours from the list on this page: <http://www.ctan.org/tex-archive/info/lshort/>

It is recommended to take a little time out to learn how to use L^AT_EX by creating several, small 'test' documents, or having a close look at several

templates on:

<http://www.LaTeXTemplates.com>

Making the effort now means you're not stuck learning the system when what you *really* need to be doing is writing your thesis.

5.2.2 A Short Math Guide for L^AT_EX

If you are writing a technical or mathematical thesis, then you may want to read the document by the AMS (American Mathematical Society) called, "A Short Math Guide for L^AT_EX". It can be found online here: <http://www.ams.org/tex/amslatex.html> under the "Additional Documentation" section towards the bottom of the page.

5.2.3 Common L^AT_EX Math Symbols

There are a multitude of mathematical symbols available for L^AT_EX and it would take a great effort to learn the commands for them all. The most common ones you are likely to use are shown on this page: <http://www.sunilpatel.co.uk/latex-type/latex-math-symbols/>

You can use this page as a reference or crib sheet, the symbols are rendered as large, high quality images so you can quickly find the L^AT_EX command for the symbol you need.

Algorithm 3 Embedding Procedure - General

Input: L sized, vectorized n -dimensional dataset

Input: number of centers per dimension - C

Output: $emb - set$: L sized set, embedded, sparsed vectors

```

1: Find centers vectors
2:  $V$  shall be a set of centers vectors
3: for all  $dim$  in  $n$  do
4:    $V_{dim} \leftarrow centers \quad vector \quad per \quad dim$ 
5: end for
6: Find embedded coefficients for all dataset
7:  $\vec{\phi} = C^n$  length empty  $emb - set$  embedded vectors
8: for all  $vec$  in  $L$  do
9:   find  $vec$  bounding hypercube
10:  find  $vec$  bounding simplex (permutation method)
11:   $\vec{\lambda} \leftarrow$  find  $vec$  barycentric coefficients
12:   $\vec{\lambda} \leftarrow$  normalize( $\vec{\lambda}$ )
13: end for
14: Assign
15: for all  $\vec{vec}$  in  $emb - set$  do
16:    $inds \leftarrow$  find vertices from hypercube and simplex locations
17:   for all  $i$  in  $inds$  do
18:      $\vec{vec}(i) \leftarrow \vec{\lambda}(j(i))$  -  $j$  is the assigning function between the coef.
        vector and embedding vector
19:   end for
20: end for
21: return  $\vec{\phi}$ 
```

5.2.4 L^AT_EX on a Mac

The L^AT_EX distribution is available for many systems including Windows, Linux and Mac OS X. The package for OS X is called MacTeX and it contains all the applications you need – bundled together and pre-customized – for a fully working L^AT_EX environment and work flow.

MacTeX includes a custom dedicated L^AT_EX editor called TeXShop for writing your ‘.tex’ files and BibDesk: a program to manage your references and create your bibliography section just as easily as managing songs and creating playlists in iTunes.

5.3 Getting Started with this Template

If you are familiar with L^AT_EX, then you should explore the directory structure of the template and then proceed to place your own information into the *THESIS INFORMATION* block of the **main.tex** file. You can then modify the rest of this file to your unique specifications based on your degree/university. Section 9.5 on page 83 will help you do this. Make sure you also read section 9.7 about thesis conventions to get the most out of this template.

If you are new to L^AT_EX it is recommended that you carry on reading through the rest of the information in this document.

Before you begin using this template you should ensure that its style complies with the thesis style guidelines imposed by your institution. In most cases this template style and layout will be suitable. If it is not, it may only require a small change to bring the template in line with your institution’s recommendations. These modifications will need to be done on the **MastersDoctoralThesis.cls** file.

5.3.1 About this Template

This L^AT_EX Thesis Template is originally based and created around a L^AT_EX style file created by Steve R. Gunn from the University of Southampton (UK), department of Electronics and Computer Science. You can find his original thesis style file at his site, here: <http://www.ecs.soton.ac.uk/~srg/softwaretools/document/templates/>

Steve’s **ecsthesis.cls** was then taken by Sunil Patel who modified it by creating a skeleton framework and folder structure to place the thesis files in. The resulting template can be found on Sunil’s site here: <http://www.sunilpatel.co.uk/thesis-template>

Sunil’s template was made available through <http://www.LaTeXTemplates.com> where it was modified many times based on user requests and questions. Version 2.0 and onwards of this template represents a major modification to Sunil’s template and is, in fact, hardly recognisable. The work to make version 2.0 possible was carried out by **Vel** and Johannes Böttcher.

5.4 What this Template Includes

5.4.1 Folders

This template comes as a single zip file that expands out to several files and folders. The folder names are mostly self-explanatory:

Appendices – this is the folder where you put the appendices. Each appendix should go into its own separate `.tex` file. An example and template are included in the directory.

Chapters – this is the folder where you put the thesis chapters. A thesis usually has about six chapters, though there is no hard rule on this. Each chapter should go in its own separate `.tex` file and they can be split as:

- Chapter 1: Introduction to the thesis topic
- Chapter 2: Background information and theory
- Chapter 3: (Laboratory) experimental setup
- Chapter 4: Details of experiment 1
- Chapter 5: Details of experiment 2
- Chapter 6: Discussion of the experimental results
- Chapter 7: Conclusion and future directions

This chapter layout is specialised for the experimental sciences.

Figures – this folder contains all figures for the thesis. These are the final images that will go into the thesis document.

5.4.2 Files

Included are also several files, most of them are plain text and you can see their contents in a text editor. After initial compilation, you will see that more auxiliary files are created by \LaTeX or BibTeX and which you don't need to delete or worry about:

example.bib – this is an important file that contains all the bibliographic information and references that you will be citing in the thesis for use with BibTeX. You can write it manually, but there are reference manager programs available that will create and manage it for you. Bibliographies in \LaTeX are a large subject and you may need to read about BibTeX before starting with this. Many modern reference managers will allow you to export your references in BibTeX format which greatly eases the amount of work you have to do.

MastersDoctoralThesis.cls – this is an important file. It is the class file that tells \LaTeX how to format the thesis.

main.pdf – this is your beautifully typeset thesis (in the PDF file format) created by \LaTeX . It is supplied in the PDF with the template and after you compile the template you should get an identical version.

main.tex – this is an important file. This is the file that you tell \LaTeX to compile to produce your thesis as a PDF file. It contains the framework and constructs that tell \LaTeX how to layout the thesis. It is heavily commented so you can read exactly what each line of code does and why it is there.

After you put your own information into the *THESIS INFORMATION* block – you have now started your thesis!

Files that are *not* included, but are created by L^AT_EX as auxiliary files include:

main.aux – this is an auxiliary file generated by L^AT_EX, if it is deleted L^AT_EX simply regenerates it when you run the main **.tex** file.

main.bbl – this is an auxiliary file generated by BibTeX, if it is deleted, BibTeX simply regenerates it when you run the **main.aux** file. Whereas the **.bib** file contains all the references you have, this **.bbl** file contains the references you have actually cited in the thesis and is used to build the bibliography section of the thesis.

main.blg – this is an auxiliary file generated by BibTeX, if it is deleted BibTeX simply regenerates it when you run the main **.aux** file.

main.lof – this is an auxiliary file generated by L^AT_EX, if it is deleted L^AT_EX simply regenerates it when you run the main **.tex** file. It tells L^AT_EX how to build the *List of Figures* section.

main.log – this is an auxiliary file generated by L^AT_EX, if it is deleted L^AT_EX simply regenerates it when you run the main **.tex** file. It contains messages from L^AT_EX, if you receive errors and warnings from L^AT_EX, they will be in this **.log** file.

main.lot – this is an auxiliary file generated by L^AT_EX, if it is deleted L^AT_EX simply regenerates it when you run the main **.tex** file. It tells L^AT_EX how to build the *List of Tables* section.

main.out – this is an auxiliary file generated by L^AT_EX, if it is deleted L^AT_EX simply regenerates it when you run the main **.tex** file.

So from this long list, only the files with the **.bib**, **.cls** and **.tex** extensions are the most important ones. The other auxiliary files can be ignored or deleted as L^AT_EX and BibTeX will regenerate them.

5.5 Filling in Your Information in the **main.tex** File

You will need to personalise the thesis template and make it your own by filling in your own information. This is done by editing the **main.tex** file in a text editor or your favourite LaTeX environment.

Open the file and scroll down to the second large block titled *THESIS INFORMATION* where you can see the entries for *University Name*, *Department Name*, etc ...

Fill out the information about yourself, your group and institution. You can also insert web links, if you do, make sure you use the full URL, including the `http://` for this. If you don't want these to be linked, simply remove the `\href{url}{name}` and only leave the name.

When you have done this, save the file and recompile **main.tex**. All the information you filled in should now be in the PDF, complete with web links. You can now begin your thesis proper!

5.6 The **main.tex** File Explained

The **main.tex** file contains the structure of the thesis. There are plenty of written comments that explain what pages, sections and formatting the

L^AT_EX code is creating. Each major document element is divided into commented blocks with titles in all capitals to make it obvious what the following bit of code is doing. Initially there seems to be a lot of L^AT_EX code, but this is all formatting, and it has all been taken care of so you don't have to do it.

Begin by checking that your information on the title page is correct. For the thesis declaration, your institution may insist on something different than the text given. If this is the case, just replace what you see with what is required in the *DECLARATION PAGE* block.

Then comes a page which contains a funny quote. You can put your own, or quote your favourite scientist, author, person, and so on. Make sure to put the name of the person who you took the quote from.

Following this is the abstract page which summarises your work in a condensed way and can almost be used as a standalone document to describe what you have done. The text you write will cause the heading to move up so don't worry about running out of space.

Next come the acknowledgements. On this page, write about all the people who you wish to thank (not forgetting parents, partners and your advisor/supervisor).

The contents pages, list of figures and tables are all taken care of for you and do not need to be manually created or edited. The next set of pages are more likely to be optional and can be deleted since they are for a more technical thesis: insert a list of abbreviations you have used in the thesis, then a list of the physical constants and numbers you refer to and finally, a list of mathematical symbols used in any formulae. Making the effort to fill these tables means the reader has a one-stop place to refer to instead of searching the internet and references to try and find out what you meant by certain abbreviations or symbols.

The list of symbols is split into the Roman and Greek alphabets. Whereas the abbreviations and symbols ought to be listed in alphabetical order (and this is *not* done automatically for you) the list of physical constants should be grouped into similar themes.

The next page contains a one line dedication. Who will you dedicate your thesis to?

Finally, there is the block where the chapters are included. Uncomment the lines (delete the % character) as you write the chapters. Each chapter should be written in its own file and put into the *Chapters* folder and named **Chapter1**, **Chapter2**, etc... Similarly for the appendices, uncomment the lines as you need them. Each appendix should go into its own file and placed in the *Appendices* folder.

After the preamble, chapters and appendices finally comes the bibliography. The bibliography style (called *authoryear*) is used for the bibliography and is a fully featured style that will even include links to where the referenced paper can be found online. Do not underestimate how grateful your reader will be to find that a reference to a paper is just a click away. Of course, this relies on you putting the URL information into the BibTeX file in the first place.

5.7 Thesis Features and Conventions

To get the best out of this template, there are a few conventions that you may want to follow.

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5.7.1 Printing Format

This thesis template is designed for double sided printing (i.e. content on the front and back of pages) as most theses are printed and bound this way. Switching to one sided printing is as simple as uncommenting the *oneside* option of the `documentclass` command at the top of the **main.tex** file. You may then wish to adjust the margins to suit specifications from your institution.

The headers for the pages contain the page number on the outer side (so it is easy to flick through to the page you want) and the chapter name on the inner side.

The text is set to 11 point by default with single line spacing, again, you can tune the text size and spacing should you want or need to using the options at the very start of **main.tex**. The spacing can be changed similarly by replacing the *singlespacing* with *onehalfspacing* or *doublespacing*.

5.7.2 Using US Letter Paper

The paper size used in the template is A4, which is the standard size in Europe. If you are using this thesis template elsewhere and particularly in the United States, then you may have to change the A4 paper size to the US Letter size. This can be done in the margins settings section in **main.tex**.

Due to the differences in the paper size, the resulting margins may be different to what you like or require (as it is common for institutions to dictate certain margin sizes). If this is the case, then the margin sizes can be tweaked by modifying the values in the same block as where you set the paper size. Now your document should be set up for US Letter paper size with suitable margins.

5.7.3 References

The `biblatex` package is used to format the bibliography and inserts references such as this one (**Reference1**). The options used in the **main.tex** file mean that the in-text citations of references are formatted with the author(s) listed with the date of the publication. Multiple references are separated by semicolons (e.g. (**Reference2**; **Reference1**)) and references with more than three authors only show the first author with *et al.* indicating there are more authors (e.g. (**Reference3**)). This is done automatically for you. To see how you use references, have a look at the **Chapter1.tex** source file. Many reference managers allow you to simply drag the reference into the document as you type.

Scientific references should come *before* the punctuation mark if there is one (such as a comma or period). The same goes for footnotes¹. You can change this but the most important thing is to keep the convention consistent throughout the thesis. Footnotes themselves should be full, descriptive sentences (beginning with a capital letter and ending with a full stop). The APA6 states: “Footnote numbers should be superscripted, [...], following any punctuation mark except a dash.” The Chicago manual of style states: “A note number should be placed at the end of a sentence or clause. The number follows any punctuation mark except the dash, which it precedes. It follows a closing parenthesis.”

The bibliography is typeset with references listed in alphabetical order by the first author’s last name. This is similar to the APA referencing style. To see how \LaTeX typesets the bibliography, have a look at the very end of this document (or just click on the reference number links in in-text citations).

5.7.3.1 A Note on bibtex

The bibtex backend used in the template by default does not correctly handle unicode character encoding (i.e. “international” characters). You may see a warning about this in the compilation log and, if your references contain unicode characters, they may not show up correctly or at all. The solution to this is to use the biber backend instead of the outdated bibtex backend. This is done by finding this in **main.tex**: `backend=bibtex` and changing it to `backend=biber`. You will then need to delete all auxiliary BibTeX files and navigate to the template directory in your terminal (command prompt). Once there, simply type `biber main` and biber will compile your bibliography. You can then compile **main.tex** as normal and your bibliography will be updated. An alternative is to set up your LaTeX editor to compile with biber instead of bibtex, see [here](#) for how to do this for various editors.

5.7.4 Tables

Tables are an important way of displaying your results, below is an example table which was generated with this code:

```
\begin{table}
\caption{The effects of treatments X and Y on the four groups studied.}
\label{tab:treatments}
\centering
\begin{tabular}{l l l}
\toprule
\thead{Groups} & \thead{Treatment X} & \thead{Treatment Y} \\
\midrule
1 & 0.2 & 0.8 \\
2 & 0.17 & 0.7 \\
3 & 0.24 & 0.75 \\
4 & 0.68 & 0.3 \\
\bottomrule
\end{tabular}
\end{table}
```

TABLE 5.1: The effects of treatments X and Y on the four groups studied.

Groups	Treatment X	Treatment Y
1	0.2	0.8
2	0.17	0.7
3	0.24	0.75
4	0.68	0.3

You can reference tables with `\ref{<label>}` where the label is defined within the table environment. See **Chapter1.tex** for an example of the label and citation (e.g. Table 9.1).

5.7.5 Figures

There will hopefully be many figures in your thesis (that should be placed in the *Figures* folder). The way to insert figures into your thesis is to use a code template like this:

```
\begin{figure}
\centering
\includegraphics{Figures/Electron}
\decoRule
\caption[An Electron]{An electron (artist's impression).}
\label{fig:Electron}
\end{figure}
```

Also look in the source file. Putting this code into the source file produces the picture of the electron that you can see in the figure below.

Sometimes figures don't always appear where you write them in the source. The placement depends on how much space there is on the page for the figure. Sometimes there is not enough room to fit a figure directly where it should go (in relation to the text) and so \LaTeX puts it at the top of the next page. Positioning figures is the job of \LaTeX and so you should only worry about making them look good!

Figures usually should have captions just in case you need to refer to them (such as in Figure 9.1). The `\caption` command contains two parts, the first part, inside the square brackets is the title that will appear in the *List of Figures*, and so should be short. The second part in the curly brackets should contain the longer and more descriptive caption text.

The `\decoRule` command is optional and simply puts an aesthetic horizontal line below the image. If you do this for one image, do it for all of them.

\LaTeX is capable of using images in pdf, jpg and png format.

¹Such as this footnote, here down at the bottom of the page.



FIGURE 5.1: An electron (artist's impression).

5.7.6 Typesetting mathematics

If your thesis is going to contain heavy mathematical content, be sure that \LaTeX will make it look beautiful, even though it won't be able to solve the equations for you.

The “Not So Short Introduction to \LaTeX ” (available on [CTAN](#)) should tell you everything you need to know for most cases of typesetting mathematics. If you need more information, a much more thorough mathematical guide is available from the AMS called, “A Short Math Guide to \LaTeX ” and can be downloaded from: <ftp://ftp.ams.org/pub/tex/doc/amsmath/short-math-guide.pdf>

There are many different \LaTeX symbols to remember, luckily you can find the most common symbols in [The Comprehensive \$\text{\LaTeX}\$ Symbol List](#).

You can write an equation, which is automatically given an equation number by \LaTeX like this:

```
\begin{equation}
E = mc^{2}
\label{eqn:Einstein}
\end{equation}
```

This will produce Einstein's famous energy-matter equivalence equation:

$$E = mc^2 \tag{5.1}$$

All equations you write (which are not in the middle of paragraph text) are automatically given equation numbers by \LaTeX . If you don't want a particular equation numbered, use the unnumbered form:

`\[a^{2}=4 \]`

5.8 Sectioning and Subsectioning

You should break your thesis up into nice, bite-sized sections and subsections. \LaTeX automatically builds a table of Contents by looking at all the `\chapter{}`, `\section{}` and `\subsection{}` commands you write in the source.

The Table of Contents should only list the sections to three (3) levels. A `chapter{}` is level zero (0). A `\section{}` is level one (1) and so a `\subsection{}` is level two (2). In your thesis it is likely that you will even use a `subsubsection{}`, which is level three (3). The depth to which the Table of Contents is formatted is set within **MastersDoctoralThesis.cls**. If you need this changed, you can do it in **main.tex**.

5.9 In Closing

You have reached the end of this mini-guide. You can now rename or overwrite this pdf file and begin writing your own **Chapter1.tex** and the rest of your thesis. The easy work of setting up the structure and framework has been taken care of for you. It's now your job to fill it out!

Good luck and have lots of fun!

Guide written by —
Sunil Patel: www.sunilpatel.co.uk
Vel: LaTeXTemplates.com

Chapter 6

Memory Complexity

6.1 Welcome and Thank You

Welcome to this L^AT_EX Thesis Template, a beautiful and easy to use template for writing a thesis using the L^AT_EX typesetting system.

If you are writing a thesis (or will be in the future) and its subject is technical or mathematical (though it doesn't have to be), then creating it in L^AT_EX is highly recommended as a way to make sure you can just get down to the essential writing without having to worry over formatting or wasting time arguing with your word processor.

L^AT_EX is easily able to professionally typeset documents that run to hundreds or thousands of pages long. With simple mark-up commands, it automatically sets out the table of contents, margins, page headers and footers and keeps the formatting consistent and beautiful. One of its main strengths is the way it can easily typeset mathematics, even *heavy* mathematics. Even if those equations are the most horribly twisted and most difficult mathematical problems that can only be solved on a super-computer, you can at least count on L^AT_EX to make them look stunning.

6.2 Learning algebra ··· ψ

L^AT_EX is not a WYSIWYG (What You See is What You Get) program, unlike word processors such as Microsoft Word or Apple's Pages. Instead, a document written for L^AT_EX is actually a simple, plain text file that contains *no formatting*. You tell L^AT_EX how you want the formatting in the finished document by writing in simple commands amongst the text, for example, if I want to use *italic text for emphasis*, I write the `\emph{text}` command and put the text I want in italics in between the curly braces. This means that L^AT_EX is a "mark-up" language, very much like HTML.

6.2.1 A (not so short) Introduction to L^AT_EX_d

If you are new to L^AT_EX, there is a very good eBook – freely available online as a PDF file – called, "The Not So Short Introduction to L^AT_EX". The book's title is typically shortened to just *lshort*. You can download the latest version (as it is occasionally updated) from here: <http://www.ctan.org/tex-archive/info/lshort/english/lshort.pdf>

It is also available in several other languages. Find yours from the list on this page: <http://www.ctan.org/tex-archive/info/lshort/>

It is recommended to take a little time out to learn how to use L^AT_EX by creating several, small 'test' documents, or having a close look at several

templates on:

<http://www.LaTeXTemplates.com>

Making the effort now means you're not stuck learning the system when what you *really* need to be doing is writing your thesis.

6.2.2 A Short Math Guide for L^AT_EX

If you are writing a technical or mathematical thesis, then you may want to read the document by the AMS (American Mathematical Society) called, "A Short Math Guide for L^AT_EX". It can be found online here: <http://www.ams.org/tex/amslatex.html> under the "Additional Documentation" section towards the bottom of the page.

6.2.3 Common L^AT_EX Math Symbols

There are a multitude of mathematical symbols available for L^AT_EX and it would take a great effort to learn the commands for them all. The most common ones you are likely to use are shown on this page: <http://www.sunilpatel.co.uk/latex-type/latex-math-symbols/>

You can use this page as a reference or crib sheet, the symbols are rendered as large, high quality images so you can quickly find the L^AT_EX command for the symbol you need.

Algorithm 4 Embedding Procedure - General

Input: L sized, vectorized n -dimensional dataset

Input: number of centers per dimension - C

Output: $emb - set$: L sized set, embedded, sparsed vectors

```

1: Find centers vectors
2:  $V$  shall be a set of centers vectors
3: for all  $dim$  in  $n$  do
4:    $V_{dim} \leftarrow centers \quad vector \quad per \quad dim$ 
5: end for
6: Find embedded coefficients for all dataset
7:  $\vec{\phi} = C^n$  length empty  $emb - set$  embedded vectors
8: for all  $vec$  in  $L$  do
9:   find  $vec$  bounding hypercube
10:  find  $vec$  bounding simplex (permutation method)
11:   $\vec{\lambda} \leftarrow$  find  $vec$  barycentric coefficients
12:   $\vec{\lambda} \leftarrow$  normalize( $\vec{\lambda}$ )
13: end for
14: Assign
15: for all  $\vec{eve\vec{c}}$  in  $emb - set$  do
16:    $inds \leftarrow$  find vertices from hypercube and simplex locations
17:   for all  $i$  in  $inds$  do
18:      $\vec{eve\vec{c}}(i) \leftarrow \vec{\lambda}(j(i))$  -  $j$  is the assigning function between the coef.
       vector and embedding vector
19:   end for
20: end for
21: return  $\vec{\phi}$ 
```

6.2.4 L^AT_EX on a Mac

The L^AT_EX distribution is available for many systems including Windows, Linux and Mac OS X. The package for OS X is called MacTeX and it contains all the applications you need – bundled together and pre-customized – for a fully working L^AT_EX environment and work flow.

MacTeX includes a custom dedicated L^AT_EX editor called TeXShop for writing your ‘.tex’ files and BibDesk: a program to manage your references and create your bibliography section just as easily as managing songs and creating playlists in iTunes.

6.3 Getting Started with this Template

If you are familiar with L^AT_EX, then you should explore the directory structure of the template and then proceed to place your own information into the *THESIS INFORMATION* block of the **main.tex** file. You can then modify the rest of this file to your unique specifications based on your degree/university. Section 9.5 on page 83 will help you do this. Make sure you also read section 9.7 about thesis conventions to get the most out of this template.

If you are new to L^AT_EX it is recommended that you carry on reading through the rest of the information in this document.

Before you begin using this template you should ensure that its style complies with the thesis style guidelines imposed by your institution. In most cases this template style and layout will be suitable. If it is not, it may only require a small change to bring the template in line with your institution’s recommendations. These modifications will need to be done on the **MastersDoctoralThesis.cls** file.

6.3.1 About this Template

This L^AT_EX Thesis Template is originally based and created around a L^AT_EX style file created by Steve R. Gunn from the University of Southampton (UK), department of Electronics and Computer Science. You can find his original thesis style file at his site, here: <http://www.ecs.soton.ac.uk/~srg/softwaretools/document/templates/>

Steve’s **ecsthesis.cls** was then taken by Sunil Patel who modified it by creating a skeleton framework and folder structure to place the thesis files in. The resulting template can be found on Sunil’s site here: <http://www.sunilpatel.co.uk/thesis-template>

Sunil’s template was made available through <http://www.LaTeXTemplates.com> where it was modified many times based on user requests and questions. Version 2.0 and onwards of this template represents a major modification to Sunil’s template and is, in fact, hardly recognisable. The work to make version 2.0 possible was carried out by **Vel** and Johannes Böttcher.

6.4 What this Template Includes

6.4.1 Folders

This template comes as a single zip file that expands out to several files and folders. The folder names are mostly self-explanatory:

Appendices – this is the folder where you put the appendices. Each appendix should go into its own separate `.tex` file. An example and template are included in the directory.

Chapters – this is the folder where you put the thesis chapters. A thesis usually has about six chapters, though there is no hard rule on this. Each chapter should go in its own separate `.tex` file and they can be split as:

- Chapter 1: Introduction to the thesis topic
- Chapter 2: Background information and theory
- Chapter 3: (Laboratory) experimental setup
- Chapter 4: Details of experiment 1
- Chapter 5: Details of experiment 2
- Chapter 6: Discussion of the experimental results
- Chapter 7: Conclusion and future directions

This chapter layout is specialised for the experimental sciences.

Figures – this folder contains all figures for the thesis. These are the final images that will go into the thesis document.

6.4.2 Files

Included are also several files, most of them are plain text and you can see their contents in a text editor. After initial compilation, you will see that more auxiliary files are created by \LaTeX or BibTeX and which you don't need to delete or worry about:

example.bib – this is an important file that contains all the bibliographic information and references that you will be citing in the thesis for use with BibTeX. You can write it manually, but there are reference manager programs available that will create and manage it for you. Bibliographies in \LaTeX are a large subject and you may need to read about BibTeX before starting with this. Many modern reference managers will allow you to export your references in BibTeX format which greatly eases the amount of work you have to do.

MastersDoctoralThesis.cls – this is an important file. It is the class file that tells \LaTeX how to format the thesis.

main.pdf – this is your beautifully typeset thesis (in the PDF file format) created by \LaTeX . It is supplied in the PDF with the template and after you compile the template you should get an identical version.

main.tex – this is an important file. This is the file that you tell \LaTeX to compile to produce your thesis as a PDF file. It contains the framework and constructs that tell \LaTeX how to layout the thesis. It is heavily commented so you can read exactly what each line of code does and why it is there.

After you put your own information into the *THESIS INFORMATION* block – you have now started your thesis!

Files that are *not* included, but are created by L^AT_EX as auxiliary files include:

main.aux – this is an auxiliary file generated by L^AT_EX, if it is deleted L^AT_EX simply regenerates it when you run the main **.tex** file.

main.bbl – this is an auxiliary file generated by BibTeX, if it is deleted, BibTeX simply regenerates it when you run the **main.aux** file. Whereas the **.bib** file contains all the references you have, this **.bbl** file contains the references you have actually cited in the thesis and is used to build the bibliography section of the thesis.

main.blg – this is an auxiliary file generated by BibTeX, if it is deleted BibTeX simply regenerates it when you run the main **.aux** file.

main.lof – this is an auxiliary file generated by L^AT_EX, if it is deleted L^AT_EX simply regenerates it when you run the main **.tex** file. It tells L^AT_EX how to build the *List of Figures* section.

main.log – this is an auxiliary file generated by L^AT_EX, if it is deleted L^AT_EX simply regenerates it when you run the main **.tex** file. It contains messages from L^AT_EX, if you receive errors and warnings from L^AT_EX, they will be in this **.log** file.

main.lot – this is an auxiliary file generated by L^AT_EX, if it is deleted L^AT_EX simply regenerates it when you run the main **.tex** file. It tells L^AT_EX how to build the *List of Tables* section.

main.out – this is an auxiliary file generated by L^AT_EX, if it is deleted L^AT_EX simply regenerates it when you run the main **.tex** file.

So from this long list, only the files with the **.bib**, **.cls** and **.tex** extensions are the most important ones. The other auxiliary files can be ignored or deleted as L^AT_EX and BibTeX will regenerate them.

6.5 Filling in Your Information in the **main.tex** File

You will need to personalise the thesis template and make it your own by filling in your own information. This is done by editing the **main.tex** file in a text editor or your favourite LaTeX environment.

Open the file and scroll down to the second large block titled *THESIS INFORMATION* where you can see the entries for *University Name*, *Department Name*, etc ...

Fill out the information about yourself, your group and institution. You can also insert web links, if you do, make sure you use the full URL, including the `http://` for this. If you don't want these to be linked, simply remove the `\href{url}{name}` and only leave the name.

When you have done this, save the file and recompile **main.tex**. All the information you filled in should now be in the PDF, complete with web links. You can now begin your thesis proper!

6.6 The **main.tex** File Explained

The **main.tex** file contains the structure of the thesis. There are plenty of written comments that explain what pages, sections and formatting the

L^AT_EX code is creating. Each major document element is divided into commented blocks with titles in all capitals to make it obvious what the following bit of code is doing. Initially there seems to be a lot of L^AT_EX code, but this is all formatting, and it has all been taken care of so you don't have to do it.

Begin by checking that your information on the title page is correct. For the thesis declaration, your institution may insist on something different than the text given. If this is the case, just replace what you see with what is required in the *DECLARATION PAGE* block.

Then comes a page which contains a funny quote. You can put your own, or quote your favourite scientist, author, person, and so on. Make sure to put the name of the person who you took the quote from.

Following this is the abstract page which summarises your work in a condensed way and can almost be used as a standalone document to describe what you have done. The text you write will cause the heading to move up so don't worry about running out of space.

Next come the acknowledgements. On this page, write about all the people who you wish to thank (not forgetting parents, partners and your advisor/supervisor).

The contents pages, list of figures and tables are all taken care of for you and do not need to be manually created or edited. The next set of pages are more likely to be optional and can be deleted since they are for a more technical thesis: insert a list of abbreviations you have used in the thesis, then a list of the physical constants and numbers you refer to and finally, a list of mathematical symbols used in any formulae. Making the effort to fill these tables means the reader has a one-stop place to refer to instead of searching the internet and references to try and find out what you meant by certain abbreviations or symbols.

The list of symbols is split into the Roman and Greek alphabets. Whereas the abbreviations and symbols ought to be listed in alphabetical order (and this is *not* done automatically for you) the list of physical constants should be grouped into similar themes.

The next page contains a one line dedication. Who will you dedicate your thesis to?

Finally, there is the block where the chapters are included. Uncomment the lines (delete the % character) as you write the chapters. Each chapter should be written in its own file and put into the *Chapters* folder and named **Chapter1**, **Chapter2**, etc... Similarly for the appendices, uncomment the lines as you need them. Each appendix should go into its own file and placed in the *Appendices* folder.

After the preamble, chapters and appendices finally comes the bibliography. The bibliography style (called *authoryear*) is used for the bibliography and is a fully featured style that will even include links to where the referenced paper can be found online. Do not underestimate how grateful your reader will be to find that a reference to a paper is just a click away. Of course, this relies on you putting the URL information into the BibTeX file in the first place.

6.7 Thesis Features and Conventions

To get the best out of this template, there are a few conventions that you may want to follow.

One of the most important (and most difficult) things to keep track of in such a long document as a thesis is consistency. Using certain conventions and ways of doing things (such as using a Todo list) makes the job easier. Of course, all of these are optional and you can adopt your own method.

6.7.1 Printing Format

This thesis template is designed for double sided printing (i.e. content on the front and back of pages) as most theses are printed and bound this way. Switching to one sided printing is as simple as uncommenting the *oneside* option of the `documentclass` command at the top of the `main.tex` file. You may then wish to adjust the margins to suit specifications from your institution.

The headers for the pages contain the page number on the outer side (so it is easy to flick through to the page you want) and the chapter name on the inner side.

The text is set to 11 point by default with single line spacing, again, you can tune the text size and spacing should you want or need to using the options at the very start of `main.tex`. The spacing can be changed similarly by replacing the *singlespacing* with *onehalfspacing* or *doublespacing*.

6.7.2 Using US Letter Paper

The paper size used in the template is A4, which is the standard size in Europe. If you are using this thesis template elsewhere and particularly in the United States, then you may have to change the A4 paper size to the US Letter size. This can be done in the margins settings section in `main.tex`.

Due to the differences in the paper size, the resulting margins may be different to what you like or require (as it is common for institutions to dictate certain margin sizes). If this is the case, then the margin sizes can be tweaked by modifying the values in the same block as where you set the paper size. Now your document should be set up for US Letter paper size with suitable margins.

6.7.3 References

The `biblatex` package is used to format the bibliography and inserts references such as this one (**Reference1**). The options used in the `main.tex` file mean that the in-text citations of references are formatted with the author(s) listed with the date of the publication. Multiple references are separated by semicolons (e.g. (**Reference2**; **Reference1**)) and references with more than three authors only show the first author with *et al.* indicating there are more authors (e.g. (**Reference3**)). This is done automatically for you. To see how you use references, have a look at the `Chapter1.tex` source file. Many reference managers allow you to simply drag the reference into the document as you type.

Scientific references should come *before* the punctuation mark if there is one (such as a comma or period). The same goes for footnotes¹. You can change this but the most important thing is to keep the convention consistent throughout the thesis. Footnotes themselves should be full, descriptive sentences (beginning with a capital letter and ending with a full stop). The APA6 states: “Footnote numbers should be superscripted, [...], following any punctuation mark except a dash.” The Chicago manual of style states: “A note number should be placed at the end of a sentence or clause. The number follows any punctuation mark except the dash, which it precedes. It follows a closing parenthesis.”

The bibliography is typeset with references listed in alphabetical order by the first author’s last name. This is similar to the APA referencing style. To see how \LaTeX typesets the bibliography, have a look at the very end of this document (or just click on the reference number links in in-text citations).

6.7.3.1 A Note on bibtex

The bibtex backend used in the template by default does not correctly handle unicode character encoding (i.e. “international” characters). You may see a warning about this in the compilation log and, if your references contain unicode characters, they may not show up correctly or at all. The solution to this is to use the biber backend instead of the outdated bibtex backend. This is done by finding this in **main.tex**: `backend=bibtex` and changing it to `backend=biber`. You will then need to delete all auxiliary BibTeX files and navigate to the template directory in your terminal (command prompt). Once there, simply type `biber main` and biber will compile your bibliography. You can then compile **main.tex** as normal and your bibliography will be updated. An alternative is to set up your LaTeX editor to compile with biber instead of bibtex, see [here](#) for how to do this for various editors.

6.7.4 Tables

Tables are an important way of displaying your results, below is an example table which was generated with this code:

```
\begin{table}
\caption{The effects of treatments X and Y on the four groups studied.}
\label{tab:treatments}
\centering
\begin{tabular}{l l l}
\toprule
\thead{Groups} & \thead{Treatment X} & \thead{Treatment Y} \\
\midrule
1 & 0.2 & 0.8 \\
2 & 0.17 & 0.7 \\
3 & 0.24 & 0.75 \\
4 & 0.68 & 0.3 \\
\bottomrule
\end{tabular}
\end{table}
```

TABLE 6.1: The effects of treatments X and Y on the four groups studied.

Groups	Treatment X	Treatment Y
1	0.2	0.8
2	0.17	0.7
3	0.24	0.75
4	0.68	0.3

You can reference tables with `\ref{<label>}` where the label is defined within the table environment. See **Chapter1.tex** for an example of the label and citation (e.g. Table 9.1).

6.7.5 Figures

There will hopefully be many figures in your thesis (that should be placed in the *Figures* folder). The way to insert figures into your thesis is to use a code template like this:

```
\begin{figure}
\centering
\includegraphics{Figures/Electron}
\decoRule
\caption[An Electron]{An electron (artist's impression).}
\label{fig:Electron}
\end{figure}
```

Also look in the source file. Putting this code into the source file produces the picture of the electron that you can see in the figure below.

Sometimes figures don't always appear where you write them in the source. The placement depends on how much space there is on the page for the figure. Sometimes there is not enough room to fit a figure directly where it should go (in relation to the text) and so \LaTeX puts it at the top of the next page. Positioning figures is the job of \LaTeX and so you should only worry about making them look good!

Figures usually should have captions just in case you need to refer to them (such as in Figure 9.1). The `\caption` command contains two parts, the first part, inside the square brackets is the title that will appear in the *List of Figures*, and so should be short. The second part in the curly brackets should contain the longer and more descriptive caption text.

The `\decoRule` command is optional and simply puts an aesthetic horizontal line below the image. If you do this for one image, do it for all of them.

\LaTeX is capable of using images in pdf, jpg and png format.

¹Such as this footnote, here down at the bottom of the page.



FIGURE 6.1: An electron (artist's impression).

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There are many different \LaTeX symbols to remember, luckily you can find the most common symbols in [The Comprehensive \$\text{\LaTeX}\$ Symbol List](#).

You can write an equation, which is automatically given an equation number by \LaTeX like this:

```
\begin{equation}
E = mc^{2}
\label{eqn:Einstein}
\end{equation}
```

This will produce Einstein's famous energy-matter equivalence equation:

$$E = mc^2 \tag{6.1}$$

All equations you write (which are not in the middle of paragraph text) are automatically given equation numbers by \LaTeX . If you don't want a particular equation numbered, use the unnumbered form:

`\[a^{2}=4 \]`

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6.9 In Closing

You have reached the end of this mini-guide. You can now rename or overwrite this pdf file and begin writing your own **Chapter1.tex** and the rest of your thesis. The easy work of setting up the structure and framework has been taken care of for you. It's now your job to fill it out!

Good luck and have lots of fun!

Guide written by —
Sunil Patel: www.sunilpatel.co.uk
Vel: LaTeXTemplates.com

Chapter 7

Learning

7.1 Welcome and Thank You

Welcome to this L^AT_EX Thesis Template, a beautiful and easy to use template for writing a thesis using the L^AT_EX typesetting system.

If you are writing a thesis (or will be in the future) and its subject is technical or mathematical (though it doesn't have to be), then creating it in L^AT_EX is highly recommended as a way to make sure you can just get down to the essential writing without having to worry over formatting or wasting time arguing with your word processor.

L^AT_EX is easily able to professionally typeset documents that run to hundreds or thousands of pages long. With simple mark-up commands, it automatically sets out the table of contents, margins, page headers and footers and keeps the formatting consistent and beautiful. One of its main strengths is the way it can easily typeset mathematics, even *heavy* mathematics. Even if those equations are the most horribly twisted and most difficult mathematical problems that can only be solved on a super-computer, you can at least count on L^AT_EX to make them look stunning.

Bin to bin comparison between pairs of data samples is beneficial when the data is not dimensionally correlated, and has no relations between one dimension in the first vector, to another. For example, when performing SIFT analysis to compare between two images for pattern recognition, there might be relations between one element to its own neighbors, but also to its paired - candidate neighbor. For this and other purposes we may consider a cross-bin comparison method.

Let us now address describing the theories behind our method.

7.2 Learning algebra $\cdot \cdot \cdot \psi$

L^AT_EX is not a WYSIWYG (What You See is What You Get) program, unlike word processors such as Microsoft Word or Apple's Pages. Instead, a document written for L^AT_EX is actually a simple, plain text file that contains *no formatting*. You tell L^AT_EX how you want the formatting in the finished document by writing in simple commands amongst the text, for example, if I want to use *italic text for emphasis*, I write the `\emph{text}` command and put the text I want in italics in between the curly braces. This means that L^AT_EX is a "mark-up" language, very much like HTML.

7.2.1 A (not so short) Introduction to L^AT_EX

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It is also available in several other languages. Find yours from the list on this page: <http://www.ctan.org/tex-archive/info/lshort/>

It is recommended to take a little time out to learn how to use L^AT_EX by creating several, small ‘test’ documents, or having a close look at several templates on:

<http://www.LaTeXTemplates.com>

Making the effort now means you’re not stuck learning the system when what you *really* need to be doing is writing your thesis.

7.2.2 A Short Math Guide for L^AT_EX

If you are writing a technical or mathematical thesis, then you may want to read the document by the AMS (American Mathematical Society) called, “A Short Math Guide for L^AT_EX”. It can be found online here: <http://www.ams.org/tex/amslatex.html> under the “Additional Documentation” section towards the bottom of the page.

7.2.3 Common L^AT_EX Math Symbols

There are a multitude of mathematical symbols available for L^AT_EX and it would take a great effort to learn the commands for them all. The most common ones you are likely to use are shown on this page: <http://www.sunilpatel.co.uk/latex-type/latex-math-symbols/>

You can use this page as a reference or crib sheet, the symbols are rendered as large, high quality images so you can quickly find the L^AT_EX command for the symbol you need.

7.2.4 L^AT_EX on a Mac

The L^AT_EX distribution is available for many systems including Windows, Linux and Mac OS X. The package for OS X is called MacTeX and it contains all the applications you need – bundled together and pre-customized – for a fully working L^AT_EX environment and work flow.

MacTeX includes a custom dedicated L^AT_EX editor called TeXShop for writing your ‘.tex’ files and BibDesk: a program to manage your references and create your bibliography section just as easily as managing songs and creating playlists in iTunes.

7.3 Getting Started with this Template

If you are familiar with L^AT_EX, then you should explore the directory structure of the template and then proceed to place your own information into the *THESIS INFORMATION* block of the `main.tex` file. You can then

Algorithm 5 Embedding Procedure - General

Input: L sized, vectorized n -dimensional dataset**Input:** number of centers per dimension - C **Output:** $emb - set$: L sized set, embedded, sparsed vectors

```

1: Find centers vectors
2:  $V$  shall be a set of centers vectors
3: for all  $dim$  in  $n$  do
4:    $V_{dim} \leftarrow centers \ vector \ per \ dim$ 
5: end for
6: Find embedded coefficients for all dataset
7:  $\vec{\phi} = C^n$  length empty  $emb - set$  embedded vectors
8: for all  $vec$  in  $L$  do
9:   find  $vec$  bounding hypercube
10:  find  $vec$  bounding simplex (permutation method)
11:   $\vec{\lambda} \leftarrow$  find  $vec$  barycentric coefficients
12:   $\vec{\lambda} \leftarrow$  normalize( $\vec{\lambda}$ )
13: end for
14: Assign
15: for all  $\vec{eve\ell}$  in  $emb - set$  do
16:   $inds \leftarrow$  find vertices from hypercube and simplex locations
17:  for all  $i$  in  $inds$  do
18:     $\vec{eve\ell}(i) \leftarrow \vec{\lambda}(j(i))$  -  $j$  is the assigning function between the coef.
      vector and embedding vector
19:  end for
20: end for
21: return  $\vec{\phi}$ 

```

modify the rest of this file to your unique specifications based on your degree/university. Section 9.5 on page 83 will help you do this. Make sure you also read section 9.7 about thesis conventions to get the most out of this template.

If you are new to \LaTeX it is recommended that you carry on reading through the rest of the information in this document.

Before you begin using this template you should ensure that its style complies with the thesis style guidelines imposed by your institution. In most cases this template style and layout will be suitable. If it is not, it may only require a small change to bring the template in line with your institution's recommendations. These modifications will need to be done on the `MastersDoctoralThesis.cls` file.

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This \LaTeX Thesis Template is originally based and created around a \LaTeX style file created by Steve R. Gunn from the University of Southampton (UK), department of Electronics and Computer Science. You can find his original thesis style file at his site, here: <http://www.ecs.soton.ac.uk/~srg/softwaretools/document/templates/>

Steve's `ecsthesis.cls` was then taken by Sunil Patel who modified it by creating a skeleton framework and folder structure to place the thesis files in. The resulting template can be found on Sunil's site here: <http://www.sunilpatel.co.uk/thesis-template>

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7.4 What this Template Includes

7.4.1 Folders

This template comes as a single zip file that expands out to several files and folders. The folder names are mostly self-explanatory:

Appendices – this is the folder where you put the appendices. Each appendix should go into its own separate `.tex` file. An example and template are included in the directory.

Chapters – this is the folder where you put the thesis chapters. A thesis usually has about six chapters, though there is no hard rule on this. Each chapter should go in its own separate `.tex` file and they can be split as:

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This chapter layout is specialised for the experimental sciences.

Figures – this folder contains all figures for the thesis. These are the final images that will go into the thesis document.

7.4.2 Files

Included are also several files, most of them are plain text and you can see their contents in a text editor. After initial compilation, you will see that more auxiliary files are created by L^AT_EX or BibTeX and which you don't need to delete or worry about:

example.bib – this is an important file that contains all the bibliographic information and references that you will be citing in the thesis for use with BibTeX. You can write it manually, but there are reference manager programs available that will create and manage it for you. Bibliographies in L^AT_EX are a large subject and you may need to read about BibTeX before starting with this. Many modern reference managers will allow you to export your references in BibTeX format which greatly eases the amount of work you have to do.

MastersDoctoralThesis.cls – this is an important file. It is the class file that tells L^AT_EX how to format the thesis.

main.pdf – this is your beautifully typeset thesis (in the PDF file format) created by L^AT_EX. It is supplied in the PDF with the template and after you compile the template you should get an identical version.

main.tex – this is an important file. This is the file that you tell L^AT_EX to compile to produce your thesis as a PDF file. It contains the framework and constructs that tell L^AT_EX how to layout the thesis. It is heavily commented so you can read exactly what each line of code does and why it is there. After you put your own information into the *THESIS INFORMATION* block – you have now started your thesis!

Files that are *not* included, but are created by L^AT_EX as auxiliary files include:

main.aux – this is an auxiliary file generated by L^AT_EX, if it is deleted L^AT_EX simply regenerates it when you run the main **.tex** file.

main.bbl – this is an auxiliary file generated by BibTeX, if it is deleted, BibTeX simply regenerates it when you run the **main.aux** file. Whereas the **.bib** file contains all the references you have, this **.bbl** file contains the references you have actually cited in the thesis and is used to build the bibliography section of the thesis.

main.blg – this is an auxiliary file generated by BibTeX, if it is deleted BibTeX simply regenerates it when you run the main **.aux** file.

main.lof – this is an auxiliary file generated by L^AT_EX, if it is deleted L^AT_EX simply regenerates it when you run the main **.tex** file. It tells L^AT_EX how to build the *List of Figures* section.

main.log – this is an auxiliary file generated by L^AT_EX, if it is deleted L^AT_EX simply regenerates it when you run the main **.tex** file. It contains messages from L^AT_EX, if you receive errors and warnings from L^AT_EX, they will be in this **.log** file.

main.lot – this is an auxiliary file generated by L^AT_EX, if it is deleted L^AT_EX simply regenerates it when you run the main **.tex** file. It tells L^AT_EX how to build the *List of Tables* section.

main.out – this is an auxiliary file generated by L^AT_EX, if it is deleted L^AT_EX simply regenerates it when you run the main **.tex** file.

So from this long list, only the files with the **.bib**, **.cls** and **.tex** extensions are the most important ones. The other auxiliary files can be ignored or deleted as L^AT_EX and BibTeX will regenerate them.

7.5 Filling in Your Information in the **main.tex** File

You will need to personalise the thesis template and make it your own by filling in your own information. This is done by editing the **main.tex** file in a text editor or your favourite LaTeX environment.

Open the file and scroll down to the second large block titled *THESIS INFORMATION* where you can see the entries for *University Name*, *Department Name*, etc ...

Fill out the information about yourself, your group and institution. You can also insert web links, if you do, make sure you use the full URL, including the `http://` for this. If you don't want these to be linked, simply remove the `\href{url}{name}` and only leave the name.

When you have done this, save the file and recompile **main.tex**. All the information you filled in should now be in the PDF, complete with web links. You can now begin your thesis proper!

7.6 The **main.tex** File Explained

The **main.tex** file contains the structure of the thesis. There are plenty of written comments that explain what pages, sections and formatting the L^AT_EX code is creating. Each major document element is divided into commented blocks with titles in all capitals to make it obvious what the following bit of code is doing. Initially there seems to be a lot of L^AT_EX code, but this is all formatting, and it has all been taken care of so you don't have to do it.

Begin by checking that your information on the title page is correct. For the thesis declaration, your institution may insist on something different than the text given. If this is the case, just replace what you see with what is required in the *DECLARATION PAGE* block.

Then comes a page which contains a funny quote. You can put your own, or quote your favourite scientist, author, person, and so on. Make sure to put the name of the person who you took the quote from.

Following this is the abstract page which summarises your work in a condensed way and can almost be used as a standalone document to describe what you have done. The text you write will cause the heading to move up so don't worry about running out of space.

Next come the acknowledgements. On this page, write about all the people who you wish to thank (not forgetting parents, partners and your advisor/supervisor).

The contents pages, list of figures and tables are all taken care of for you and do not need to be manually created or edited. The next set of pages

are more likely to be optional and can be deleted since they are for a more technical thesis: insert a list of abbreviations you have used in the thesis, then a list of the physical constants and numbers you refer to and finally, a list of mathematical symbols used in any formulae. Making the effort to fill these tables means the reader has a one-stop place to refer to instead of searching the internet and references to try and find out what you meant by certain abbreviations or symbols.

The list of symbols is split into the Roman and Greek alphabets. Whereas the abbreviations and symbols ought to be listed in alphabetical order (and this is *not* done automatically for you) the list of physical constants should be grouped into similar themes.

The next page contains a one line dedication. Who will you dedicate your thesis to?

Finally, there is the block where the chapters are included. Uncomment the lines (delete the % character) as you write the chapters. Each chapter should be written in its own file and put into the *Chapters* folder and named **Chapter1**, **Chapter2**, etc. . . Similarly for the appendices, uncomment the lines as you need them. Each appendix should go into its own file and placed in the *Appendices* folder.

After the preamble, chapters and appendices finally comes the bibliography. The bibliography style (called *authoryear*) is used for the bibliography and is a fully featured style that will even include links to where the referenced paper can be found online. Do not underestimate how grateful your reader will be to find that a reference to a paper is just a click away. Of course, this relies on you putting the URL information into the BibTeX file in the first place.

7.7 Thesis Features and Conventions

To get the best out of this template, there are a few conventions that you may want to follow.

One of the most important (and most difficult) things to keep track of in such a long document as a thesis is consistency. Using certain conventions and ways of doing things (such as using a Todo list) makes the job easier. Of course, all of these are optional and you can adopt your own method.

7.7.1 Printing Format

This thesis template is designed for double sided printing (i.e. content on the front and back of pages) as most theses are printed and bound this way. Switching to one sided printing is as simple as uncommenting the *oneside* option of the `documentclass` command at the top of the **main.tex** file. You may then wish to adjust the margins to suit specifications from your institution.

The headers for the pages contain the page number on the outer side (so it is easy to flick through to the page you want) and the chapter name on the inner side.

The text is set to 11 point by default with single line spacing, again, you can tune the text size and spacing should you want or need to using the options at the very start of **main.tex**. The spacing can be changed similarly by replacing the *singlespacing* with *onehalfspacing* or *doublespacing*.

7.7.2 Using US Letter Paper

The paper size used in the template is A4, which is the standard size in Europe. If you are using this thesis template elsewhere and particularly in the United States, then you may have to change the A4 paper size to the US Letter size. This can be done in the margins settings section in **main.tex**.

Due to the differences in the paper size, the resulting margins may be different to what you like or require (as it is common for institutions to dictate certain margin sizes). If this is the case, then the margin sizes can be tweaked by modifying the values in the same block as where you set the paper size. Now your document should be set up for US Letter paper size with suitable margins.

7.7.3 References

The **biblatex** package is used to format the bibliography and inserts references such as this one (**Reference1**). The options used in the **main.tex** file mean that the in-text citations of references are formatted with the author(s) listed with the date of the publication. Multiple references are separated by semicolons (e.g. (**Reference2**; **Reference1**)) and references with more than three authors only show the first author with *et al.* indicating there are more authors (e.g. (**Reference3**)). This is done automatically for you. To see how you use references, have a look at the **Chapter1.tex** source file. Many reference managers allow you to simply drag the reference into the document as you type.

Scientific references should come *before* the punctuation mark if there is one (such as a comma or period). The same goes for footnotes¹. You can change this but the most important thing is to keep the convention consistent throughout the thesis. Footnotes themselves should be full, descriptive sentences (beginning with a capital letter and ending with a full stop). The APA6 states: "Footnote numbers should be superscripted, [...], following any punctuation mark except a dash." The Chicago manual of style states: "A note number should be placed at the end of a sentence or clause. The number follows any punctuation mark except the dash, which it precedes. It follows a closing parenthesis."

The bibliography is typeset with references listed in alphabetical order by the first author's last name. This is similar to the APA referencing style. To see how **L^AT_EX** typesets the bibliography, have a look at the very end of this document (or just click on the reference number links in in-text citations).

7.7.3.1 A Note on **bibtex**

The **bibtex** backend used in the template by default does not correctly handle unicode character encoding (i.e. "international" characters). You may

¹Such as this footnote, here down at the bottom of the page.

TABLE 7.1: The effects of treatments X and Y on the four groups studied.

Groups	Treatment X	Treatment Y
1	0.2	0.8
2	0.17	0.7
3	0.24	0.75
4	0.68	0.3

see a warning about this in the compilation log and, if your references contain unicode characters, they may not show up correctly or at all. The solution to this is to use the biber backend instead of the outdated bibtex backend. This is done by finding this in **main.tex**: `backend=bibtex` and changing it to `backend=biber`. You will then need to delete all auxiliary BibTeX files and navigate to the template directory in your terminal (command prompt). Once there, simply type `biber main` and biber will compile your bibliography. You can then compile **main.tex** as normal and your bibliography will be updated. An alternative is to set up your LaTeX editor to compile with biber instead of bibtex, see [here](#) for how to do this for various editors.

7.7.4 Tables

Tables are an important way of displaying your results, below is an example table which was generated with this code:

```
\begin{table}
\caption{The effects of treatments X and Y on the four groups studied.}
\label{tab:treatments}
\centering
\begin{tabular}{l l l}
\toprule
\thead{Groups} & \thead{Treatment X} & \thead{Treatment Y} \\
\midrule
1 & 0.2 & 0.8 \\
2 & 0.17 & 0.7 \\
3 & 0.24 & 0.75 \\
4 & 0.68 & 0.3 \\
\bottomrule
\end{tabular}
\end{table}
```

You can reference tables with `\ref{<label>}` where the label is defined within the table environment. See **Chapter1.tex** for an example of the label and citation (e.g. Table [9.1](#)).

7.7.5 Figures

There will hopefully be many figures in your thesis (that should be placed in the *Figures* folder). The way to insert figures into your thesis is to use a code template like this:

```

\begin{figure}
\centering
\includegraphics{Figures/Electron}
\decoRule
\caption[An Electron]{An electron (artist's impression).}
\label{fig:Electron}
\end{figure}

```

Also look in the source file. Putting this code into the source file produces the picture of the electron that you can see in the figure below.



FIGURE 7.1: An electron (artist's impression).

Sometimes figures don't always appear where you write them in the source. The placement depends on how much space there is on the page for the figure. Sometimes there is not enough room to fit a figure directly where it should go (in relation to the text) and so \LaTeX puts it at the top of the next page. Positioning figures is the job of \LaTeX and so you should only worry about making them look good!

Figures usually should have captions just in case you need to refer to them (such as in Figure 9.1). The `\caption` command contains two parts, the first part, inside the square brackets is the title that will appear in the *List of Figures*, and so should be short. The second part in the curly brackets should contain the longer and more descriptive caption text.

The `\decoRule` command is optional and simply puts an aesthetic horizontal line below the image. If you do this for one image, do it for all of them.

\LaTeX is capable of using images in pdf, jpg and png format.

7.7.6 Typesetting mathematics

If your thesis is going to contain heavy mathematical content, be sure that \LaTeX will make it look beautiful, even though it won't be able to solve the equations for you.

The “Not So Short Introduction to \LaTeX ” (available on [CTAN](http://www.ctan.org)) should tell you everything you need to know for most cases of typesetting mathematics. If you need more information, a much more thorough mathematical guide is available from the AMS called, “A Short Math Guide to \LaTeX ” and can be downloaded from: [ftp://ftp.ams.org/pub/tex/doc/amsmath/short-math-guide.pdf](http://ftp.ams.org/pub/tex/doc/amsmath/short-math-guide.pdf)

There are many different \LaTeX symbols to remember, luckily you can find the most common symbols in [The Comprehensive \$\text{\LaTeX}\$ Symbol List](#).

You can write an equation, which is automatically given an equation number by \LaTeX like this:

```
\begin{equation}
E = mc^{2}
\label{eqn:Einstein}
\end{equation}
```

This will produce Einstein's famous energy-matter equivalence equation:

$$E = mc^2 \quad (7.1)$$

All equations you write (which are not in the middle of paragraph text) are automatically given equation numbers by \LaTeX . If you don't want a particular equation numbered, use the unnumbered form:

```
\[ a^{2}=4 \]
```

7.8 Sectioning and Subsectioning

You should break your thesis up into nice, bite-sized sections and subsections. \LaTeX automatically builds a table of Contents by looking at all the `\chapter{}`, `\section{}` and `\subsection{}` commands you write in the source.

The Table of Contents should only list the sections to three (3) levels. A `\chapter{}` is level zero (0). A `\section{}` is level one (1) and so a `\subsection{}` is level two (2). In your thesis it is likely that you will even use a `\subsubsection{}`, which is level three (3). The depth to which the Table of Contents is formatted is set within **MastersDoctoralThesis.cls**. If you need this changed, you can do it in **main.tex**.

7.9 In Closing

You have reached the end of this mini-guide. You can now rename or overwrite this pdf file and begin writing your own **Chapter1.tex** and the rest of your thesis. The easy work of setting up the structure and framework has been taken care of for you. It's now your job to fill it out!

Good luck and have lots of fun!

Guide written by —
Sunil Patel: www.sunilpatel.co.uk
Vel: LaTeXTemplates.com

Chapter 8

Results

8.1 Welcome and Thank You

Welcome to this L^AT_EX Thesis Template, a beautiful and easy to use template for writing a thesis using the L^AT_EX typesetting system.

If you are writing a thesis (or will be in the future) and its subject is technical or mathematical (though it doesn't have to be), then creating it in L^AT_EX is highly recommended as a way to make sure you can just get down to the essential writing without having to worry over formatting or wasting time arguing with your word processor.

L^AT_EX is easily able to professionally typeset documents that run to hundreds or thousands of pages long. With simple mark-up commands, it automatically sets out the table of contents, margins, page headers and footers and keeps the formatting consistent and beautiful. One of its main strengths is the way it can easily typeset mathematics, even *heavy* mathematics. Even if those equations are the most horribly twisted and most difficult mathematical problems that can only be solved on a super-computer, you can at least count on L^AT_EX to make them look stunning.

8.2 Learning algebra ··· ψ

L^AT_EX is not a WYSIWYG (What You See is What You Get) program, unlike word processors such as Microsoft Word or Apple's Pages. Instead, a document written for L^AT_EX is actually a simple, plain text file that contains *no formatting*. You tell L^AT_EX how you want the formatting in the finished document by writing in simple commands amongst the text, for example, if I want to use *italic text for emphasis*, I write the `\emph{text}` command and put the text I want in italics in between the curly braces. This means that L^AT_EX is a "mark-up" language, very much like HTML.

8.2.1 A (not so short) Introduction to L^AT_EX_d

If you are new to L^AT_EX, there is a very good eBook – freely available online as a PDF file – called, "The Not So Short Introduction to L^AT_EX". The book's title is typically shortened to just *lshort*. You can download the latest version (as it is occasionally updated) from here: <http://www.ctan.org/tex-archive/info/lshort/english/lshort.pdf>

It is also available in several other languages. Find yours from the list on this page: <http://www.ctan.org/tex-archive/info/lshort/>

It is recommended to take a little time out to learn how to use L^AT_EX by creating several, small 'test' documents, or having a close look at several

templates on:

<http://www.LaTeXTemplates.com>

Making the effort now means you're not stuck learning the system when what you *really* need to be doing is writing your thesis.

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Input: number of centers per dimension - C

Output: $emb - set$: L sized set, embedded, sparsed vectors

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1: Find centers vectors
2:  $V$  shall be a set of centers vectors
3: for all  $dim$  in  $n$  do
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5: end for
6: Find embedded coefficients for all dataset
7:  $\vec{\phi} = C^n$  length empty  $emb - set$  embedded vectors
8: for all  $vec$  in  $L$  do
9:   find  $vec$  bounding hypercube
10:  find  $vec$  bounding simplex (permutation method)
11:   $\vec{\lambda} \leftarrow$  find  $vec$  barycentric coefficients
12:   $\vec{\lambda} \leftarrow$  normalize( $\vec{\lambda}$ )
13: end for
14: Assign
15: for all  $\vec{vec}$  in  $emb - set$  do
16:    $inds \leftarrow$  find vertices from hypercube and simplex locations
17:   for all  $i$  in  $inds$  do
18:      $\vec{vec}(i) \leftarrow \vec{\lambda}(j(i))$  -  $j$  is the assigning function between the coef.
       vector and embedding vector
19:   end for
20: end for
21: return  $\vec{\phi}$ 

```

8.2.4 L^AT_EX on a Mac

The L^AT_EX distribution is available for many systems including Windows, Linux and Mac OS X. The package for OS X is called MacTeX and it contains all the applications you need – bundled together and pre-customized – for a fully working L^AT_EX environment and work flow.

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- Chapter 6: Discussion of the experimental results
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This chapter layout is specialised for the experimental sciences.

Figures – this folder contains all figures for the thesis. These are the final images that will go into the thesis document.

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Included are also several files, most of them are plain text and you can see their contents in a text editor. After initial compilation, you will see that more auxiliary files are created by \LaTeX or BibTeX and which you don't need to delete or worry about:

example.bib – this is an important file that contains all the bibliographic information and references that you will be citing in the thesis for use with BibTeX. You can write it manually, but there are reference manager programs available that will create and manage it for you. Bibliographies in \LaTeX are a large subject and you may need to read about BibTeX before starting with this. Many modern reference managers will allow you to export your references in BibTeX format which greatly eases the amount of work you have to do.

MastersDoctoralThesis.cls – this is an important file. It is the class file that tells \LaTeX how to format the thesis.

main.pdf – this is your beautifully typeset thesis (in the PDF file format) created by \LaTeX . It is supplied in the PDF with the template and after you compile the template you should get an identical version.

main.tex – this is an important file. This is the file that you tell \LaTeX to compile to produce your thesis as a PDF file. It contains the framework and constructs that tell \LaTeX how to layout the thesis. It is heavily commented so you can read exactly what each line of code does and why it is there.

After you put your own information into the *THESIS INFORMATION* block – you have now started your thesis!

Files that are *not* included, but are created by L^AT_EX as auxiliary files include:

main.aux – this is an auxiliary file generated by L^AT_EX, if it is deleted L^AT_EX simply regenerates it when you run the main **.tex** file.

main.bbl – this is an auxiliary file generated by BibTeX, if it is deleted, BibTeX simply regenerates it when you run the **main.aux** file. Whereas the **.bib** file contains all the references you have, this **.bbl** file contains the references you have actually cited in the thesis and is used to build the bibliography section of the thesis.

main.blg – this is an auxiliary file generated by BibTeX, if it is deleted BibTeX simply regenerates it when you run the main **.aux** file.

main.lof – this is an auxiliary file generated by L^AT_EX, if it is deleted L^AT_EX simply regenerates it when you run the main **.tex** file. It tells L^AT_EX how to build the *List of Figures* section.

main.log – this is an auxiliary file generated by L^AT_EX, if it is deleted L^AT_EX simply regenerates it when you run the main **.tex** file. It contains messages from L^AT_EX, if you receive errors and warnings from L^AT_EX, they will be in this **.log** file.

main.lot – this is an auxiliary file generated by L^AT_EX, if it is deleted L^AT_EX simply regenerates it when you run the main **.tex** file. It tells L^AT_EX how to build the *List of Tables* section.

main.out – this is an auxiliary file generated by L^AT_EX, if it is deleted L^AT_EX simply regenerates it when you run the main **.tex** file.

So from this long list, only the files with the **.bib**, **.cls** and **.tex** extensions are the most important ones. The other auxiliary files can be ignored or deleted as L^AT_EX and BibTeX will regenerate them.

8.5 Filling in Your Information in the **main.tex** File

You will need to personalise the thesis template and make it your own by filling in your own information. This is done by editing the **main.tex** file in a text editor or your favourite LaTeX environment.

Open the file and scroll down to the second large block titled *THESIS INFORMATION* where you can see the entries for *University Name*, *Department Name*, etc ...

Fill out the information about yourself, your group and institution. You can also insert web links, if you do, make sure you use the full URL, including the `http://` for this. If you don't want these to be linked, simply remove the `\href{url}{name}` and only leave the name.

When you have done this, save the file and recompile **main.tex**. All the information you filled in should now be in the PDF, complete with web links. You can now begin your thesis proper!

8.6 The **main.tex** File Explained

The **main.tex** file contains the structure of the thesis. There are plenty of written comments that explain what pages, sections and formatting the

L^AT_EX code is creating. Each major document element is divided into commented blocks with titles in all capitals to make it obvious what the following bit of code is doing. Initially there seems to be a lot of L^AT_EX code, but this is all formatting, and it has all been taken care of so you don't have to do it.

Begin by checking that your information on the title page is correct. For the thesis declaration, your institution may insist on something different than the text given. If this is the case, just replace what you see with what is required in the *DECLARATION PAGE* block.

Then comes a page which contains a funny quote. You can put your own, or quote your favourite scientist, author, person, and so on. Make sure to put the name of the person who you took the quote from.

Following this is the abstract page which summarises your work in a condensed way and can almost be used as a standalone document to describe what you have done. The text you write will cause the heading to move up so don't worry about running out of space.

Next come the acknowledgements. On this page, write about all the people who you wish to thank (not forgetting parents, partners and your advisor/supervisor).

The contents pages, list of figures and tables are all taken care of for you and do not need to be manually created or edited. The next set of pages are more likely to be optional and can be deleted since they are for a more technical thesis: insert a list of abbreviations you have used in the thesis, then a list of the physical constants and numbers you refer to and finally, a list of mathematical symbols used in any formulae. Making the effort to fill these tables means the reader has a one-stop place to refer to instead of searching the internet and references to try and find out what you meant by certain abbreviations or symbols.

The list of symbols is split into the Roman and Greek alphabets. Whereas the abbreviations and symbols ought to be listed in alphabetical order (and this is *not* done automatically for you) the list of physical constants should be grouped into similar themes.

The next page contains a one line dedication. Who will you dedicate your thesis to?

Finally, there is the block where the chapters are included. Uncomment the lines (delete the % character) as you write the chapters. Each chapter should be written in its own file and put into the *Chapters* folder and named **Chapter1**, **Chapter2**, etc... Similarly for the appendices, uncomment the lines as you need them. Each appendix should go into its own file and placed in the *Appendices* folder.

After the preamble, chapters and appendices finally comes the bibliography. The bibliography style (called *authoryear*) is used for the bibliography and is a fully featured style that will even include links to where the referenced paper can be found online. Do not underestimate how grateful your reader will be to find that a reference to a paper is just a click away. Of course, this relies on you putting the URL information into the BibTeX file in the first place.

8.7 Thesis Features and Conventions

To get the best out of this template, there are a few conventions that you may want to follow.

One of the most important (and most difficult) things to keep track of in such a long document as a thesis is consistency. Using certain conventions and ways of doing things (such as using a Todo list) makes the job easier. Of course, all of these are optional and you can adopt your own method.

8.7.1 Printing Format

This thesis template is designed for double sided printing (i.e. content on the front and back of pages) as most theses are printed and bound this way. Switching to one sided printing is as simple as uncommenting the *oneside* option of the `documentclass` command at the top of the `main.tex` file. You may then wish to adjust the margins to suit specifications from your institution.

The headers for the pages contain the page number on the outer side (so it is easy to flick through to the page you want) and the chapter name on the inner side.

The text is set to 11 point by default with single line spacing, again, you can tune the text size and spacing should you want or need to using the options at the very start of `main.tex`. The spacing can be changed similarly by replacing the *singlespacing* with *onehalfspacing* or *doublespacing*.

8.7.2 Using US Letter Paper

The paper size used in the template is A4, which is the standard size in Europe. If you are using this thesis template elsewhere and particularly in the United States, then you may have to change the A4 paper size to the US Letter size. This can be done in the margins settings section in `main.tex`.

Due to the differences in the paper size, the resulting margins may be different to what you like or require (as it is common for institutions to dictate certain margin sizes). If this is the case, then the margin sizes can be tweaked by modifying the values in the same block as where you set the paper size. Now your document should be set up for US Letter paper size with suitable margins.

8.7.3 References

The `biblatex` package is used to format the bibliography and inserts references such as this one (**Reference1**). The options used in the `main.tex` file mean that the in-text citations of references are formatted with the author(s) listed with the date of the publication. Multiple references are separated by semicolons (e.g. (**Reference2**; **Reference1**)) and references with more than three authors only show the first author with *et al.* indicating there are more authors (e.g. (**Reference3**)). This is done automatically for you. To see how you use references, have a look at the `Chapter1.tex` source file. Many reference managers allow you to simply drag the reference into the document as you type.

Scientific references should come *before* the punctuation mark if there is one (such as a comma or period). The same goes for footnotes¹. You can change this but the most important thing is to keep the convention consistent throughout the thesis. Footnotes themselves should be full, descriptive sentences (beginning with a capital letter and ending with a full stop). The APA6 states: “Footnote numbers should be superscripted, [...], following any punctuation mark except a dash.” The Chicago manual of style states: “A note number should be placed at the end of a sentence or clause. The number follows any punctuation mark except the dash, which it precedes. It follows a closing parenthesis.”

The bibliography is typeset with references listed in alphabetical order by the first author’s last name. This is similar to the APA referencing style. To see how \LaTeX typesets the bibliography, have a look at the very end of this document (or just click on the reference number links in in-text citations).

8.7.3.1 A Note on bibtex

The bibtex backend used in the template by default does not correctly handle unicode character encoding (i.e. “international” characters). You may see a warning about this in the compilation log and, if your references contain unicode characters, they may not show up correctly or at all. The solution to this is to use the biber backend instead of the outdated bibtex backend. This is done by finding this in **main.tex**: `backend=bibtex` and changing it to `backend=biber`. You will then need to delete all auxiliary BibTeX files and navigate to the template directory in your terminal (command prompt). Once there, simply type `biber main` and biber will compile your bibliography. You can then compile **main.tex** as normal and your bibliography will be updated. An alternative is to set up your LaTeX editor to compile with biber instead of bibtex, see [here](#) for how to do this for various editors.

8.7.4 Tables

Tables are an important way of displaying your results, below is an example table which was generated with this code:

```
\begin{table}
\caption{The effects of treatments X and Y on the four groups studied.}
\label{tab:treatments}
\centering
\begin{tabular}{l l l}
\toprule
\thead{Groups} & \thead{Treatment X} & \thead{Treatment Y} \\
\midrule
1 & 0.2 & 0.8 \\
2 & 0.17 & 0.7 \\
3 & 0.24 & 0.75 \\
4 & 0.68 & 0.3 \\
\bottomrule
\end{tabular}
\end{table}
```

TABLE 8.1: The effects of treatments X and Y on the four groups studied.

Groups	Treatment X	Treatment Y
1	0.2	0.8
2	0.17	0.7
3	0.24	0.75
4	0.68	0.3

You can reference tables with `\ref{<label>}` where the label is defined within the table environment. See **Chapter1.tex** for an example of the label and citation (e.g. Table 9.1).

8.7.5 Figures

There will hopefully be many figures in your thesis (that should be placed in the *Figures* folder). The way to insert figures into your thesis is to use a code template like this:

```
\begin{figure}
\centering
\includegraphics{Figures/Electron}
\decoRule
\caption[An Electron]{An electron (artist's impression).}
\label{fig:Electron}
\end{figure}
```

Also look in the source file. Putting this code into the source file produces the picture of the electron that you can see in the figure below.

Sometimes figures don't always appear where you write them in the source. The placement depends on how much space there is on the page for the figure. Sometimes there is not enough room to fit a figure directly where it should go (in relation to the text) and so \LaTeX puts it at the top of the next page. Positioning figures is the job of \LaTeX and so you should only worry about making them look good!

Figures usually should have captions just in case you need to refer to them (such as in Figure 9.1). The `\caption` command contains two parts, the first part, inside the square brackets is the title that will appear in the *List of Figures*, and so should be short. The second part in the curly brackets should contain the longer and more descriptive caption text.

The `\decoRule` command is optional and simply puts an aesthetic horizontal line below the image. If you do this for one image, do it for all of them.

\LaTeX is capable of using images in pdf, jpg and png format.

¹Such as this footnote, here down at the bottom of the page.



FIGURE 8.1: An electron (artist's impression).

8.7.6 Typesetting mathematics

If your thesis is going to contain heavy mathematical content, be sure that \LaTeX will make it look beautiful, even though it won't be able to solve the equations for you.

The “Not So Short Introduction to \LaTeX ” (available on [CTAN](#)) should tell you everything you need to know for most cases of typesetting mathematics. If you need more information, a much more thorough mathematical guide is available from the AMS called, “A Short Math Guide to \LaTeX ” and can be downloaded from: <ftp://ftp.ams.org/pub/tex/doc/amsmath/short-math-guide.pdf>

There are many different \LaTeX symbols to remember, luckily you can find the most common symbols in [The Comprehensive \$\text{\LaTeX}\$ Symbol List](#).

You can write an equation, which is automatically given an equation number by \LaTeX like this:

```
\begin{equation}
E = mc^{2}
\label{eqn:Einstein}
\end{equation}
```

This will produce Einstein's famous energy-matter equivalence equation:

$$E = mc^2 \tag{8.1}$$

All equations you write (which are not in the middle of paragraph text) are automatically given equation numbers by \LaTeX . If you don't want a particular equation numbered, use the unnumbered form:

`\[a^{2}=4 \]`

8.8 Sectioning and Subsectioning

You should break your thesis up into nice, bite-sized sections and subsections. \LaTeX automatically builds a table of Contents by looking at all the `\chapter{}`, `\section{}` and `\subsection{}` commands you write in the source.

The Table of Contents should only list the sections to three (3) levels. A `chapter{}` is level zero (0). A `\section{}` is level one (1) and so a `\subsection{}` is level two (2). In your thesis it is likely that you will even use a `subsubsection{}`, which is level three (3). The depth to which the Table of Contents is formatted is set within **MastersDoctoralThesis.cls**. If you need this changed, you can do it in **main.tex**.

8.9 In Closing

You have reached the end of this mini-guide. You can now rename or overwrite this pdf file and begin writing your own **Chapter1.tex** and the rest of your thesis. The easy work of setting up the structure and framework has been taken care of for you. It's now your job to fill it out!

Good luck and have lots of fun!

Guide written by —
Sunil Patel: www.sunilpatel.co.uk
Vel: LaTeXTemplates.com

Chapter 9

Conclusions and discussion

9.1 Welcome and Thank You

Welcome to this L^AT_EX Thesis Template, a beautiful and easy to use template for writing a thesis using the L^AT_EX typesetting system.

If you are writing a thesis (or will be in the future) and its subject is technical or mathematical (though it doesn't have to be), then creating it in L^AT_EX is highly recommended as a way to make sure you can just get down to the essential writing without having to worry over formatting or wasting time arguing with your word processor.

L^AT_EX is easily able to professionally typeset documents that run to hundreds or thousands of pages long. With simple mark-up commands, it automatically sets out the table of contents, margins, page headers and footers and keeps the formatting consistent and beautiful. One of its main strengths is the way it can easily typeset mathematics, even *heavy* mathematics. Even if those equations are the most horribly twisted and most difficult mathematical problems that can only be solved on a super-computer, you can at least count on L^AT_EX to make them look stunning.

9.2 Learning algebra ··· ψ

L^AT_EX is not a WYSIWYG (What You See is What You Get) program, unlike word processors such as Microsoft Word or Apple's Pages. Instead, a document written for L^AT_EX is actually a simple, plain text file that contains *no formatting*. You tell L^AT_EX how you want the formatting in the finished document by writing in simple commands amongst the text, for example, if I want to use *italic text for emphasis*, I write the `\emph{text}` command and put the text I want in italics in between the curly braces. This means that L^AT_EX is a "mark-up" language, very much like HTML.

9.2.1 A (not so short) Introduction to L^AT_EX_d

If you are new to L^AT_EX, there is a very good eBook – freely available online as a PDF file – called, "The Not So Short Introduction to L^AT_EX". The book's title is typically shortened to just *lshort*. You can download the latest version (as it is occasionally updated) from here: <http://www.ctan.org/tex-archive/info/lshort/english/lshort.pdf>

It is also available in several other languages. Find yours from the list on this page: <http://www.ctan.org/tex-archive/info/lshort/>

It is recommended to take a little time out to learn how to use L^AT_EX by creating several, small 'test' documents, or having a close look at several

templates on:

<http://www.LaTeXTemplates.com>

Making the effort now means you're not stuck learning the system when what you *really* need to be doing is writing your thesis.

9.2.2 A Short Math Guide for L^AT_EX

If you are writing a technical or mathematical thesis, then you may want to read the document by the AMS (American Mathematical Society) called, "A Short Math Guide for L^AT_EX". It can be found online here: <http://www.ams.org/tex/amslatex.html> under the "Additional Documentation" section towards the bottom of the page.

9.2.3 Common L^AT_EX Math Symbols

There are a multitude of mathematical symbols available for L^AT_EX and it would take a great effort to learn the commands for them all. The most common ones you are likely to use are shown on this page: <http://www.sunilpatel.co.uk/latex-type/latex-math-symbols/>

You can use this page as a reference or crib sheet, the symbols are rendered as large, high quality images so you can quickly find the L^AT_EX command for the symbol you need.

Algorithm 7 Embedding Procedure - General

Input: L sized, vectorized n -dimensional dataset

Input: number of centers per dimension - C

Output: $emb - set$: L sized set, embedded, sparsed vectors

```

1: Find centers vectors
2:  $V$  shall be a set of centers vectors
3: for all  $dim$  in  $n$  do
4:    $V_{dim} \leftarrow centers \quad vector \quad per \quad dim$ 
5: end for
6: Find embedded coefficients for all dataset
7:  $\vec{\phi} = C^n$  length empty  $emb - set$  embedded vectors
8: for all  $vec$  in  $L$  do
9:   find  $vec$  bounding hypercube
10:  find  $vec$  bounding simplex (permutation method)
11:   $\vec{\lambda} \leftarrow$  find  $vec$  barycentric coefficients
12:   $\vec{\lambda} \leftarrow$  normalize( $\vec{\lambda}$ )
13: end for
14: Assign
15: for all  $\vec{vec}$  in  $emb - set$  do
16:    $inds \leftarrow$  find vertices from hypercube and simplex locations
17:   for all  $i$  in  $inds$  do
18:      $\vec{vec}(i) \leftarrow \vec{\lambda}(j(i))$  -  $j$  is the assigning function between the coef.
        vector and embedding vector
19:   end for
20: end for
21: return  $\vec{\phi}$ 

```

9.2.4 L^AT_EX on a Mac

The L^AT_EX distribution is available for many systems including Windows, Linux and Mac OS X. The package for OS X is called MacTeX and it contains all the applications you need – bundled together and pre-customized – for a fully working L^AT_EX environment and work flow.

MacTeX includes a custom dedicated L^AT_EX editor called TeXShop for writing your ‘.tex’ files and BibDesk: a program to manage your references and create your bibliography section just as easily as managing songs and creating playlists in iTunes.

9.3 Getting Started with this Template

If you are familiar with L^AT_EX, then you should explore the directory structure of the template and then proceed to place your own information into the *THESIS INFORMATION* block of the **main.tex** file. You can then modify the rest of this file to your unique specifications based on your degree/university. Section 9.5 on page 83 will help you do this. Make sure you also read section 9.7 about thesis conventions to get the most out of this template.

If you are new to L^AT_EX it is recommended that you carry on reading through the rest of the information in this document.

Before you begin using this template you should ensure that its style complies with the thesis style guidelines imposed by your institution. In most cases this template style and layout will be suitable. If it is not, it may only require a small change to bring the template in line with your institution’s recommendations. These modifications will need to be done on the **MastersDoctoralThesis.cls** file.

9.3.1 About this Template

This L^AT_EX Thesis Template is originally based and created around a L^AT_EX style file created by Steve R. Gunn from the University of Southampton (UK), department of Electronics and Computer Science. You can find his original thesis style file at his site, here: <http://www.ecs.soton.ac.uk/~srg/softwaretools/document/templates/>

Steve’s **ecsthesis.cls** was then taken by Sunil Patel who modified it by creating a skeleton framework and folder structure to place the thesis files in. The resulting template can be found on Sunil’s site here: <http://www.sunilpatel.co.uk/thesis-template>

Sunil’s template was made available through <http://www.LaTeXTemplates.com> where it was modified many times based on user requests and questions. Version 2.0 and onwards of this template represents a major modification to Sunil’s template and is, in fact, hardly recognisable. The work to make version 2.0 possible was carried out by [Vel](#) and Johannes Böttcher.

9.4 What this Template Includes

9.4.1 Folders

This template comes as a single zip file that expands out to several files and folders. The folder names are mostly self-explanatory:

Appendices – this is the folder where you put the appendices. Each appendix should go into its own separate `.tex` file. An example and template are included in the directory.

Chapters – this is the folder where you put the thesis chapters. A thesis usually has about six chapters, though there is no hard rule on this. Each chapter should go in its own separate `.tex` file and they can be split as:

- Chapter 1: Introduction to the thesis topic
- Chapter 2: Background information and theory
- Chapter 3: (Laboratory) experimental setup
- Chapter 4: Details of experiment 1
- Chapter 5: Details of experiment 2
- Chapter 6: Discussion of the experimental results
- Chapter 7: Conclusion and future directions

This chapter layout is specialised for the experimental sciences.

Figures – this folder contains all figures for the thesis. These are the final images that will go into the thesis document.

9.4.2 Files

Included are also several files, most of them are plain text and you can see their contents in a text editor. After initial compilation, you will see that more auxiliary files are created by \LaTeX or BibTeX and which you don't need to delete or worry about:

example.bib – this is an important file that contains all the bibliographic information and references that you will be citing in the thesis for use with BibTeX. You can write it manually, but there are reference manager programs available that will create and manage it for you. Bibliographies in \LaTeX are a large subject and you may need to read about BibTeX before starting with this. Many modern reference managers will allow you to export your references in BibTeX format which greatly eases the amount of work you have to do.

MastersDoctoralThesis.cls – this is an important file. It is the class file that tells \LaTeX how to format the thesis.

main.pdf – this is your beautifully typeset thesis (in the PDF file format) created by \LaTeX . It is supplied in the PDF with the template and after you compile the template you should get an identical version.

main.tex – this is an important file. This is the file that you tell \LaTeX to compile to produce your thesis as a PDF file. It contains the framework and constructs that tell \LaTeX how to layout the thesis. It is heavily commented so you can read exactly what each line of code does and why it is there.

After you put your own information into the *THESIS INFORMATION* block – you have now started your thesis!

Files that are *not* included, but are created by L^AT_EX as auxiliary files include:

main.aux – this is an auxiliary file generated by L^AT_EX, if it is deleted L^AT_EX simply regenerates it when you run the main **.tex** file.

main.bbl – this is an auxiliary file generated by BibTeX, if it is deleted, BibTeX simply regenerates it when you run the **main.aux** file. Whereas the **.bib** file contains all the references you have, this **.bbl** file contains the references you have actually cited in the thesis and is used to build the bibliography section of the thesis.

main.blg – this is an auxiliary file generated by BibTeX, if it is deleted BibTeX simply regenerates it when you run the main **.aux** file.

main.lof – this is an auxiliary file generated by L^AT_EX, if it is deleted L^AT_EX simply regenerates it when you run the main **.tex** file. It tells L^AT_EX how to build the *List of Figures* section.

main.log – this is an auxiliary file generated by L^AT_EX, if it is deleted L^AT_EX simply regenerates it when you run the main **.tex** file. It contains messages from L^AT_EX, if you receive errors and warnings from L^AT_EX, they will be in this **.log** file.

main.lot – this is an auxiliary file generated by L^AT_EX, if it is deleted L^AT_EX simply regenerates it when you run the main **.tex** file. It tells L^AT_EX how to build the *List of Tables* section.

main.out – this is an auxiliary file generated by L^AT_EX, if it is deleted L^AT_EX simply regenerates it when you run the main **.tex** file.

So from this long list, only the files with the **.bib**, **.cls** and **.tex** extensions are the most important ones. The other auxiliary files can be ignored or deleted as L^AT_EX and BibTeX will regenerate them.

9.5 Filling in Your Information in the **main.tex** File

You will need to personalise the thesis template and make it your own by filling in your own information. This is done by editing the **main.tex** file in a text editor or your favourite LaTeX environment.

Open the file and scroll down to the second large block titled *THESIS INFORMATION* where you can see the entries for *University Name*, *Department Name*, etc ...

Fill out the information about yourself, your group and institution. You can also insert web links, if you do, make sure you use the full URL, including the `http://` for this. If you don't want these to be linked, simply remove the `\href{url}{name}` and only leave the name.

When you have done this, save the file and recompile **main.tex**. All the information you filled in should now be in the PDF, complete with web links. You can now begin your thesis proper!

9.6 The **main.tex** File Explained

The **main.tex** file contains the structure of the thesis. There are plenty of written comments that explain what pages, sections and formatting the

L^AT_EX code is creating. Each major document element is divided into commented blocks with titles in all capitals to make it obvious what the following bit of code is doing. Initially there seems to be a lot of L^AT_EX code, but this is all formatting, and it has all been taken care of so you don't have to do it.

Begin by checking that your information on the title page is correct. For the thesis declaration, your institution may insist on something different than the text given. If this is the case, just replace what you see with what is required in the *DECLARATION PAGE* block.

Then comes a page which contains a funny quote. You can put your own, or quote your favourite scientist, author, person, and so on. Make sure to put the name of the person who you took the quote from.

Following this is the abstract page which summarises your work in a condensed way and can almost be used as a standalone document to describe what you have done. The text you write will cause the heading to move up so don't worry about running out of space.

Next come the acknowledgements. On this page, write about all the people who you wish to thank (not forgetting parents, partners and your advisor/supervisor).

The contents pages, list of figures and tables are all taken care of for you and do not need to be manually created or edited. The next set of pages are more likely to be optional and can be deleted since they are for a more technical thesis: insert a list of abbreviations you have used in the thesis, then a list of the physical constants and numbers you refer to and finally, a list of mathematical symbols used in any formulae. Making the effort to fill these tables means the reader has a one-stop place to refer to instead of searching the internet and references to try and find out what you meant by certain abbreviations or symbols.

The list of symbols is split into the Roman and Greek alphabets. Whereas the abbreviations and symbols ought to be listed in alphabetical order (and this is *not* done automatically for you) the list of physical constants should be grouped into similar themes.

The next page contains a one line dedication. Who will you dedicate your thesis to?

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After the preamble, chapters and appendices finally comes the bibliography. The bibliography style (called *authoryear*) is used for the bibliography and is a fully featured style that will even include links to where the referenced paper can be found online. Do not underestimate how grateful your reader will be to find that a reference to a paper is just a click away. Of course, this relies on you putting the URL information into the BibTeX file in the first place.

9.7 Thesis Features and Conventions

To get the best out of this template, there are a few conventions that you may want to follow.

One of the most important (and most difficult) things to keep track of in such a long document as a thesis is consistency. Using certain conventions and ways of doing things (such as using a Todo list) makes the job easier. Of course, all of these are optional and you can adopt your own method.

9.7.1 Printing Format

This thesis template is designed for double sided printing (i.e. content on the front and back of pages) as most theses are printed and bound this way. Switching to one sided printing is as simple as uncommenting the *oneside* option of the `documentclass` command at the top of the **main.tex** file. You may then wish to adjust the margins to suit specifications from your institution.

The headers for the pages contain the page number on the outer side (so it is easy to flick through to the page you want) and the chapter name on the inner side.

The text is set to 11 point by default with single line spacing, again, you can tune the text size and spacing should you want or need to using the options at the very start of **main.tex**. The spacing can be changed similarly by replacing the *singlespacing* with *onehalfspacing* or *doublespacing*.

9.7.2 Using US Letter Paper

The paper size used in the template is A4, which is the standard size in Europe. If you are using this thesis template elsewhere and particularly in the United States, then you may have to change the A4 paper size to the US Letter size. This can be done in the margins settings section in **main.tex**.

Due to the differences in the paper size, the resulting margins may be different to what you like or require (as it is common for institutions to dictate certain margin sizes). If this is the case, then the margin sizes can be tweaked by modifying the values in the same block as where you set the paper size. Now your document should be set up for US Letter paper size with suitable margins.

9.7.3 References

The `biblatex` package is used to format the bibliography and inserts references such as this one (**Reference1**). The options used in the **main.tex** file mean that the in-text citations of references are formatted with the author(s) listed with the date of the publication. Multiple references are separated by semicolons (e.g. (**Reference2**; **Reference1**)) and references with more than three authors only show the first author with *et al.* indicating there are more authors (e.g. (**Reference3**)). This is done automatically for you. To see how you use references, have a look at the **Chapter1.tex** source file. Many reference managers allow you to simply drag the reference into the document as you type.

Scientific references should come *before* the punctuation mark if there is one (such as a comma or period). The same goes for footnotes¹. You can change this but the most important thing is to keep the convention consistent throughout the thesis. Footnotes themselves should be full, descriptive sentences (beginning with a capital letter and ending with a full stop). The APA6 states: “Footnote numbers should be superscripted, [...], following any punctuation mark except a dash.” The Chicago manual of style states: “A note number should be placed at the end of a sentence or clause. The number follows any punctuation mark except the dash, which it precedes. It follows a closing parenthesis.”

The bibliography is typeset with references listed in alphabetical order by the first author’s last name. This is similar to the APA referencing style. To see how \LaTeX typesets the bibliography, have a look at the very end of this document (or just click on the reference number links in in-text citations).

9.7.3.1 A Note on bibtex

The bibtex backend used in the template by default does not correctly handle unicode character encoding (i.e. “international” characters). You may see a warning about this in the compilation log and, if your references contain unicode characters, they may not show up correctly or at all. The solution to this is to use the biber backend instead of the outdated bibtex backend. This is done by finding this in **main.tex**: `backend=bibtex` and changing it to `backend=biber`. You will then need to delete all auxiliary BibTeX files and navigate to the template directory in your terminal (command prompt). Once there, simply type `biber main` and biber will compile your bibliography. You can then compile **main.tex** as normal and your bibliography will be updated. An alternative is to set up your LaTeX editor to compile with biber instead of bibtex, see [here](#) for how to do this for various editors.

9.7.4 Tables

Tables are an important way of displaying your results, below is an example table which was generated with this code:

```
\begin{table}
\caption{The effects of treatments X and Y on the four groups studied.}
\label{tab:treatments}
\centering
\begin{tabular}{l l l}
\toprule
\thead{Groups} & \thead{Treatment X} & \thead{Treatment Y} \\
\midrule
1 & 0.2 & 0.8 \\
2 & 0.17 & 0.7 \\
3 & 0.24 & 0.75 \\
4 & 0.68 & 0.3 \\
\bottomrule
\end{tabular}
\end{table}
```

TABLE 9.1: The effects of treatments X and Y on the four groups studied.

Groups	Treatment X	Treatment Y
1	0.2	0.8
2	0.17	0.7
3	0.24	0.75
4	0.68	0.3

You can reference tables with `\ref{<label>}` where the label is defined within the table environment. See **Chapter1.tex** for an example of the label and citation (e.g. Table 9.1).

9.7.5 Figures

There will hopefully be many figures in your thesis (that should be placed in the *Figures* folder). The way to insert figures into your thesis is to use a code template like this:

```
\begin{figure}
\centering
\includegraphics{Figures/Electron}
\decoRule
\caption[An Electron]{An electron (artist's impression).}
\label{fig:Electron}
\end{figure}
```

Also look in the source file. Putting this code into the source file produces the picture of the electron that you can see in the figure below.

Sometimes figures don't always appear where you write them in the source. The placement depends on how much space there is on the page for the figure. Sometimes there is not enough room to fit a figure directly where it should go (in relation to the text) and so \LaTeX puts it at the top of the next page. Positioning figures is the job of \LaTeX and so you should only worry about making them look good!

Figures usually should have captions just in case you need to refer to them (such as in Figure 9.1). The `\caption` command contains two parts, the first part, inside the square brackets is the title that will appear in the *List of Figures*, and so should be short. The second part in the curly brackets should contain the longer and more descriptive caption text.

The `\decoRule` command is optional and simply puts an aesthetic horizontal line below the image. If you do this for one image, do it for all of them.

\LaTeX is capable of using images in pdf, jpg and png format.

¹Such as this footnote, here down at the bottom of the page.



FIGURE 9.1: An electron (artist's impression).

9.7.6 Typesetting mathematics

If your thesis is going to contain heavy mathematical content, be sure that \LaTeX will make it look beautiful, even though it won't be able to solve the equations for you.

The “Not So Short Introduction to \LaTeX ” (available on [CTAN](#)) should tell you everything you need to know for most cases of typesetting mathematics. If you need more information, a much more thorough mathematical guide is available from the AMS called, “A Short Math Guide to \LaTeX ” and can be downloaded from: <ftp://ftp.ams.org/pub/tex/doc/amsmath/short-math-guide.pdf>

There are many different \LaTeX symbols to remember, luckily you can find the most common symbols in [The Comprehensive \$\text{\LaTeX}\$ Symbol List](#).

You can write an equation, which is automatically given an equation number by \LaTeX like this:

```
\begin{equation}
E = mc^{2}
\label{eqn:Einstein}
\end{equation}
```

This will produce Einstein's famous energy-matter equivalence equation:

$$E = mc^2 \tag{9.1}$$

All equations you write (which are not in the middle of paragraph text) are automatically given equation numbers by \LaTeX . If you don't want a particular equation numbered, use the unnumbered form:

`\[a^{2}=4 \]`

9.8 Sectioning and Subsectioning

You should break your thesis up into nice, bite-sized sections and subsections. \LaTeX automatically builds a table of Contents by looking at all the `\chapter{}`, `\section{}` and `\subsection{}` commands you write in the source.

The Table of Contents should only list the sections to three (3) levels. A `chapter{}` is level zero (0). A `\section{}` is level one (1) and so a `\subsection{}` is level two (2). In your thesis it is likely that you will even use a `subsubsection{}`, which is level three (3). The depth to which the Table of Contents is formatted is set within **MastersDoctoralThesis.cls**. If you need this changed, you can do it in **main.tex**.

9.9 In Closing

You have reached the end of this mini-guide. You can now rename or overwrite this pdf file and begin writing your own **Chapter1.tex** and the rest of your thesis. The easy work of setting up the structure and framework has been taken care of for you. It's now your job to fill it out!

Good luck and have lots of fun!

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Appendix A

Appendix Title Here

Write your Appendix content here. blablabla