Degree Project in Scientific Computing

Second cycle, 30 credits

Chest X-ray Transmission Map Reconstruction

Constrained Optimization to Invert a Family of Image Processing Algorithms

ANDRES ALAM SANCHEZ TORRES

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Abstract

An abstract is (typically) about 250 and 350 words (1/2 A4-page) with the following components:

- What is the topic area? (optional) Introduces the subject area for the project.
- Short problem statement
- Why was this problem worth a Bachelor's/Master's thesis project? (*i.e.*, why is the problem both significant and of a suitable degree of difficulty for a Bachelor's/Master's thesis project? Why has no one else solved it yet?)
- How did you solve the problem? What was your method/insight?
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$$\int_a^b x^2\, dx$$

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Nonlinear Optimization, Medical Imaging, Digital Image Processing

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Choose the most specific keyword from those used in your domain, see for example: the ACM Computing Classification System (https://www.acm.org/publications/computing-classification-system/how-to-use), the IEEE Taxonomy (https://www.ieee.org/publications/services/thesaurus-thank-you.html), PhySH (Physics Subject Headings) (https://physh.aps.org/), ...or keyword selection tools such as the National Library of Medicine's Medical Subject Headings (MeSH) (https://www.nlm.nih.gov/mesh/authors.html) or Google's Keyword Tool (https://keywordtool.io/)

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Acknowledgments

I would like to thank xxxx for having yyyy. Or in the case of two authors:
We would like to thank xxxx for having yyyy.

Stockholm, May 2025
Andres Alam Sanchez Torres

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Listings

If you have listings in your thesis. If not, then remove this preface page.

List of acronyms and abbreviations

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Chapter 1

Introduction

1.1 Background

Digital radiography systems and their technological advancements for better X-ray image acquisition play a vital role in enabling accurate disease diagnosis and progression monitoring. Naturally, a demand for automated image interpretation and diagnosis has emerged, followed by a need of large and diverse X-ray image datasets. Collecting such data is however a challenge given the complexity of the acquisition, annotation process, and the tendency of these datasets to have an imbalance when underrepresenting certain conditions, such as normal cases, while simultaneously overrepresenting pneumonia [1].

Another source of bias is the different capture conditions across (or even within) datasets. These can be found in images that go through different enhancing methods, device quality, and patient positioning. Some of these differences are depicted in Figure 1.1. And even though these differences can be mitigated by mixing datasets, this method can also lead to models discriminating on the source dataset [2]. Most importantly, any conditions that are not represented in the data can lead to existing models performing poorly.

A potential solution to these dataset biases lies in the fundamental physics of X-ray imaging. In projection radiography, all imaging systems—whether using film, computed radiography phosphor plates, or flat panel detectors—measure the spatial distribution of X-ray radiation incident on the detector after passing through the patient [3]. Different detector technologies employ various methods to convert the incoming x-rays into a visual representation, potentially losing information in the process. Furthermore,

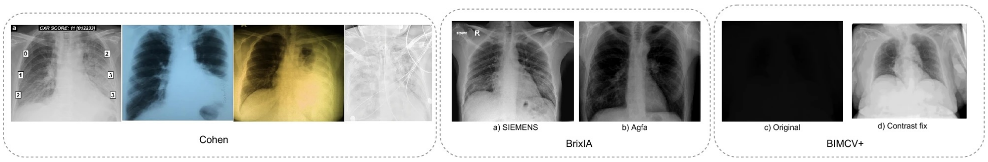


Figure 1.1: Examples of different capture conditions across datasets, taken from [2, Figure 6].

digital detectors perform image processing algorithms to increase the image quality for diagnosis, but also contribute to the differences in image appearance across different detectors.

This observation suggests a promising approach: by recovering these fundamental transmission patterns from processed clinical images, existing annotated datasets could be translated into detector-agnostic representations. This could enable Machine Learning and Deep Learning models to generalize across different imaging systems without requiring new data for each specific detector. This thesis explores the feasibility and effectiveness of transmission map recovery as a preprocessing step for improving the generalization of chest X-ray analysis models.

1.2 Problem Statement

1.2.1 Original Problem Definition

All projection radiography technologies, and their subsequent processing pipelines operate on the same *transmission maps*, which represent the X-ray radiation that passed through the patient's body. For digital radiography systems, if no processing were applied and the images captured were directly transformed into gray levels, they would appear as extremely dark due to the lack of contrast [4, p. 148]. Thus, clinical grade equipment manufacturers (e.g., Siemens, Philips, GE) apply proprietary digital image processing algorithms that include non-linear operations—likely including a combination of denoising, frequency filtering, and dynamic range adjustments. These operations form a "black-box" that varies across manufacturers, and even on an image-by-image basis.

This describes the primary goal of this project: to develop a framework that inverts the image processing transformations from high-quality, chest x-ray images. This will recover the latent images described in Figure 1.2 that will enable the extension of exiting labeled datasets via the siulation of non-

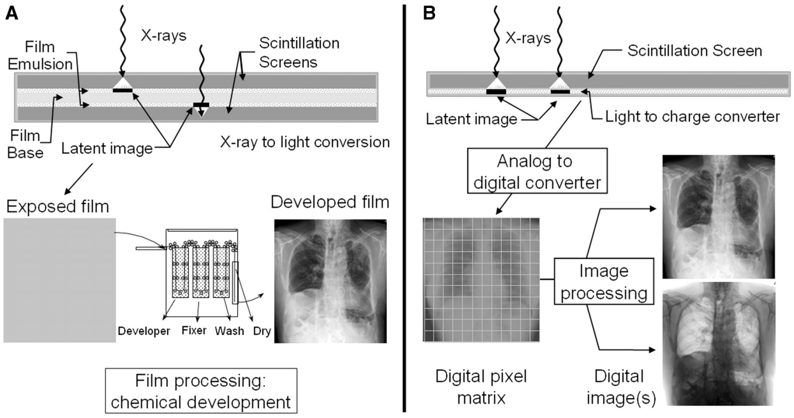


Figure 1.2: X-ray image acquisition pipeline. All projection radiography capture the same x-ray energies and form a latent image, which is distorted by the systems' methods to capture x-rays and subsequent processing steps. Taken from [3, p. 13]

represented radiography sysyems.

1.2.2 Scientific and Engineering Challenges

The problem to solve lies in the category of inverse problems, and has several critical challenges:

Ill-posedness A single processed image can map back to multiple possible "realistic" transmission maps. The same holds on the other way around, where a single transmission map can map back to multiple processed images. This makes the inverse problem fundamentally ill-posed.

Diversity of processing approaches Each manufacturer implements proprietary image processing pipelines that differ in their specific algorithms and parameters.

Limited ground truth We lack labeled data showing the original transmission maps corresponding to processed images.

Scaling requirements We need to process many images to build a representative dataset.

1.3 Purpose

refine this and goals section, may have too many bullet points add references to x-ray detector accessibility

This research aims to support the development and experimentation with alternative X-ray detector technologies. More specifically, we aim to:

- Enable the development of X-ray detector technologies for resource-limited settings.
- Provide a common baseline for comparing different detector technologies.
- Support development of radiography machine learning models specific for non-standard imaging systems.

1.4 Goals

Regarding concrete outcomes of this project, the specific goals are delimited as follows:

1. Analyze limited X-ray transmission map data to identify and characterize the essential features that define radiologically realistic representations.
2. Characterize the diversity of image processing pipelines applied to these maps in commercial systems.
3. Develop and evaluate optimization algorithms that can recover plausible transmission maps from processed images.

1.5 Research Methodology

Overall, the research methodology involves a combination of theoretical and experimental analysis, and computational modeling, described in the following steps:

- Investigating established image processing algorithms used in radiography and a potential concensus across manufacturers
- Identifying common properties in processed images and their corresponding transmission maps
- Developing optimization algorithms with appropriate forward operators and loss functions

- Evaluating recovered maps through comparison with known physics models and visual assessment

1.6 Thesis Structure

The remainder of this thesis is organized as follows: Chapter 2 presents background information on X-ray transmission, digital image processing, and relevant optimization methods. Chapter 3 describes our proposed method for solving the inverse problem. Chapter 4 details the implementation of our computational pipeline. Chapter 5 presents experimental results, and Chapter 6 discusses implications and directions for future work.

Chapter 2

Background

2.1 X-ray Transmission Model

2.1.1 X-ray intensity and Beer's law

X-rays are thought of as a flux of very high-energy, electromagnetic radiation. The x-ray beam is described by a vector valued function $I(x)$. The direction of I at x is the direction of the flux at x and its magnitude,

$$I(x) = \|I(x)\| \tag{2.1}$$

is the intensity of the beam. If dS is an infinitesimal surface element at x of area $|dS|$, placed at right angles to $I(x)$, then the energy-per-unit-time passing through dS is [5, p. 56].

$$I(x)|dS|. \tag{2.2}$$

When x-rays encounter any form of matter, they are partly transmitted and partly absorbed. The fractional decrease in the intensity I of an x-ray beam as it passes through any homogeneous substance is proportional to the distance traversed x and the material encounterd[6, p. 11]. The intensity I of the x-ray beam satisfies Beer's law:

$$\frac{dI}{ds} = -\mu(x)I, \tag{2.3}$$

where s is the arc-length along the straight-line trajectory of the x-ray beam. Each material encountered has a characteristic *linear attenuation coefficient* μ for x-rays of a given energy, and is dependent on the substance composition, density, and the wavelength of the x-rays [5, p. 57].

For a homogeneous medium of thickness x with linear attenuation coefficient μ, if radiation of intensity I_{in} is incident upon the medium, the transmitted intensity I_{out} is given by:

$$I_{\text{out}} = I_{\text{in}} \cdot e^{-\mu(x)} \tag{2.4}$$

2.1.2 X-ray Image acquisition

In the context of X-ray imaging, we measure intensities at the detector plane. Let

- $I_0(x, y)$ denote the intensity measured at detector position (x, y) in the absence of any object (the reference or flat-field measurement), and
- $I(x, y)$ denote the intensity measured at detector position (x, y) with the object present.

Then, for radiation traversing a heterogeneous medium, such as body tissues, along a ray path L from source to detector position (x, y), the relation of the incident and transmitted intensity is given by:

$$I(x, y) = I_0(x, y) \cdot \exp\left(-\int_L \mu(s)\, ds\right) \tag{2.5}$$

where $\mu(s)$ represents the spatially varying attenuation coefficient along the ray path [5, p. 57].

In a real measurement, the x-ray source is turned on for a known period of time. The total energy I incident on the object along a given line l is known. The total energy, I_0, emerging from the object along l is then measured by an x-ray detector. Integrating Beer's law we obtain [5, p. 60]

$$-\log \frac{I(x, y)}{I_0(x, y)} = \int_l \mu(s)\, ds, \tag{2.6}$$

where $\frac{I(x,y)}{I_0(x,y)}$ is the *transmission map*, which describes the fraction of the incident radiation that transmits through the patient at each position (x, y), and applying the negative logarithm captures the energy absorbed by the object.

For a medium composed of n distinct homogeneous regions with attenuation coefficients $\{\mu_i\}_{i=1}^n$ and thicknesses $\{d_i\}_{i=1}^n$ along a given ray path,

Tissue Type	Attenuation Coefficient
water	0
air	-1000
bone	1086
blood	53
fat	-61
breast tissue	9
muscle	41
soft tissue	51

Figure 2.1: Body tissue attenuation coefficients in Hounsfeld units. Adapted from [5, p. 54]

a simplified model can be expressed as

$$I(x, y) = I_0(x, y) \cdot \exp\left(-\sum_{i=1}^{n} \mu_i d_i\right). \tag{2.7}$$

Note that ideal x-ray image acquisition and the described model assume a point x-ray source, a straight line trajectory from the source through the object, and complete detection of the x-ray beam that strikes the detector. These are not realistic assumptions, however, clinical detectors apply methods to counteract nonideal conditions [3, p. 9].

2.1.3 Application to Human Chest Imaging

In the context of chest radiography, the human thorax can be modeled as a composition of distinct, but known tissue types, and therefore, different anatomical structures have different attenuation coefficients. Bone has a much higher attenuation coefficient than soft tissue, and different soft tissues have slightly different coefficients. More precisely, Figure 2.1 shows the attenuation coefficients of common body tissue types. The table is presented in a dimensionless quantity called a Hounsfield unit, which is a measure relative to the attenuation coefficient of water, defined as [5, p. 54]

$$H_{\text{tissue}} = 1000 \cdot \frac{\mu_{\text{tissue}} \mu_{\text{water}}}{\mu_{\text{water}}} \tag{2.8}$$

2.2 Digital Image Processing in Radiography

Digital radiography systems can capture the wide attenuation differences between lungs and mediastinum due to their wide dynamic range and linear response to th incident radiation. Hoever, it leads to a lack of contrast on the direct conversion to gray values. At the same time, image sharpness may not be as good as in screen-film due to the pixel size constraint [4, p. 148]. Screen-film systems, despite having greater spatial resolution, they have a non-linear (S-shaped) response, leading to under- or overexposed images[7, p. 551]. Regardless of the imaging modality, digital image processing is not only used to take full advantage of the positive characteristics of the radiography systems, but also to amend the intrisic limitations of each detector. To overcome this, different algorithms are applied to the captured x-ray image, with the goals of:

- displaying the full range of attenuation differences in the chest,
- optimizaing spatial resolution of digital chest radiographs,
- enhancing structural contrast in the lungs and mediastinum, and
- supress image noise [4, p. 149].

2.2.1 Gradation Curves

Digital radiography systems apply various processing steps to the raw transmission map to produce diagnostically useful images. As described by [**?**], gradation curves map detector signals to display values. These include:

- **Automated Signal Normalization**: Detects the collimated region and stretches the relevant histogram range to fit the available gray scale values. This process includes:
  1. Detection of the collimated region to exclude direct, unattenuated radiation
  2. Histogram analysis of pixel values within the collimated region
  3. Linear mapping to exclude input values where the histogram is (close to) zero
- **Gradational Adjustment**: Applies lookup tables to optimize contrast for different anatomical regions. Theoretical optimums like the Kanamori curve [**?**] have been proposed, but many radiologists prefer

sigmoid-shaped curves that more closely match the appearance of conventional radiographs.

2.2.2 Spatial Frequency Processing

2.2.2.1 Unsharp Masking

Unsharp masking enhances edges and fine details in radiographs. The process involves:

1. Creating a blurred version of the image using low-pass filtering
2. Subtracting this from the original to obtain high-frequency information
3. Combining the original with the weighted high-frequency image

The resulting processed image can be expressed as:

$$I' = I + f \cdot (I - B) \tag{2.9}$$

where I is the original image, B is the blurred version, and f is an enhancement factor, typically around 0.5 for chest radiographs [**?**].

Mathematically equivalent formulations include:

$$I' = I - f^* \cdot B \tag{2.10}$$

where $f^* = \frac{f}{1+f}$, and:

$$I' = B + (1 + f) \cdot (I - B) \tag{2.11}$$

The effects of unsharp masking depend critically on the size of the filter kernel used to create the blurred image B. Kernels of 20-30mm typically give the best results for general chest imaging [**?**], as they enhance structures of diagnostic interest while avoiding suppression of relevant pathology.

2.2.2.2 Multiscale Processing

More advanced systems use multiscale decomposition, dividing the image into frequency bands that can be independently processed. As detailed by [**?**], this approach allows for:

- Size-independent enhancement of structures
- Better handling of dynamic range differences

- More effective noise suppression

The Laplacian pyramid decomposition, introduced by [?], is a hierarchical structure where the original image is repeatedly filtered and downsampled:

1. The image is blurred with a low-pass filter (typically a 3×3 or 5×5 binomial kernel)
2. The blurred image is downsampled by a factor of 2 in each direction
3. The downsampled image is expanded back to the original size using interpolation
4. The expanded image is subtracted from the original to create a "detail" or bandpass image
5. The process repeats with the downsampled image as the new input

This creates a series of bandpass images $\{B_0, B_1, ..., B_{n-2}\}$ plus a residual low-pass image B_{n-1}. The original image can be perfectly reconstructed by reversing the process:

$$I_{\text{original}} = B_{n-1} + \sum_{i=0}^{n-2} B_i \tag{2.12}$$

For enhancement, each bandpass image can be processed independently before reconstruction. This allows for targeted enhancement of structures of specific sizes without affecting others, as implemented in commercial systems like MUSICA (Agfa) [?], MFP (Fuji) [?], and UNIQUE (Philips) [?].

2.2.2.3 Dynamic Range Reduction

Chest radiographs must cope with large attenuation differences between the lungs and mediastinum. Dynamic range reduction (DRR) or compression (DRC) harmonizes the image by reducing these differences while preserving local contrast [?, ?].

With unsharp masking, DRR is accomplished by nonlinear subtraction of a low-pass image with a large kernel (2-4cm). The subtraction weight varies with pixel values—minimal for lungs but substantial (e.g., 0.2) for the mediastinum—effectively increasing density in high-absorption areas without affecting well-exposed regions.

In multiscale processing, DRR works by applying nonlinear transformations to the lowest frequency bands, which contain the large-area density differences [?].

2.2.3 Noise Characteristics and Management

Noise in radiographic images comes from multiple sources:

- Quantum noise (Poisson-distributed, proportional to $\sqrt{N}$ where N is the number of photons)
- Detector structure noise
- Electronic noise
- Quantization noise

Noise power is distributed across spatial frequencies and varies with detector dose. After logarithmic processing and intensity inversion in storage phosphor systems, noise is most prominent in high-brightness (low optical density) regions [**?**, **?**].

Subjectively, noise is most visible in areas with minimal texture or "activity." [**?**] developed a noise containment approach where enhancement is reduced in noise-sensitive regions defined by spatial frequency, local image density, and local activity measures.

Their blending technique can be expressed as:

$$S_{i,\text{robust}}(x,y) = b_D(x,y)\cdot b_A(x,y)\cdot S_{i,\text{fully\_enh}}(x,y)+(1-b_D(x,y)\cdot b_A(x,y))\cdot S_{i,\text{orig}}(x,y) \tag{2.13}$$

where b_D and b_A are weighting factors dependent on local density and activity, respectively.

2.3 Nonlinear Optimization

2.3.1 Gradient Descent Methods

Our approach to recovering transmission maps relies on gradient-based optimization. Given a forward model F that maps transmission maps to processed images, we seek to find the transmission map x that minimizes:

$$\arg\min_{x,\theta} \mathcal{L}(F(x,\theta), y) \tag{2.14}$$

where y is the observed processed image, θ represents parameters of the forward model, and $\mathcal{L}$ is a suitable loss function.

The optimization uses automatic differentiation to compute gradients efficiently. We employ the Adam optimizer [**?**], which adapts the learning rate for each parameter based on estimates of first and second moments of the gradients:

$$m_t = \beta_1 m_{t-1} + (1-\beta_1) g_t \tag{2.15}$$
$$v_t = \beta_2 v_{t-1} + (1-\beta_2) g_t^2 \tag{2.16}$$
$$\hat{m}_t = \frac{m_t}{1-\beta_1^t} \tag{2.17}$$
$$\hat{v}_t = \frac{v_t}{1-\beta_2^t} \tag{2.18}$$
$$\theta_t = \theta_{t-1} - \alpha \frac{\hat{m}_t}{\sqrt{\hat{v}_t} + \epsilon} \tag{2.19}$$

where g_t is the gradient, m_t and v_t are the biased first and second moment estimates, $\hat{m}_t$ and $\hat{v}_t$ are the bias-corrected estimates, and α, β_1, β_2, ϵ are hyperparameters.

2.3.2 Regularization for Ill-Posed Problems

2.3.2.1 Regularization Strategies

The inverse problem of finding x such that $F(x) = y$ is ill-posed when:

- A solution may not exist for all y
- Solutions may not be unique
- Solutions may not depend continuously on the data (small changes in y can cause large changes in x)

To address these challenges, we employ regularization by adding penalty terms to the objective function:

$$\arg\min_x \{\|F(x) - y\|^2 + \sum_i \lambda_i R_i(x)\} \tag{2.20}$$

where R_i are regularization functionals and $\lambda_i > 0$ control the regularization strength.

2.3.2.2 Gradient-Based Regularization

We explore gradient-based regularization that promotes spatial smoothness while preserving important features. The general form is:

$$R_{\text{grad}}(x) = \frac{1}{2}\left(\|\nabla_x x\|_p^p + \|\nabla_y x\|_p^p\right) \tag{2.21}$$

where ∇_x and ∇_y are the horizontal and vertical finite difference operators, and p determines the norm used. For $p = 2$, this yields a squared gradient penalty that promotes smooth variations while being differentiable everywhere, which is crucial for our JAX-based optimization framework.

2.3.2.3 Anatomically-Informed Regularization

Beyond generic smoothness priors, we incorporate anatomical knowledge through segmentation-guided regularization. This approach leverages the fact that different tissue types have characteristic transmission ranges:

$$R_{\text{anat}}(x, S) = \sum_{m=1}^{M} \lambda_m P_m(x, S^m) \tag{2.22}$$

where $S = \{S^1, S^2, \ldots, S^M\}$ are segmentation masks for M anatomical regions, and P_m penalizes deviations from expected physical ranges for region m.

2.3.2.4 Perceptual Regularization

To preserve diagnostic features, we also explore perceptual regularization terms that maintain high-frequency details important for clinical interpretation. One approach uses the similarity of detail layers extracted through frequency decomposition:

$$R_{\text{detail}}(x, y) = \|D_\sigma(F(x)) - D_\sigma(y)\|^2 \tag{2.23}$$

where D_σ extracts details at scale σ through unsharp masking or similar operations.

2.4 Image Quality Metrics

2.4.1 Mean Squared Error (MSE)

The mean squared error quantifies the average squared difference between pixel values:

$$\text{MSE}(x, y) = \frac{1}{N}\sum_{i=1}^{N}(x_i - y_i)^2 \tag{2.24}$$

While simple to compute, MSE does not always correlate well with perceived image quality.

2.4.2 Structural Similarity Index (SSIM)

SSIM [?] better aligns with human perception by considering structural information:

$$\mathrm{SSIM}(x, y) = \frac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)} \tag{2.25}$$

where μ_x, μ_y are means, σ_x, σ_y are standard deviations, σ_{xy} is the covariance, and C_1, C_2 are constants to avoid instability.

2.4.3 Peak Signal-to-Noise Ratio (PSNR)

PSNR measures the ratio between the maximum possible power of a signal and the power of corrupting noise:

$$\mathrm{PSNR}(x, y) = 10 \cdot \log_{10}\left(\frac{\mathrm{MAX}_I^2}{\mathrm{MSE}(x, y)}\right) \tag{2.26}$$

where MAX_I is the maximum possible pixel value.

2.5 Available Chest X-ray Datasets

Several large datasets of chest radiographs are available, though none provide the raw transmission maps:

- **CheXpert** [?]: Over 200,000 images from Stanford Hospital, with labels for 14 different pathologies
- **MIMIC-CXR** [?]: Over 377,000 chest radiographs from Beth Israel Deaconess Medical Center
- **Open-i** [?]: A collection from the National Library of Medicine with associated radiology reports
- **PLCO** [?]: From the Prostate, Lung, Colorectal and Ovarian Cancer Screening Trial

None of these datasets report radiography hardware specifications or processing parameters, making the inverse problem challenging.

2.6 Related Work

2.6.1 Digital Radiography Processing

Digital radiography processing has evolved from simple unsharp masking to sophisticated multiscale techniques. [?] provides a comprehensive overview of the principles used in clinical systems, while [?] details the nonlinear multiscale approach now common in commercial systems.

2.6.2 Inverse Problems in Medical Imaging

While image recovery from processed versions has been studied in photography [?], similar work in medical imaging is limited. Most related work focuses on denoising, deblurring, or super-resolution rather than recovering physically meaningful quantities like transmission maps [?].

2.6.3 Low-Cost X-ray Imaging

Several initiatives aim to develop affordable X-ray systems for resource-limited settings. The World Health Organization's specifications for basic radiographic systems [?] guide such efforts. [?] highlights the critical need for affordable diagnostic imaging in developing countries.

2.7 Summary

The background presented establishes the foundation for our approach to transmission map recovery. We understand the physics of X-ray transmission, the typical processing steps applied in digital radiography, and the mathematical framework for tackling the inverse problem. Our approach leverages advanced optimization techniques, appropriate regularization, and insights from the literature on digital radiography processing to recover physically plausible transmission maps from processed images.

Chapter 3

Method

3.1 Mathematical Model

For this thesis project, a family of models are explored to recover transmission maps under the lack of prior knowledge about the ground truth, and the diversity of black-box models that are used in practice to process radiographic images. The motivations driving the design of the methods can be summarized as follows:

is this the right term

can we say this?

- If all images are processed to match a same visual profile , we could model all black boxes using a single, although parameterized, image processing algorithm.

cite DIP paper or reference to section

- If we recover an appropriate forward model (image processing algorithm) , we can reconstruct a 'realistic' transmission map from the processed images.

express forward model and image processing are synonims

Given the previous knowledge, we can formulate a general optimization problem using the following notation:

- N as the size of the image dataset.
- d is the number of parameters of the image processing operator.
- r, c as the fixed row and columns in pixels, respectively, of all images in the dataset.
- $Y = \{y_1, y_2, \ldots, y_N\}, y_i \in [0, 1]^{r,c}$ is the given set of processed X-ray images.

Image formal notation?

- $X = \{x_1, x_2, \ldots, x_N\}$ as the corresponding set of unknown transmission maps, with $x_i \in [0,1]^{r,c}$ for all $i \in \{1, 2, \ldots, N\}$.

can we specify domain sets?

- $F : [0,1]^{r,c} \times \mathbb{R}^d \to [0,1]^{r,c}$ as a known image processing algorithm with parameters $\theta \in \mathbb{R}^d$.

Then, we formulate the optimization problem to recover X and θ

$$\min_{X,\theta} \sum_{i=1}^{N} \left(\ell(y_i, F(x_i, \theta)) + \sum_{j=1}^{K} \lambda_j R_j(x_i) \right) \tag{3.1}$$

where ℓ is a loss function measuring the discrepancy between the processed versions of our estimated transmission maps and the observed processed images, R is a regularization term applied to X, with weights λ.

Furthermore, the following concrete models can be considered:

Known parameters If we assume there is a known set of parameters for the operator F that can model all the observed processed images, then we get

$$\min_{X} \sum_{i=1}^{N} \left(\ell(y_i, F(x_i, \theta)) + \sum_{j=1}^{K} \lambda_j R_j(x_i) \right) \tag{3.2}$$

such that $\theta \in \mathbb{R}^d$ is known.

Common operator parameters If we assume that there exists a single set of parameters θ (yet unknown) for all processed images, i.e. $F(x_i, \theta) = y_i$ for all $i = \{1, \ldots, N\}$. Then the problem can be modeled as

$$\min_{X,\theta} \sum_{i=1}^{N} \left(\ell(y_i, F(x_i, \theta)) + \sum_{j=1}^{K} \lambda_j R_j(x_i) \right) \tag{3.3}$$

Per-image operator parameters If we assume we can model all the observed processed images with F, but not necessarily with the same parameters on an image bases, i.e. $F(x_i, \theta_i) = y_i$ for all $i = \{1, \ldots, N\}$, with $\theta = \{\theta_1, \theta_2, \ldots, \theta_N\}$. Then we aim to solve

$$\min_{X,\theta} \sum_{i=1}^{N} \left(\ell(y_i, F(x_i, \theta_i)) + \sum_{j=1}^{K} \lambda_j R_j(x_i) \right) \tag{3.4}$$

where we now have a set of parameters $\theta = \{\theta_1, \theta_2, \ldots, \theta_N\}$ with $\theta_i \in \mathbb{R}^d$.

The method employed in this project involved an iterative process of defining a loss function and regularization, which can be applied to all described model variations, and finding a framework that can yield results considered realistic. In the following sections, we will discuss the choices made for the functions F, ℓ and R, and how these contribute to the reconstruction of transmission maps.

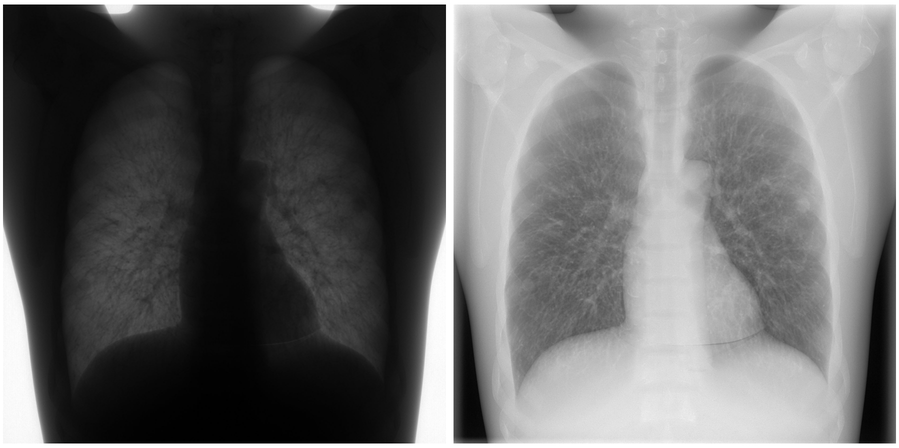
3.2 Data Collection and Preprocessing

3.2.1 Transmission Maps

To our knowledge, there are currently no open datasets of X-ray transmission maps. We had access to, precisely, two images taken from the same chest phantom at the Hard X-ray lab in KTH, one paired with a processed image produced by a clinical detector . Figure 3.1 shows the obtained sample pair of transmission map and processed image.

is it correct to say the image comes from the detector

proper source of the transmission maps



(a) Real transmission map. (b) Processed X-ray image (commercial detector).

Figure 3.1: Sample pair of images from chest phantom

3.2.2 Diagnostic chest X-ray images

Throughout the experiments, data was collected from the CheXpert dataset [8] and NIH Chest X-ray dataset [9]. The motivation to use these datasets is the diagnostic labels they include, which can be tied to the simulated transmission maps. However, these labels are not used for the model. .

refer to implementation for transformation details

3.2.3 Segmentation

For the implementation of segmentation-based regularizations, the ChestXDet [10] model was used to obtain segmentation labels. Concretely, the segmentation model identifies 13 categories, which are grouped in 3 groups. These groups and their corresponding labels are listed in Table 3.1.

The motivation of the selected groups is the similar absorption coefficients among the different body tissues, which vary by about 2% of the dynamic range of an X-ray measurement [5, p. 54]. Thus, if we expect certain ranges of X-ray intensities over different chest regions, these will depend on the absorption coefficients of all tissues transversed. It is assumed that the projected intensities can vary significantly across regions where: bones are present, lungs are present (air content), and only soft tissues are transversed .

maybe the terminology isn't quite right

I feel I'm not explaining myself

Group name	**Grouped labels**
Bone	Left Clavicle
	Right Clavicle
	Left Scapula
	Right Scapula
	Spine
Lung	Left Lung
	Right Lung
	Left Hilus Pulmonis
	Right Hilus Pulmonis
Soft tissue	Heart
	Aorta
	Mediastinum
	Facies Diaphragmatica
	Weasand

Table 3.1: Segmentation category groups

3.2.3.1 Mask groups

To compute the segmentation masks, the ChestXdet model returns confidence values on a 0 to 1 range. To get hard masks, we include in our model a threshold parameter. The threshold is used to create binary masks where the values are above it, then the segmentation targets are joined according to the groups described in Table 3.1. The join operation is performed by taking the logical OR of the masks.

Since the mask groups may contain overlapping regions, a difference is applied to obtain exclusive masks. This is done in an ordered manner, starting from the groups with higher absorption (bone) up to lower absorption values (lung). This ensures that each pixel is assigned to the mask that produces the higher attenuation. The complete merging operation is described in algorithm 1. Figure 3.2 shows a sample set of the processed segmentation masks over a CheXpert image using a threshold of 0.5.

maybe add a figure to explain this algorithm

Algorithm 1 Algorithms for creating exclusive segmentation masks

Input: *pred* - Batch of prediction masks with shape (batch, labels, height, width)
Input: *threshold* - Optional threshold value
Output: *ordered_groups* - List of mask group identifiers
Output: *exclusive_masks* - Array of exclusive masks with shape (batch, reduced_labels, height, width)

```
Function BatchGetExclusiveMasks(pred, threshold):
    complete_masks ← [ ]
    foreach group ∈ MASK_GROUPS do
        group_mask ← GetGroupMask(pred, group, threshold)
        Concatenate on labels axis group_mask to complete_masks
    end
    exclusive_masks ← Copy(complete_masks)
    groups_count ← len(MASK_GROUPS)
    /* Masks are substracted in specific order, denser groups last     */
    for i ← 0 to groups_count − 1 do
        for j ← 0 to groups_count − 1 do
            if j < i then
                /* Subtract already exclusive masks                    */
                exclusive_masks[:, i] ← SubtractMask(
                        exclusive_masks[:, i], exclusive_masks[:, j])
            end
            if j > i then
                /* Subtract entire masks                               */
                exclusive_masks[:, i] ← SubtractMask(
                        exclusive_masks[:, i], complete_masks[:, j])
            else
        end
    end
    return exclusive_masks

Function GetGroupMask(pred, group, threshold):
    /* Select only the labels in the group                              */
    group_masks ← FilterPredMasks(pred, group)
    normalized_masks ← Sigmoid(group_masks)
    /* Indicator function: 1 where condition is true, 0 otherwise      */
    thresholded_masks ← 𝟙{normalized_masks > threshold}
    joined_masks ← sum(thresholded_masks, axis = 1)
    return clip(thresholded_masks, 0.0, 1.0)
```

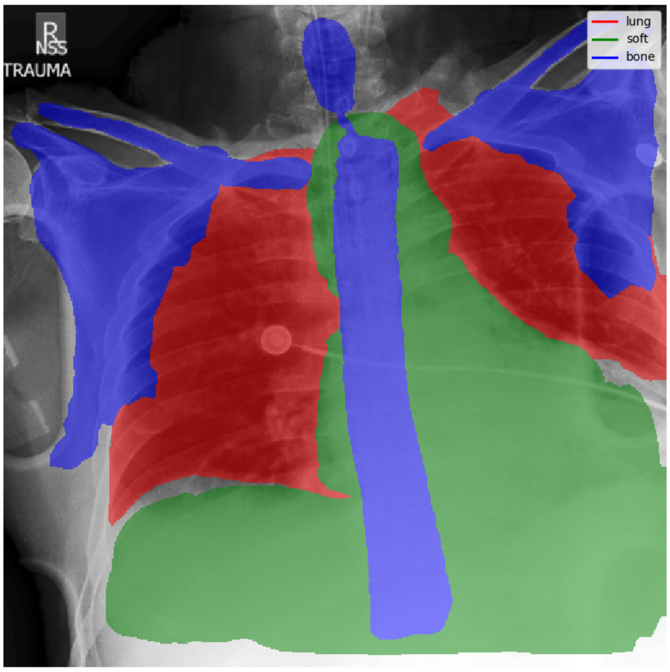


Figure 3.2: Segmentation masks

3.3 Analysis of Transmission Map Properties

To constrain our solution space, an analysis was done on the limited transmission map data

is 'collimated area' the right term?

Collimated area range Only a fraction of the dynamic range of a transmission map contains diagnostic information. Figure 3.3 shows the histograms of the transmission map samples. It can be observed that the captured transmission values are concentrated in the range below 0.4, with the outliers corresponding to the regions outside the collimated area.

Histogram cluster ranges Figure 3.4 shows the histograms of different regions. It can be observed that the captured transmission values are concentrated in a closed range of intensity values for each group, indicating the presence of distinct tissue types.

Non-uniform histogram Figure 3.5 shows the histograms of a real pair of transmission map and processed image. There is an evident difference with the processed image having more uniform histograms,

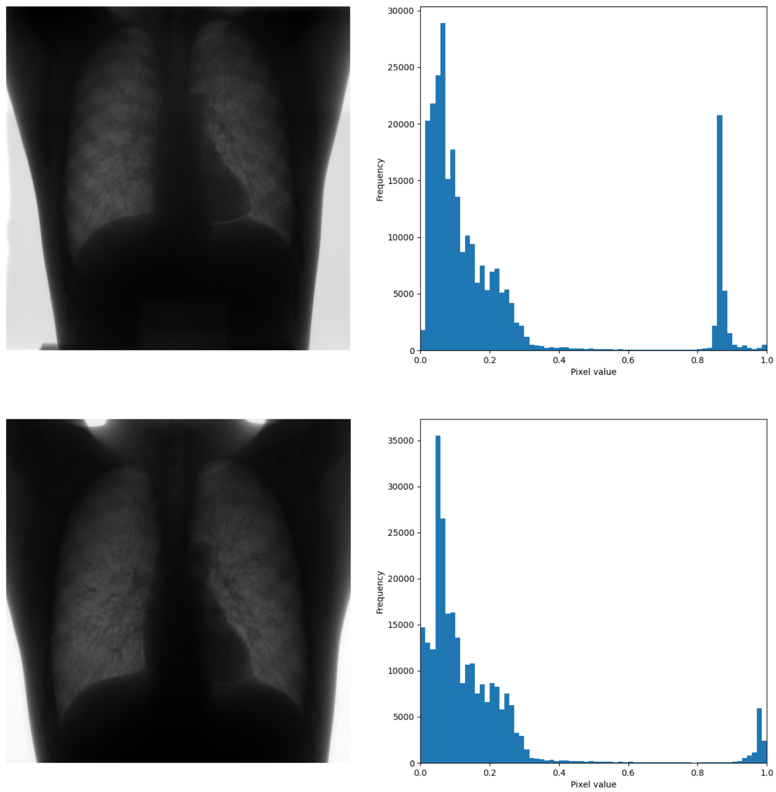


Figure 3.3: Histograms of chest phantom transmission maps

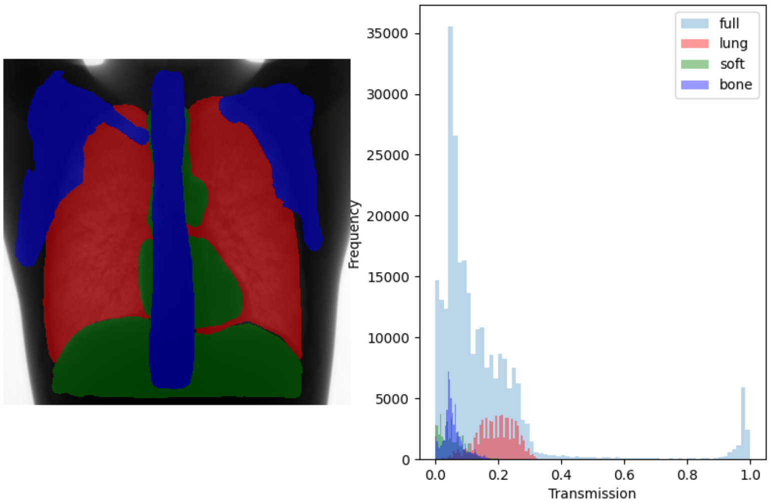


Figure 3.4: Histograms of chest phantom transmission maps grouped by regions

likely resulting from a histogram equalization process. In contrast, transmission maps have higher frequencies in the values closer to zero.

3.4 Forward Operator Model

Throughout the entire model experimentation, a fixed forward operator is used to represent a digital radiography processing pipeline. According to the literature, modern iterations on image processing algorithms maintain a consistent appearance of images that the radiologists are used to [11, p. 57]. The motivation then is to work with a model that can produce X-ray images with an appearance consistent to the existing image datasets. Then, it is expected that inverting this would produce transmission maps with realistic values.

The goals of image processing can be condensed in the following [4, p. 149]:

- to display the full range of attenuation differences in the chest,
- to optimize spatial resolution of digital chest radio- graphs,
- to enhance structural contrast in the lungs and medi- astinum, and

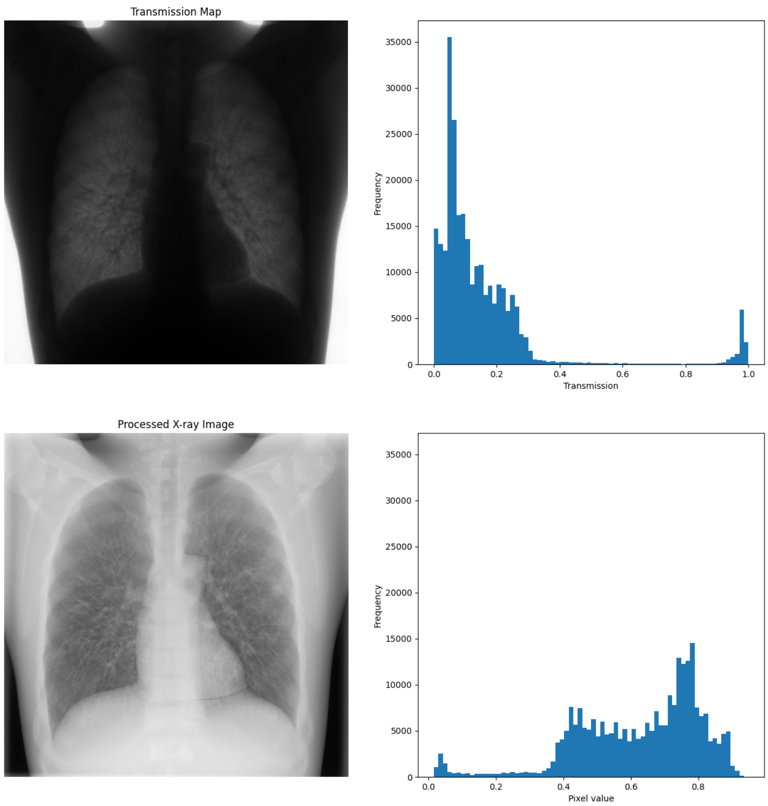


Figure 3.5: Histograms of processed transmission maps

- to suppress image noise.

These goals, and choosing transformations that are appropriate for autodifferentiation, rule the design of our operator F as a composition of several transformations:

$$F = F_n \circ F_{n-1} \circ \cdots \circ F_1 \tag{3.5}$$

where the component transformations include:

Negative logarithm $F_1(x) = -\log(x + \epsilon)$, where ϵ is a small constant to avoid numerical instability

Transmission maps represent the ratio of X-ray intensities I_1 and I_0,

$$\frac{I_1}{I_0} = e^{-\mu x}. \tag{3.6}$$

However, processed images operate on the thickness terms μx (explaining the negative relationship between transmission maps and diagnostic images), which can be extracted through a negative logarithm.

Windowing As a way of implementing gradational adjustment, a window function is implemented, that creates an S-shape lookup table to achieve signal normalization:

$$F_2(x) = \frac{1}{1 + e^{-\gamma \frac{x-c}{w}}}, \tag{3.7}$$

where c is the center of the sigmoid function, w is a width parameter, and γ is a steepness parameter. The effect of these parameters and how these translate into a LUT is shown in Figure 3.6.

Unsharp masking

$$F_4(x) = x + \alpha \cdot (x - G_\sigma * x), \tag{3.8}$$

where G_σ is a Gaussian kernel with standard deviation σ. This operation achieves edge enhancement, and motivates the search of parameters with non-zero α and σ values, in which case would be equivaling to ignoring this transformation.

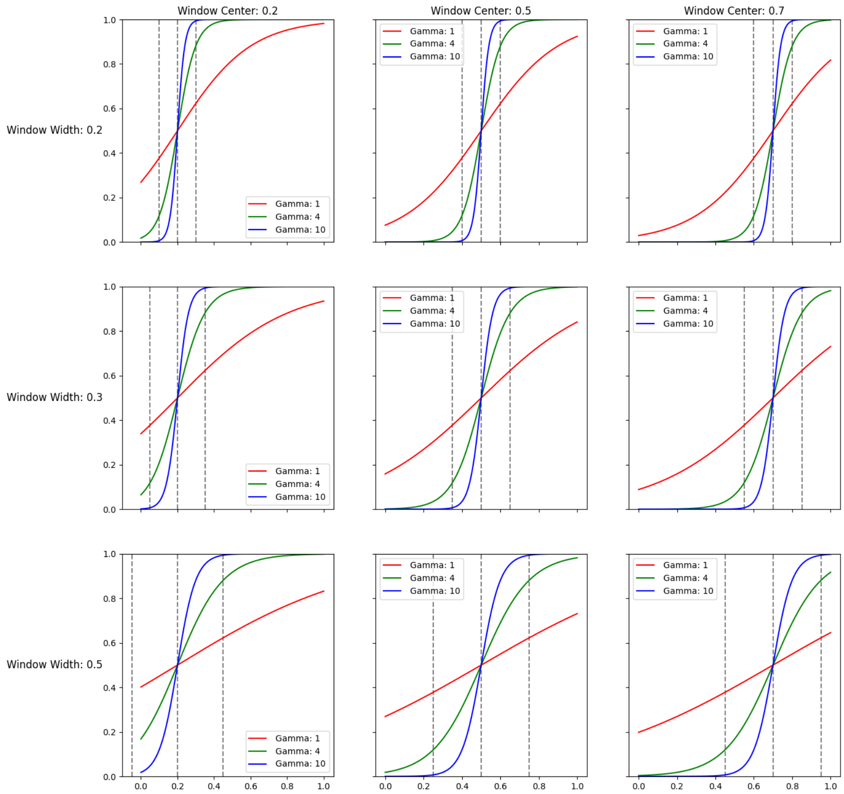


Figure 3.6: Windowing function with different parameter settings.

Range normalization

$$F_3(x) = \frac{x - \min(x)}{\max(x) - \min(x)}, \tag{3.9}$$

as a mean to normalize values to the $[0, 1]$ range, since operations such as windowing and unsharp masking can lead to values outside this range.

Clipping

$$F_5(x) = \min(\max(x, 0), 1) \tag{3.10}$$

The parameter vector θ includes all parameters of these transformations, such as $\{c, w, \alpha, \sigma\}$.

3.5 Optimization Approach

3.5.1 Loss Function Design

We employ a composite loss function to guide the optimization of transmission maps:

$$\begin{aligned} \ell(Y, F(X, \theta), X, S) = &\ell_{\text{MSE}}(Y, F(X, \theta)) + \\ &\lambda_{\text{TV}} \cdot R_{\text{TV}}(X) + \\ &\lambda_{\text{seg}} \cdot R_{\text{seg}}(X, S) + \\ &\lambda_{\text{UMS}} \cdot \ell_{\text{UMS}}(Y, F(X, \theta)) \end{aligned} \tag{3.11}$$

where λ_{TV}, λ_{seg}, and λ_{UMS} are weighting factors that control the influence of each term, and S represents the segmentation masks.

3.5.1.1 Data Fidelity Term

The mean squared error measures how well our forward model matches the observed processed images:

$$\ell_{\text{MSE}}(Y, F(X, \theta)) = \frac{1}{N} \sum_{i=1}^{N} \|y_i - F(x_i, \theta)\|_2^2 \tag{3.12}$$

3.5.1.2 Unsharp Mask Similarity Term

To ensure that the high-frequency details of the reconstructed images match those of the target images, we include an unsharp mask similarity term. Let

G_σ be a Gaussian kernel with standard deviation σ. The detail layer extracted by unsharp masking is:

$$D(z) = z - G_\sigma * z \tag{3.13}$$

The unsharp mask similarity loss is then:

$$\ell_{\text{UMS}}(Y, F(X, \theta)) = \frac{1}{N} \sum_{i=1}^{N} \|D(y_i) - D(F(x_i, \theta))\|_2^2 \tag{3.14}$$

This term encourages the preservation of edge and texture details in the reconstructed images, which is particularly important for maintaining diagnostic features.

3.5.2 Regularization Terms

3.5.2.1 Total Variation Regularization

Total variation regularization promotes piecewise smoothness while preserving edges in the reconstructed transmission maps:

$$R_{\text{TV}}(X) = \frac{1}{N} \sum_{i=1}^{N} R_{\text{TV}}(x_i) \tag{3.15}$$

where for a single image x_i:

$$R_{\text{TV}}(x_i) = \frac{1}{2} \left(\|\nabla_h x_i\|_F^2 + \|\nabla_v x_i\|_F^2 \right) \tag{3.16}$$

3.5.2.2 Segmentation-Based Regularization

We incorporate physics-based constraints derived from anatomical segmentation to ensure realistic transmission values for different tissue types:

$$R_{\text{seg}}(X, S) = \frac{1}{N} \sum_{i=1}^{N} R_{\text{seg}}(x_i, S_i) \tag{3.17}$$

where $S_i = \{S_i^1, S_i^2, \ldots, S_i^M\}$ are the segmentation masks for the M anatomical regions in image i, and:

$$R_{\text{seg}}(x_i, S_i) = \sum_{m=1}^{M} P_m(x_i, S_i^m) \tag{3.18}$$

The penalty function P_m for region m computes the squared deviation of pixel values from the expected range $[v_{min}^m, v_{max}^m]$:

$$P_m(x_i, S_i^m) = \frac{\sum_{j,k} \left(\max(0, v_{min}^m - x_i(j,k))^2 + \max(0, x_i(j,k) - v_{max}^m)^2\right) \cdot S_i^m(j,k)}{\sum_{j,k} S_i^m(j,k)} \tag{3.19}$$

This penalizes transmission values that fall outside the expected physical ranges for each anatomical region, normalized by the size of the region.

3.5.3 Constraint Enforcement via Projections

To ensure the optimization process stays within physically plausible regions of the parameter space, we employ projection operators after each gradient update step. These projections enforce hard constraints on both the transmission maps and the forward model parameters.

3.5.3.1 Transmission Map Constraints

Physical principles dictate that transmission values must lie between 0 and 1, where 0 represents complete absorption and 1 represents no absorption. We enforce this using a hypercube projection:

$$P_{\text{hypercube}}(x) = \min(\max(x, 0), 1) \tag{3.20}$$

This ensures that after each optimization step, all pixel values in the transmission maps remain physically valid.

3.5.3.2 Forward Model Parameter Constraints

To ensure the forward model produces realistic processed images, we constrain its parameters within ranges that correspond to clinically relevant image processing operations. These constraints are implemented as:

$$P_{\text{param}}(\theta) = \{P_{\text{box}}(\theta_k; a_k, b_k) \mid k \in \text{keys}(\theta)\} \tag{3.21}$$

where P_{box} is a box projection that constrains a parameter to lie within a specified interval $[a, b]$:

$$P_{\text{box}}(\theta_k; a_k, b_k) = \min(\max(\theta_k, a_k), b_k) \tag{3.22}$$

Specifically, we apply the following constraints to the forward model parameters:

- Windowing parameters: window_center $\in [0.1, 0.8]$, window_width $\in [0.1, 1.0]$
- Sigmoid steepness: $\gamma \in [1, 20]$
- Unsharp masking parameters: low_sigma $\in [0.5, 10]$, low_enhance_factor $\in [0.3, 1.0]$

These constraints ensure that:

1. The window center stays within the meaningful range of X-ray transmission values
2. The window width allows for appropriate contrast adjustment
3. The sigmoid steepness produces S-curves similar to those used in clinical practice
4. Unsharp masking uses filter sizes appropriate for enhancing structures at diagnostically relevant scales
5. Enhancement factors avoid under and over-sharpening artifacts

3.5.3.3 Projection in the Optimization Loop

After each gradient update step, we apply these projections sequentially:

$$x_{t+1} = P_{\text{hypercube}}(x_t - \alpha_x \nabla_x L(x_t, \theta_t)) \tag{3.23}$$

$$\theta_{t+1} = P_{\text{param}}(\theta_t - \alpha_\theta \nabla_\theta L(x_t, \theta_t)) \tag{3.24}$$

where α_x and α_θ are learning rates for the transmission maps and forward model parameters, respectively. This projection-based approach ensures that the optimization remains faithful to the physical and practical constraints of the problem, avoiding physically implausible solutions even when the loss function might favor them.

3.5.4 Optimization Procedure

We employ the JAX-based optimization framework with the following steps:

1. Initialize transmission maps X and parameters θ with reasonable values
2. Compute forward process $F(X, \theta)$
3. Calculate the composite loss and gradients
4. Update parameters using Adam optimizer
5. Apply projection to enforce constraints on X and θ
6. Repeat until convergence or maximum iterations

The optimization is performed by minimizing the complete loss function with respect to both the transmission maps and the parameters of the forward model.

3.6 Evaluation Methodology

We evaluate our method using several metrics:

- **Image quality metrics**: SSIM, PSNR between reconstructed processed images and originals
- **Forward reconstruction error**: MSE between $F(X, \theta)$ and Y
- **Physics compliance**: How well the recovered maps adhere to physical constraints
- **Visual assessment**: Qualitative evaluation by medical imaging experts

For the limited cases where ground truth is available (e.g., from phantoms), we also calculate direct error metrics on the recovered transmission maps.

Chapter 4

Implementation

4.1 Software Architecture

Our implementation is structured as a Python package with the following components:

- **Data loading and preprocessing**: Modules for handling datasets and preparing images
- **Forward operators**: Differentiable implementations of radiographic processing steps
- **Optimization core**: JAX-based optimization framework with automatic differentiation
- **Regularization functions**: Total variation and other constraints
- **Evaluation metrics**: Functions for assessing reconstruction quality
- **Visualization utilities**: Tools for displaying and analyzing results

The code is built using JAX for efficient optimization with automatic differentiation and GPU acceleration.

4.2 JAX-Based Optimization Framework

Our implementation is built around JAX [**?**], which significantly influenced our design decisions and approach to the optimization problem.

4.2.1 Automatic Differentiation Requirements

JAX's automatic differentiation capabilities require all operations in the forward model to be differentiable. This constraint directly impacted our design:

- **Smooth approximations**: We replaced non-differentiable operations with differentiable approximations. For example, we use sigmoid functions instead of hard thresholds.
- **Avoiding discontinuities**: Operations like rounding or thresholding were avoided in favor of continuous alternatives.
- **Epsilon terms**: Small constants were added to prevent numerical instabilities:

```python
def negative_log(image, eps=1e-6):
    return -jnp.log(jnp.maximum(image, eps))
```

4.3 Experimental Setup

Our experiments are configured to explore different models and hyperparameters:

- **Known vs. Unknown Transformation**: We compare scenarios where the forward transformation is known versus when it must be inferred
- **Single vs. Batch Processing**: We evaluate optimizing for individual images versus batches
- **Regularization Strength**: We vary the total variation regularization parameter
- **Initialization Strategies**: We test different initialization methods for the transmission maps

Each experiment is run with multiple random seeds to ensure robustness, and results are logged to Weights & Biases for analysis.

Chapter 5

Results and Analysis

In this chapter, we present the experimental results of our transmission map recovery method and analyze its performance across different configurations and datasets.

5.1 Experimental Setup

Our experiments were conducted on subsets of the CheXpert dataset, with the following configurations:

- **Batch sizes**: 8, 16, and 32 images
- **Image resolution**: 512×512 pixels (downsampled from original)
- **Optimization steps**: 300, 600, and 1200 iterations
- **Hardware**: NVIDIA RTX 3090 GPU with 24GB memory

5.2 Hyperparameter Optimization Results

Through Bayesian optimization over 200 sweep runs, we identified optimal hyperparameter ranges:

5.3 Reconstruction Quality Metrics

[Note: Insert actual results here once experiments are complete]

Table 5.1: Optimal hyperparameter ranges identified through Bayesian optimization

Parameter	Optimal Range	Best Value
Learning rate	0.005 - 0.04	0.0084
Gradient penalty weight (λ_{grad})	0 - 0.0001	9.8e-6
Anatomical prior weight (λ_{anat})	0.1 - 0.5	0.261
Detail similarity weight (λ_{detail})	0.1 - 0.45	0.384

5.3.1 Image Quality Assessment

The reconstruction quality was evaluated using:

- **SSIM**: Structural similarity between reconstructed processed images and targets
- **PSNR**: Peak signal-to-noise ratio
- **Anatomical Compliance**: Percentage of pixels within expected physical ranges for each tissue type

5.3.2 Physical Plausibility

We assess the physical plausibility of recovered transmission maps through:

- Distribution analysis of transmission values per anatomical region
- Comparison with the limited ground truth phantom data
- Expert radiologist evaluation (planned)

5.4 Computational Performance

5.4.1 Scaling Analysis

The computational requirements scale as:

- **Memory**: $O(B \times H \times W)$ where B is batch size
- **Time**: Approximately linear in number of optimization steps
- **Convergence**: Typically achieved within 300-600 iterations for well-chosen hyperparameters

5.4.2 Bottlenecks and Limitations

The primary computational bottlenecks identified are:

1. Segmentation model inference (can be mitigated through pre-computation)
2. Gaussian blur operations in unsharp masking (limited by convolution efficiency)
3. Hyperparameter search space exploration (requires extensive parallel computation)

Chapter 6

Discussion

6.1 Interpretation of Results

Our method demonstrates the feasibility of recovering physically plausible transmission maps from processed chest X-rays, though several challenges remain for practical deployment at scale.

6.1.1 Success Factors

The combination of gradient-based smoothness regularization with anatomically-informed constraints proves effective in producing transmission maps that:

- Maintain appropriate value ranges for different tissue types
- Preserve diagnostic features when re-processed
- Exhibit smooth transitions consistent with physical X-ray attenuation

6.1.2 Limitations and Challenges

6.1.2.1 Scalability

The current approach faces significant scalability challenges:

- **Computational Cost**: Processing the full CheXpert dataset would require approximately 100-400 GPU-hours depending on batch size and convergence criteria
- **Hyperparameter Sensitivity**: Optimal parameters vary with image characteristics, requiring adaptive strategies

- **Memory Constraints**: Large batch sizes improve parameter estimation but are limited by GPU memory

6.1.2.2 Model Assumptions

Our forward model makes several simplifying assumptions:

- Single processing pipeline for all manufacturers (may not capture vendor-specific variations)
- Fixed order of operations (actual pipelines may vary)
- Deterministic processing (ignores potential adaptive or ML-based enhancements)

6.2 Comparison with Alternative Approaches

Unlike direct inverse mapping approaches, our optimization-based method:

- Provides interpretable parameters for the forward model
- Allows incorporation of physical constraints
- Can adapt to different processing pipelines through parameter adjustment

However, it requires significantly more computation than learned inverse mappings.

6.3 Practical Implications

For practical deployment, we recommend:

1. **Hierarchical Processing**: Start with low-resolution optimization to identify good initialization points
2. **Transfer Learning**: Use parameters learned from one batch to initialize nearby batches
3. **Selective Processing**: Focus on high-value images (e.g., those with specific pathologies)

Chapter 7

Conclusions and Future work

7.1 Conclusions

This thesis presents a novel approach to recovering X-ray transmission maps from processed chest radiographs through constrained optimization. Our key contributions include:

1. **Differentiable Forward Model**: We developed a fully differentiable pipeline modeling common radiographic processing steps, enabling gradient-based optimization.
2. **Anatomically-Informed Regularization**: By incorporating segmentation-guided constraints, we ensure recovered transmission maps respect the physical properties of different tissue types.
3. **Multi-Objective Optimization Framework**: Our approach balances data fidelity, spatial smoothness, and perceptual quality through carefully designed loss functions.

The method successfully recovers transmission maps that, when processed through our forward model, closely match the target clinical images while maintaining physical plausibility.

7.2 Limitations

Several limitations constrain the current approach:

- **Computational Scalability**: Processing large datasets remains computationally intensive, requiring days of GPU time for comprehensive datasets.
- **Hyperparameter Sensitivity**: Optimal parameters vary across image characteristics, necessitating extensive search or adaptive strategies.
- **Ground Truth Scarcity**: Limited availability of paired transmission map and processed image data restricts validation options.
- **Model Complexity**: The simplified forward model may not capture all nuances of commercial processing pipelines.

7.3 Future work

7.3.1 Immediate Extensions

1. **Adaptive Hyperparameter Selection**: Develop methods to automatically select hyperparameters based on image characteristics, potentially using meta-learning approaches.
2. **Efficient Optimization Strategies**: Explore second-order optimization methods or learned optimizers to reduce the number of iterations required.
3. **Multi-Resolution Processing**: Implement coarse-to-fine optimization strategies to improve both speed and convergence.

7.3.2 Long-term Research Directions

1. **Learned Inverse Models**: Train neural networks to directly predict transmission maps, using our optimization results as training data.
2. **Manufacturer-Specific Models**: Develop specialized forward models for different equipment manufacturers based on their processing characteristics.
3. **Uncertainty Quantification**: Incorporate Bayesian approaches to quantify uncertainty in recovered transmission maps.
4. **Real-time Processing**: Develop approximation methods enabling real-time transmission map recovery for clinical applications.

7.3.3 Practical Deployment

For practical deployment in support of low-cost X-ray system development:

- Create a cloud-based processing pipeline for batch transmission map recovery
- Develop quality metrics to automatically identify successfully recovered maps
- Build a curated dataset of transmission maps with associated metadata
- Establish validation protocols with clinical partners

7.4 Reflections

This work contributes to global health equity by enabling the development of affordable diagnostic imaging systems. The ability to generate training data for alternative X-ray detectors could significantly reduce the cost barrier for medical imaging in resource-limited settings.

The project also highlights the importance of physics-informed machine learning approaches in medical imaging, demonstrating how domain knowledge can guide optimization in under-constrained problems.

While significant computational challenges remain, the framework established here provides a foundation for future work in radiographic image analysis and affordable medical technology development.

One of the most important results is the reduction in the amount of energy required to process each packet while at the same time reducing the time required to process each packet.

The thesis contributes to the United Nations (UN) Sustainable Development Goals (SDGs) numbers 1 and 9 by xxxx.

In the references, let Zotero or other tool fill this in for you. I suggest an extended version of the IEEE style, to include URLs, DOIs, ISBNs, etc., to make it easier for your reader to find them. This will make life easier for your opponents and examiner.
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References

[1] M. A. Ansari, S. Ahmad, and A. Mewada, “Mitigating risk in medical AI: Balancing X-ray datasets for reliable detection,” *Life Cycle Reliability and Safety Engineering*, May 2025. doi: 10.1007/s41872-025-00316-7 [Page 1.]

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If you do not have an appendix, do not include the \cleardoublepage command below; otherwise, the last page number in the metadata will be one too large.

Appendix A

Supporting materials

Here is a place to add supporting material that can help others build upon your work. You can include files as attachments to the PDF file or indirectly via URLs. Alternatively, consider adding supporting material uploaded as separate files in DiVA.

The BibTeX references used in this thesis are attached.

Some source code relevant to this project can be found at `https://github.com/gqmaguirejr/E-learning` and `https://github.com/gqmaguirejr/Canvas-tools`.

Your reader can access the attached (embedded) files using a PDF tool such as Adobe Acrobat Reader using the paperclip icon in the left menu, as shown in Figure A.1 or by right-clicking on the push-pin icon in the PDF file and then using the menu to save the embedded file as shown in Figure A.2.

An argument for including supporting material in the PDF file is that it will be available to anyone who has a copy of the PDF file. As a result, they do not have to look elsewhere for this material. This comes at the cost of a larger PDF file. However, the embedded files are encoded into a compressed stream within the PDF file; thus, reducing the number of additional bytes. For example, the references.bib file that was used in this example is 10 617 B in size but only occupies 4 261 B in the PDF file.

DiVA is limited to ≈1 GB for each supporting file. If you have very large amounts of supporting material, you will probably want to use one of the data repositories. For additional help with this, contact KTH Library via researchdata@kth.se.
As of Spring 2024, there are plans to migrate this supporting data from DiVA to a research data repository.

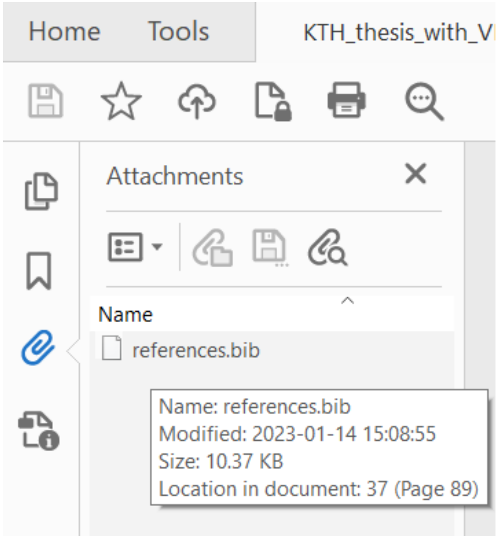

Figure A.1: Adobe Acrobat Reader using the paperclip icon for the attached references.bib file

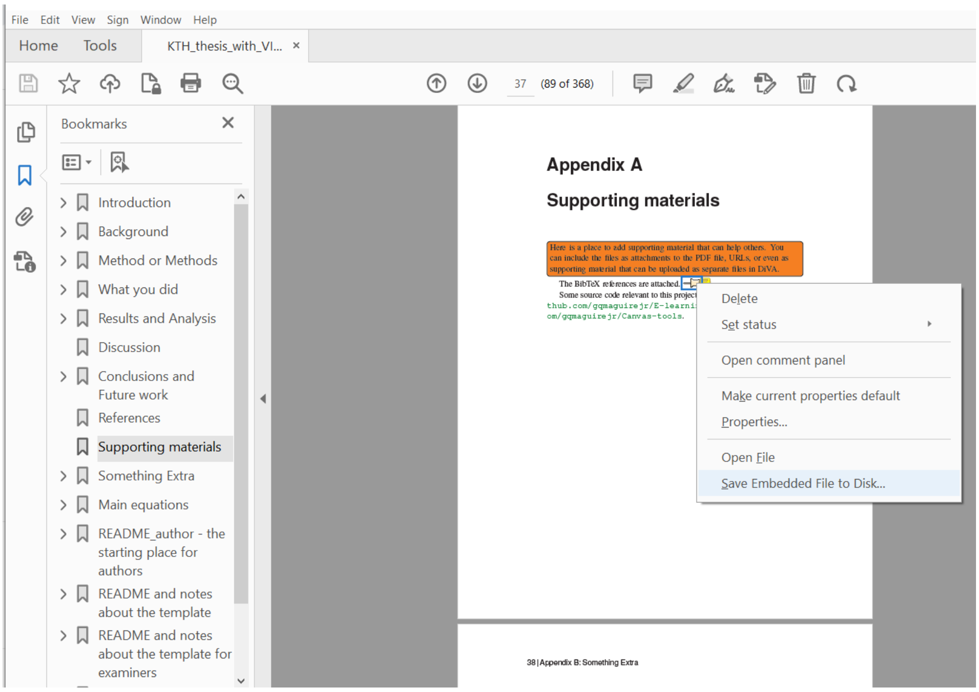

Figure A.2: Adobe Acrobat Reader after right-clicking on the push-pin icon for the attached references.bib file

Appendix B

Something Extra

svensk: Extra Material som Bilaga

B.1 Just for testing KTH colors

You have selected to optimize for print output

- Primary color
  - kth-blue
  - kth-blue80
- Secondary colors
  - kth-lightblue
  - kth-lightred
  - kth-lightred80
  - kth-lightgreen
  - kth-coolgray
  - kth-coolgray80

black

Appendix C

Main equations

This appendix gives some examples of equations that are used throughout this thesis.

C.1 A simple example

The following example is adapted from Figure 1 of the documentation for the package nomencl (`https://ctan.org/pkg/nomencl`).

$$a = \frac{N}{A} \tag{C.1}$$

The equation $\sigma = ma$ follows easily from Equation (C.1).

C.2 An even simpler example

The formula for the diameter of a circle is shown in Equation (C.2) area of a circle in eq. (C.3).

$$D_{circle} = 2\pi r \tag{C.2}$$

$$A_{circle} = \pi r^2 \tag{C.3}$$

Some more text that refers to (C.3).

Appendix D

README_author - the starting place for authors

This document, written by Gerald Q. Maguire Jr, describes the thesis template that I have developed for use at KTH Royal Institute of Technology (KTH). It is important to note that the template is **not prescriptive**, as not every thesis will have all of the parts that the template shows. However, if there is something that you decide to leave out, you should make a conscious decision to do so and you should consider the impact this may have on your thesis being approved by the examiner.

Fundamental to the design of the template are several key factors:

- Helping students be successful in their degree project,
- Helping students produce a high-quality thesis, and
- Supporting all of the (relevant) phases of the degree project process.

This document is a work in progress.

D.1 Advice for Author or Authors

One of the hardest problems an author faces is getting started writing, *i.e.,* the blank sheet of paper – empty file barrier. The template provides a non-blank starting point; hence, avoiding the blank paper barrier. Additionally, the template provides some initial structure, basically, an Introduction, Methods, Results, and Discussion (IMRAD) structure, so that there are hints of where to place material. Moreover, there are places (and notes) about material that the student should consider adding; for example, the "required reflections" section in the final chapter.

The template (located in the file `main.tex`) also provides some examples of commonly occurring types of content, so that one can easily find examples of how to include a figure, table, code listing, *etc*. These examples are not meant to be exhaustive and quite often the student will probably need to learn new LaTeX commands in the course of writing their thesis.

As an author, the first step is to configure the LaTeX engine that you will use to process the files - see Appendix D.2. The second step will be to configure the template - see Appendix D.3. The third step will be to make sure that the information about you, your supervisor(s), and the examiner are correct in the file `custom_configuration.tex` - this information uses the macros described in Appendix D.4. Now that you have a lot of the administrative details taken care of it is time to start to write - see Appendix D.6.

Note that if you are using Overleaf:

Make your own copy of the template If you have opened the template from a URL, in the upper left-hand corner, click on **Menu**. Then select **Copy Project** - this will give you your own private copy.

Use a helpful project name I suggest you include your name in the project name so that when you share it with your supervisor(s) and examiner, they will know it is your project.

Invite your supervisor(s9 and examiner to your project You can invite your supervisor(s) and examiner to your project and they can directly comment on and correct your drafts.

Log in to Overleaf with your KTH account If you log in to Overleaf with your KTH account, you get a version of Overleaf that lets you turn on "Track changes" which is very useful (particularly if you have invited your supervisor(s) and examiner to join your project). It also gives you a bit more of a time budget to compile (which can be useful if you have a lot of Tikz figures or other things that take a lot of time for the LaTeX engine to render).

.

If you have more detailed questions about the template itself - see Appendix E.

D.2 Author configuration of the LaTeX engine

The template should work with pdfLaTeX, XeLaTeX, and LuaLaTeX. If you are using Overleaf, I strongly recommend using XeLaTeX — as this will get the `Arial` fonts correct for the KTH cover. If you are running the compiler on your local machine and you use XeLaTeX **and** you have `Arial` as a system font, then it will be able to use it. Similarly, for LuaLaTeX. For pdfLaTeX I have used \fontfamilyhelvet, *i.e.,* Helvetica, as it is a sans serif font.

One student reported problems with fontspec not loading the fonts properly when running locally with macOS 12.4, TeXLive 2022, LaTeX Workshop on VS Code, and XeLaTeX - the solution is described at `https://tug.org/TUGboat/tb39-2/tb122robertson-fontspec.pdf`.

If you are using Overleaf, it is easy to select the compiler (*i.e.,* TeX engine) by using the drop-down menu, as shown in Figure D.1.

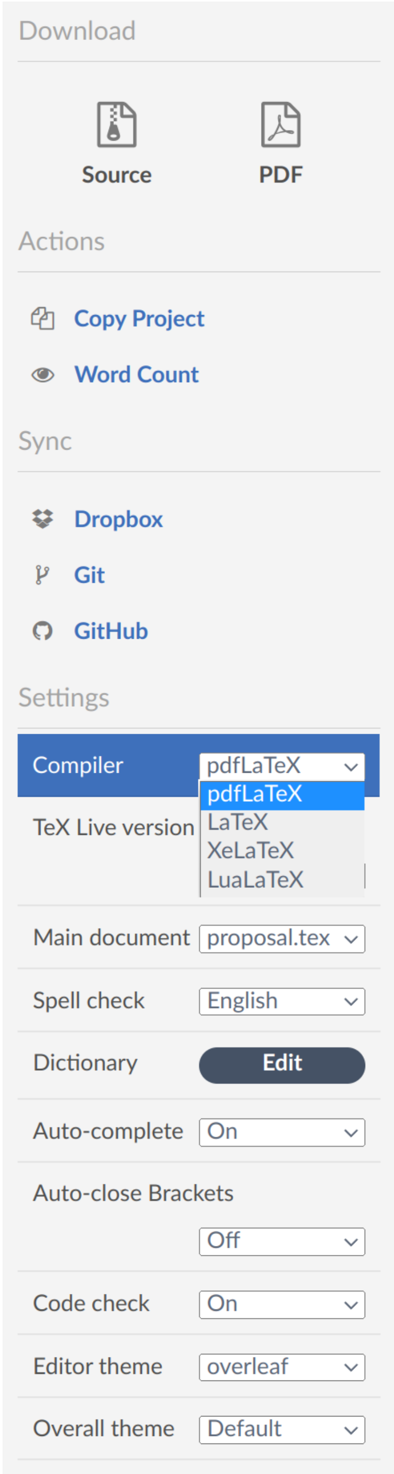

Figure D.1: Selecting a compiler (*i.e.,* TeX engine) in Overleaf

D.3 Author configuration of the template

The template is designed to handle a thesis written in English or Swedish. You can set the default language to ‘english’ or ‘swedish’ by passing an option to the documentclass. Note that the language option is written in all lowercase letters; for example, to set the document’s language to English:

```
\documentclass[english]{kththesis}
```

To set the document’s language to Swedish (uncomment the following line):

```
\documentclass[swedish]{kththesis}
```

The language option ‘swedish’ sets the conditional `\ifinswedish` to true. Among many other things, this conditional is used to configure the KTH cover and the title page to use the chosen language.

The two most common bibliographic engines are supported, *i.e.*, BibTeX and BibLaTeX. To set the language to English and use the bibliographic engine to BibTeX you would say:

```
\documentclass[english, bibtex]{kththesis}
```

To set the language to Swedish and use the bibliographic engine to BibLaTeX you would say:

```
\documentclass[swedish, biblatex]{kththesis}
```

The above illustrates that you can pass multiple options to the document class separated by commas. Also, note that the options were passed as all lowercase letters.

You can, of course, also modify the formatting of the citations and bibliography. See for example the following code snippet:

```
\ifbiblatex
    %\usepackage[language=english,bibstyle=authoryear,
        ↪ citestyle=authoryear, maxbibnames=99]{biblatex
        ↪ }
    %\usepackage[style=numeric,sorting=none,backend=
        ↪ biber]{biblatex}
    \usepackage[bibstyle=authoryear,citestyle=authoryear,
        ↪  maxbibnames=99,language=english]{biblatex}
    % alternatively you might use another style, such as
        ↪  IEEE
    %\usepackage[style=ieee]{biblatex}
    \addbibresource{references.bib}
```

```
    %\DeclareLanguageMapping{norsk}{norwegian}
\else
    % The line(s) below are for BibTeX
    \bibliographystyle{bibstyle/myIEEEtran}
    %\bibliographystyle{apalike}
\fi
```

To optimize for digital output (this changes the color palette) add the option: `digitaloutput`. There are also options for A4 or G6 paper: `a4paper` or `g5paper` (respectively). The is an option for `nomenclature`, to produce and refer to equations as shown in Appendix C . Finally, there are options for a 1st cycle thesis or 2nd cycle thesis: `bachelor` and `master` (respectively); however, these two options are **not** currently used.

One of the first things that the author(s) will want to do is add the working title and subtitle to the thesis. This is done using the \title, \subtitle, \alttitle, and \altsubtitle macros as shown below:

```
\title{Chest X-ray Transmission Map Reconstruction}
\subtitle{Constrained Optimization to Invert a Family of
   ↪ Image Processing Algorithms}

% give the alternative title -i.e., if the thesis is in
   ↪ English,
% then give a Swedish title
\alttitle{Detta är den svenska översättningen av titeln}
\altsubtitle{Detta är den svenska översättningen av
   ↪ undertiteln}
% alternative, if the thesis is in Swedish, then give an
   ↪  English title
%\alttitle{This is the English translation of the title}
%\altsubtitle{This is the English translation of the
   ↪ subtitle}
```

Setting these values once and then using them in many places reduces the work to change them while at the same time ensuring consistency.

Some additional configuration that the author(s) might do is to set the values of the macros related to the course cycle, course code, date of the thesis, number of credits, degree/exam name, subject area, and if the degree is done external to KTH to set the host information (see the file *custom_configuration.text*). Consider the snippet below for a student admitted to the "Bachelor's Programme in Information and Communication Technology (TCOMK)" program and enrolled in the degree project course "IA150X

Degree Project in Information and Communication Technology, First Cycle 15.0 credits" and working at a company "Företaget AB":

```
\hostcompany{Företaget AB} % Remove this line if the
   ↪ project was not done at a host company

\date{\today}

\courseCycle{1}
\courseCode{IA150X}
\courseCredits{15.0}

\programcode{TCOMK}
\degreeName{Bachelors degree}
% Note that the subject area for a Bachelor's thesis (
   ↪ Kandidatexamen)
% should be either Technology or Architecture
% If the thesis is in Swedish, these would be: teknik |
   ↪ arkitektur
% -- Note the use of lower case for the Swedish subject
   ↪ area
\subjectArea{Technology}
```

Note that in the above macros you have to give the English or Swedish names in the arguments to \degreeName and \subjectArea - as shown below:

```
\degreeName{Kandidatexamen}
\subjectArea{teknik}
```

For a CDATE student enrolled in the course "DA231X Degree Project in Computer Science and Engineering, Second Cycle 30.0 credits", the cycle, program, course code, degree, and subject area information would be:

```
\programcode{CDATE}
\courseCycle{2}
\courseCode{DA231X}
\courseCredits{30.0}
\degreeName{Degree of Master of Science in Engineering}
\subjectArea{Computer Science and Engineering}
```

The set of possible values for the English or Swedish names in the arguments to \degreeName are:

```
\degreeName{Higher Education Diploma}
\degreeName{Högskoleexamen}
```

```
\degreeName{Bachelors degree}
\degreeName{Kandidatexamen}

\degreeName{Master of Architecture}
\degreeName{Arkitektexamen}

\degreeName{Degree of Master of Science in Engineering}
\degreeName{Civilingenjörs}

\degreeName{Magister}
\degreeName{Magisterexamen}

\degreeName{Degree of Master of Science}
\degreeName{Masterexamen}

\degreeName{Master of Science in Engineering and Master
    ↪ of Arts in Education degree}
\degreeName{Civilingenjör och lärare examen}

\degreeName{Degree of Master of Science in Secondary
    ↪ Education}
\degreeName{Ämneslärarexamen}

\degreeName{Both}  # Degree Project in the Field of
    ↪ Technology <teknikområde> and the Main Field of
    ↪ Study <huvudområde>
\degreeName{Same}  # The case when the field of
    ↪ technology <teknikområde> and main field of study
    ↪ <huvudområde> are the same.
```

For the last two cases, the code compares the values of subjectArea and secondSubjectArea.

You can find a list of the program codes and school acronyms in the file: `lib/schools_and_programs.ins`.

There are a set of rules about what is to be displayed on the KTH cover. These can be found at https://www.kth.se/social/group/sprakkommitten/page/omrade-for-examensarbete/.

One of the reasons for many of the macros shown above and below is to collect the information that is needed to report the approved thesis in Digitala Vetenskapliga Arkivet (DiVA) and to report the title(s) and grade in Lokalt adb–baserat dokumentationssystem (LADOK).

National subject categories are a **required** field in the DiVA record. These categories follow a definition by SCB (nowadays known as Statistikmyndigheten or in English: Statistics Sweden) and HSV (Högskoleverket - nowadays known as Universitetskanslersämbetet (UK-ämbetet) and Universitets- och högskolerådet (UHR) or in English: Swedish Higher Education Authority and Swedish Council for Higher Education). While these codes refer to research areas, these codes are also used in KTH to indicate the area of the thesis. The guidance that I received from the Linköping University library was that one should try to use 5-digit codes when possible. Some examples of these codes are shown in Table D.1.

`\nationalsubjectcategories{}` comma separated list of national subject category codes - each a 3 or 5 digit code

An example for a thesis in Computer Science and Computer Systems:

```
\nationalsubjectcategories{10201, 10206}
```

You can find the subjects and their codes in:
https://www.scb.se/contentassets/3a12f556522d4bdc887c4838a37c7ec7/standard-for-svensk-indelning--av-forskningsamnen-2011-uppdaterad-aug-2016.pdf
and
https://www.scb.se/contentassets/10054f2ef27c437884e8cde0d38b9cc4/oversattningsnyckel-forskningsamnen.pdf

Table D.1: Examples of some national subject categories and their codes

Code	Category (in Swedish)	Category (in English)
102	Data- och informationsvetenskap (Datateknik)	Computer and Information Sciences
10201	Datavetenskap (datalogi)	Computer Sciences
10202	Systemvetenskap, informationssystem och informatik (samhällsvetenskaplig inriktning under 50804)	Information Systems (Social aspects to be 50804)
10203	Bioinformatik (beräkningsbiologi) (tillämpningar under 10610)	Bioinformatics (Computational Biology) (applications to be 10610)
10204	Människa-datorinteraktion (interaktionsdesign) (Samhällsvetenskapliga aspekter under 50803)	Human Computer Interaction (Social aspects to be 50803)
10205	Programvaruteknik	Software Engineering
10206	Datorteknik	Computer Engineering
10207	Datorseende och robotik (autonoma system)	Computer Vision and Robotics (Autonomous Systems)
10208	Språkteknologi (språkvetenskaplig databehandling)	Language Technology (Computational Linguistics)
10209	Medieteknik	Media and Communication Technology
10299	Annan data- och informationsvetenskap	Other Computer and Information Science
202	Elektroteknik och elektronik	Electrical Engineering, Electronic Engineering, Information Engineering
20201	Robotteknik och automation	Robotics
20202	Reglerteknik	Control Engineering
20203	Kommunikationssystem	Communication Systems
20204	Telekommunikation	Telecommunications
20205	Signalbehandling	Signal Processing
20206	Datorsystem	Computer Systems
20207	Inbäddad systemteknik	Embedded Systems
20299	Annan elektroteknik och elektronik	Other Electrical Engineering, Electronic Engineering, Information Engineering

D.4 Author macros

It is assumed that there can only be 1 or 2 authors. For many years now 2nd cycle theses are expected to only have one author.

For the author or first author, there are a number of macros defined to store information about the author, so that it can later be used in multiple places – for example, the KTH cover (produced with `\kthcover`), the title page (produced with `\titlepage`, the "For DIVA" section at the end of the thesis (produced with `\divainfo{pg:lastPageofPreface}{pg:lastPageofMainmatter}`), and possibly a JavaScript Object Notation (JSON) file named `for-diva.json` produced as a by product of the `\divainfo`. Note that the actual section name has DiVA set in all caps - which hopefully should not occur in the thesis! If the string DiVA set in all caps, does have to appear, then the section heading should be preceded by four euro signs and followed by four more euro signs (as is done this doucment).

The author-related macros are:

`\authorsLastname{}`	the last name of the author*
`\authorsFirstname{}`	the first name of the author
`\email{}`	the KTH e-mail address of the author
`\kthid{}`	the author's kthid, this generally starts with the string ·"u1" and is a unique identifier for every KTH user.
`\authorsSchool{}`	the value is generally of the form: `\schoolAcronym{EECS}`. The currently supported school acronyms are: ABE, CBH, EECS, ITM, and SCI. These are defined in the file `schools_and_programs.ins`.

If the first author is not in Stockholm, Sweden when the acknowledgements are written, then add that information via the macros described below. This information will be used when generating the acknowledgements signature. The acknowledgements signature is the text at the end of the

*Note that the author's name can include a suffix such as ", Jr." or " Jr.", i.e., the suffix can be separated with a comma or not – as the author prefers to write their name.

acknowledgements and it gives the place where the author(s) is/are when writing the acknowledgements and also gives the date and name(s).

\authorCity{A City} specify the city

\authorCountry{A Country} specify the country

\authorCityCountryDate{} pass into this function the month and year for the acknowledgement. This can be a string such as January 2022 or it can be a LaTeX expression, such as \MONTH\enspace\the\year.

If there is a second author and the place, month, and year are **all** the same, then specify the month and year for only the **first** author:

```
\authorCityCountryDate{\MONTH\enspace\the\year}
```

If there is a second author and the place is different, then say:

```
\authorCityCountryDate{}
```

If there is a second author, the macros are:

\secondAuthorsLastname{} the last name of the 2nd author

\secondAuthorsFirstname{} the first name of the 2nd author

\secondemail{} the KTH e-mail address of the 2nd author

\secondkthid{} the 2nd author's kthid

\secondAuthorsSchool{} the school of the 2nd author

If the second author is not in the same place as the first author, then add the relevant information using the macros below. This information will be used when generating the acknowledgements signature.

\secondAuthorCity{A City} specify the city

\secondAuthorCountry{A Country} specify the country

\secondAuthorCityCountryDate{\MONTH\enspace\the\year} pass into this function the month and year for the acknowledgement

If the second author is the same place as the first author, then comment out or delete the \secondAuthorCityCountryDate{} as shown below:

```
%\secondAuthorCityCountryDate{}
```

D.5 Starting to write - for the impatient

For those who are impatient and rapidly want to start writing, I suggest you start by configuring the `custom_configuration.tex` file (see Appendix D.3), your working title, and abstract (Appendix D.6.1). After this, a quick way to start writing the text in your document is to go to the table of contents in Overleaf and click on a chapter or section - this will utilize a hyperlink to go to that part of the PDF file. Next, click on the left-going arrow near the top of the border between the LaTeX on the left and the PDF on the right; this will take you (close) to the correct place in the source file where you can start to modify the content and write.

D.6 Starting to write

As you write you will notice "todo" notes in the template. They follow the following conventions:

```
\generalExpl{Comments/directions/... in English}
\sweExpl{Text på svenska}
\engExpl{English descriptions about formatting}
\sweExpl{warnings}
```

If you do not want to see these notes, you can, of course, redefine the above macros to output nothing. If you do not want to see any notes, then add the option **final** to the \documentclass arguments near the top of the file `main.tex`.

D.6.1 Working abstract

I generally recommend that every student start by writing a working abstract, this will help you keep your focus. To find where you can start to enter your abstract, look in the `main.tex` file for the line:

```
\generalExpl{Enter your abstract here!}
```

There is lots of information already in the template to help you with entering text, equations, *etc.,* in your abstract. **NB** Abstracts are supposed to stand by themselves, this means no footnotes, no cross-references, no figures, no tables, *etc.*

I suggest avoiding the use of the defined acronyms in abstracts *i.e.,* spell them out rather than using the glossary commands. This is due to the fact that the `glossaries` package (that is being used to support acronyms) does not directly provide support for multiple languages and because I do not understand how to programmatically create plurals of acronyms in Swedish or other languages. Even in an English abstract, it is desirable to avoid using the glossary commands - as this makes subsequent processing of the abstracts harder - since one has to make sure that the list of acronyms and their definitions are provided to any program that will process this LaTeX source code. For this reason, later versions of this template include the acronyms.tex file after the metadata for DiVA.

D.6.2 Structure of the abstracts and summaries

The basic LaTeX structure for an abstract or summary is shown below (for the case of an English abstract and a Swedish summary *i.e.,* sammanfattning):

```
\begin{abstract}
  \markboth{\abstractname}{}
\begin{scontents}[store-env=lang]
eng
\end{scontents}

\begin{scontents}[store-env=abstracts,print-env=true]
here is where you abstract goes.
\end{scontents}

\subsection*{Keywords}
\begin{scontents}[store-env=keywords,print-env=true]
% If you set the EnglishKeywords earlier, you can
   ↪ retrieve them with:
\InsertKeywords{english}
% If you did not set the EnglishKeywords earlier then
   ↪ simply enter the comma separate keywords here:
%such as: Canvas Learning Management System, Docker
   ↪ containers, Performance tuning
\end{scontents}
\end{abstract}

\cleardoublepage
\babelpolyLangStart{swedish}
\begin{abstract}
    \markboth{\abstractname}{}
\begin{scontents}[store-env=lang]
swe
```

```
\end{scontents}
\begin{scontents}[store-env=abstracts,print-env=true]
Swedish summary goes here
\end{scontents}
\subsection*{Nyckelord}
\begin{scontents}[store-env=keywords,print-env=true]
% SwedishKeywords were set earlier, hence we can use
    ↪ alternative 2
\InsertKeywords{swedish}
\end{scontents}
\end{abstract}
\babelpolyLangStop{swedish}
```

It is important to note that the contents of the `scontents` environment for the abstracts are stored **verbatim**, *i.e.*, the LaTeX is **not** executed. The reason for this is to be able to later have a program that can manipulate the source LaTeX to convert it to HTML for use in announcements, calendar events, and for DiVA. This means that if you write the following:

```
\begin{scontents}[store-env=abstracts,print-env=true]
\input{abstract.txt}
\end{scontents}
```

what will end up in your abstract in the metadata save for DiVA will simply be: `"\input{abstract.tex}"` – which means that someone will have to cut and paste your actual abstract to insert it into DiVA.

It is also important to note that that the following lines:

```
\begin{scontents}[store-env=lang]
eng
\end{scontents}
```

must be before the `scontents` environment for the abstracts and keywords – as these lines indicate what language the subsequent abstract and keywords are in. The three-character code used for the language is the ISO 639-2 Code – specifically the "B" (bibliographic) variant of these codes — as these codes are used in the DiVA metadata to tag what language is used.

D.6.3 Abstracts must be able to stand alone

The abstract needs to be able to stand alone; therefore, you **cannot** include citations to your references – as the references are **not** part of the abstract! It is possible (but very rare) to have footnotes as part of the abstract. However, you should be aware that quite often, if the abstract is manually entered in

DiVA, the footnote might not be entered. In this case, unless your full text is available (*e.g.,* via DiVA), a reader might not have an easy way to find out what the footnote says.

D.6.4 Acronyms

You may want to define an acronym to help you with your writing, as this can both reduce the amount of typing and help your reader by providing consistent use of acronyms. The acronyms' definitions can be found in the file *lib/acronyms.tex*. The file contains some examples. I generally try to sort the lines to help find which acronyms I already have defined and keep track of the new one(s) I want to add.

D.6.5 Some predefined macros to help when writing

The file *lib/defines.tex* includes some macros that will help you when writing. This includes \etc, to give you "*etc.,* ", \eg, \ie, and \etal. The file also defines \first, \Second, ... \eighth to give you (*i*), (*ii*), (*iii*), ... (*viii*). Note that 'Second' is written with an initial capital letter to avoid conflict with the unit 'second' in the `siunitx` package.

D.6.6 Additional abstract(s)

All theses at KTH are **required** to have an abstract in both *English* and *Swedish*. However, in addition to this, many students want to add abstracts in additional languages. The template comes pre-configured with places for abstracts in several other languages. If there is a language that you want to use that is not already supported, there are directions for how to add an additional language. If there are abstracts in languages that you do not want, please delete them or comment them out (see Appendix D.6.7).

D.6.7 Removing and hiding parts that you do not want

It is quite likely that you will find parts of the template that you do not want/need. One way of dealing with this is to delete them, and another way is to comment them out. Personally, I like to comment things out, in case I actually do want to be able to read it in the LaTeX file or uncomment it later. To comment out a portion of the file, simply use the following environment:

```
\begin{comment}
```

```
    **** what you want to comment out ****
\end{comment}
```

For example, if you are not interested in the Swedish language `todo` notes, you can look for lines with "\sweExpl" in them and comment them out (or delete them).

D.6.8 Removing the README_notes

At some point you will no longer want this README information. You can remove it by removing the line \include{README_notes/README_notes} – from the *main.tex* file. You can then remove the **README_notes** directory.

Unless you are an examiner or an administrator you can delete the file: `README_notes/README_examiner_notes.tex` and delete the include of this file from near the end of the template (*i.e., main.tex*. You can also delete the directory **README_notes/README_examiner-figures**.

D.7 Copyright or Creative Commons License

It is possible to have several variants of the bookinfo page*:

copyright
: If you want to have a bookinfo page, include the line saying \bookinfopage.

Creative Commons (CC)
: If you want to have a bookinfo page but want to have a Creative Commons license, then include \bookinfopage and use and configure the `doclicense` package as described below.

none
: If you do **not** want to have a bookinfo page, comment the line saying \bookinfopage and add a \cleardoublepage.

For background about Creative Commons licenses, see: `https://www.kb.se/samverkan-och-utveckling/oppen-tillgang-och-bibsamkonsortiet/open-access-and-bibsam-consortium/open-access/creative-commons-faq-for-researchers.html` and `https://kib.ki.se/en/publish-analyse/publi`

*When printed double sided, the bookinfo page is the back of the title page.

sh-your-article-open-access/open-licence-your-publication-cc.

Note that the lowercase version of the Creative Commons license has to be used in the modifier, *i.e.,* one of: by, by-nc, by-nd, by-nc-nd, by-sa, by-nc-sa, or zero. For the list of supported licenses, see the documentation for the doclicense package.

Note that if the doclicense package is used, it automatically redefines \bookinfopage to be \bookinfopageCC.

D.7.1 Example configuration to have a CC BY-NC-ND license

```
\usepackage[
    type={CC},
    modifier={by-nc-nd},
    version={4.0},
    hyphenation={RaggedRight},
]{doclicense}
```

Note that the option "hyphenation=RaggedRight" can be used with the configuration of the package to set the license information with a ragged right margin rather that as a filled and justified paragraph.

D.7.2 Example configuration to have a CC BY-NC-ND license with a Euro symbol rather than a Dollar sign

```
\usepackage[
    type={CC},
    modifier={by-nc-nd},
    version={4.0},
    imagemodifier={-eu-88x31}, % to get Euro symbol
       ↪ rather than Dollar sign
    hyphenation={RaggedRight},
]{doclicense}
```

D.7.3 Example configuration to have a CC0 license

```
\usepackage[
    type={CC},
    modifier={zero},
    version={1.0},
]{doclicense}
```

D.8 Use of fonts within the thesis

The choice of fonts is a very individual matter and may be affected by the kind of content that you are trying to write, the language that you are writing in, and what you want to convey to your reader. However, some points to keep in mind are:

- Use fonts with serifs for the body of your thesis, their presence makes it much easier for your reader.
- Use sans serif fonts for headings. This helps your reader distinguish them from the body.
- Be very careful when using fonts that are not widely available*. Unless you embed the fonts that you have used, your readers may not see what you want them to see. Ideally, you should embed all fonts – even if you only embed the subset you use.
- Although there are fonts that have a huge number of characters in them, they might not have the characters that you need.
- There are also fonts that, although they have a vast number of characters in them, do not have the math table that LaTeX needs to be able to set mathematical content†.
- Many fonts are proprietary, thus you need to consider whether you have an appropriate license to use them.

What can you do when the fonts you use are missing characters that you need to use? One solution is to use a font that has the character(s) that you want and then make use of them in the places that you need to.

*For example, even though it is widely used. not everyone has the Arial font. Additionally, it is a proprietary font; thus, you need to have an appropriate license to use it.

†An example of such a font is Google's Noto font. Even though it includes a vast number of characters, it lacks a math table – although there is an awareness of this missing feature

> The details of working with different fonts and characters is a rather complex area and not for the faint-hearted. However, if you **really** want to have specific characters, XeLaTeX and LuaLaTeX have the means to help you realize what you want.

D.9 One big thesis file or a master file with includes of the parts

While many students split their thesis into multiple files (such as `introduction.tex`, `background.tex`, `method.tex`, `what-you-did.tex`, `results-and-analysis.tex`, `discussion.tex`, `conclusion-and-future-work.tex`) and then include these in their main document (with a series of \includexxxx), my experience is that it actually makes it hard to be consistent in the thesis. For example, you cannot do a simple global replacement when you have decided to introduce a particular acronym. It also makes searching for things difficult, as Overleaf's search function only works on individual files*. Personally, I find it hard to correct LaTeX errors when the file is split in this way - since Overleaf does not make it simple to find the root cause of a problem when the chapters are included in this way. There can be a problem with compiling the project in Overleaf, as Overleaf doe not always handle the separate files as one document (unless you use the functions to tell LaTeX that a file is part of a larger document and identify the parent document). Although I have had some students do this splitting successfully and they liked being able to compile just a part of their report; I've personally had strange errors occur with it - hence I did not use this with the template.

There are some advantages to splitting the document into different parts:

- Overleaf has a limit on the number of changes that it can track - but this limit is per file! [Yes, I have gotten bitten by this when I have put in more changes and comments than the limit and had to stop marking up a manuscript.]
- Additionally, Overleaf has a per file size limit (*i.e.,* how large a file can be) - again this is per file [Yes, I have gotten bitten by this when exporting a Jupyter notebook that produced a LaTeX file larger than 50 MB.]

*Note that this is not a problem if you use emacs and a tags file, as this can do searching over the whole set of files and even a tags based query and replace.

- This is useful when different students (in a 1st cycle degree project) are writing different parts of the report (in this case the divisions can be even at the section or subsection level).

Similarly, many students like to group their figures along with their chapters, *i.e.,* introducing a folder for each part of the report and placing both the text and the figures relevant to this section into the relevant folder. A similar approach can be used with included code snippets, tables, *etc*.

Ultimately, I think the main issue is the degree to which the separate files are separate and can be worked on as if they were very independent. This generally is true in third-cycle theses, as the chapters tend to be rather independent - typically with one conference/journal paper as the focus of a chapter. However, my experience is that first-cycle theses have very highly interdependent parts, while 2nd cycle theses are split between highly interdependent and highly independent.

However, some might find the question of splitting or not to be a matter of taste or perhaps different ways to approach organizing their writing. So you and your supervisor(s) and examiners might want to discuss what choice is most suitable for your purposes.

Appendix E

README and notes about the template

This document, written by Gerald Q. Maguire Jr, describes the thesis template that I have developed for use at KTH Royal Institute of Technology (KTH) and provides some background about why it is the way that it is. It is important to note that the template is **not prescriptive**, as not every thesis will have all the parts the template shows. However, if there is something that you decide to leave out, you should make a conscious decision to do so, and you should consider the impact this may have on your thesis being approved by the examiner.

Fundamental to the design of the template are several key factors:

- Helping students be successful in their degree project,
- Helping students produce a high-quality thesis, and
- Supporting all of the (relevant) phases of the degree project process.

Several thousand theses are written each year by KTH students. Every approved thesis will be entered into Digitala Vetenskapliga Arkivet (DiVA) (independent of whether the full text is made available via DiVA). Collecting the data necessary for DiVA was a major driving force in the design of the template. This data is useful for many of the phases of the degree project, such as announcing the oral presentation.

This template is **not** designed for use by TIMTM and TMMTM students - as students in these two programs are using a different structure for their reports (there is another template available for them).

This document is a work in progress.

E.1 Introduction

This template evolved (radically) from an earlier thesis template that was widely used at KTH. The direction of this evolution was based on the DOCX template developed over many years for use with students for whom I was the examiner and/or supervisor. The suggested structure and contents of the thesis reflect my experience as an examiner for more than 600 degree projects and the experience I have had as a teacher and examiner for the course *II2202 Research Methodology and Scientific Writing*. The template also reflects my interest as a member of KTH's Language Committee in facilitating the parallel use of English and Swedish at KTH, as well as supporting other languages. The latter aspect reflects my experience with double-degree students, who often need to have at least the abstract of their thesis in their home university's language(s). The thesis template also reflects my experience in entering the metadata for hundreds of theses into DiVA and announcing a very large number of degree project seminars.

Appendix E.4 describes several different groups of users and how the template is relevant to them.

Several major thoughts have influenced the design of this template:

Thought 1 The template should help a student be successful in their degree project and help them produce a high-quality thesis in conjunction with their degree project.

Thought 2 The template should help support all of the (relevant) phases of the degree project process.

Thought 3 Redundant data entry should be minimized to increase consistency.

Thought 4 There are several thousand theses written each year at KTH. Theses are the second most common type of publication at KTH.

Thought 5 Every approved thesis will have at least its metadata entered into DiVA. DiVA features multi-language support for title, subtitle, abstract, and keywords.

E.2 Deliminations

This template is **not** designed for use by TIMTM and Media Management TMMTM students - as students in these two programs are using a different structure for their reports (there is another template available for them).

Additionally, I have been told by one of my colleagues in applied mathematics that theses in this area generally do not follow the Introduction, Methods, Results, and Discussion (IMRAD) structure.

Some parts of the template are conditional based on the value of a switch: `\ifinswedish`. The idea is to easily have a single template that supports theses written in English or Swedish. However, in many places, the conditional has not been used but could be. Examples of this include the Swedish names for chapters and sections. Generally, this information is in a note after the English chapter or section name. More complete implementation of the use of this condition remains as future work.

The template does not fully support the G5 paper format. In particular, the KTH cover (produced with `\kthcover)` and back cover (produced with `\kthbackcover)`) have only been adapted for A4 paper. Support for G5 paper remains as future work.

The handling of the subject area (Swedish: Område för examensarbete) is currently incomplete and remains as future work. Personally, I'm still struggling to understand the rules and how one knows what the correct values are (especially for cases of (*i*) dual degrees and (*ii*) combinations of technical subjects and education degrees).

E.3 Structure of the files for the template

Table E.1 shows the structure of the files for the template. These files are generally taken from an existing Overleaf project, a ZIP file, or a github.

One hope is that by automatically extracting information from various sources, this information is more likely to be *correct* and *consistent* (supporting Thought 3). This approach has been used to generate two of the files used for the template. These files are:

1. The file `custom_configuration.tex` contains macros and values for configuring a project. These values are generally expected to be known at the start of the project, *e.g.,* author(s), supervisor(s). examiner, course code for the degree project program code, *etc*. While this file can be manually edited, it was designed to be generated by a program that I have written that extracts most of the data from the Canvas course being used in conjunction with the degree project. One of the goals of using such a program is to extract data from Canvas automatically, the KTH profile Application Programming

Interface (API), Kurs- och programplaneringssystemet (KOPPS), and other sources. The macros for defining this information are described in Sections D.4, E.5.1, and E.5.2 - for authors, supervisors, and examiner (respectively).

2. The file `schools_and_programs.ins` contains the English and Swedish names of schools and programs. A program extracted this information from KOPPS.

We will assume that these files have been generated by someone. Later we will examine who this someone might be for each of these files.

Table E.1: Structure of files for the template

bibstyle	**directory containing files related to the style of the bibliography**	
	`myIEEEtran.bst`	a bibtex style file
figures	**directory containing files for figures**	
lib	**directory containing various library files**	
	`acronyms.tex`	a place to define the acronyms that will or might be used
	`defines.tex`	some generally useful defines
	`includes-after-hyperref.tex`	a special include file for packages that have to be included **after** the hyperref package
	`includes.tex`	a centralized place to include packages that might be useful
	`kthcolors.tex`	defines a number of colors from the KTH palette
	`pdf_related_includes.tex`	includes to be able to add the title and other information to the PDF file
	`schools_and_programs.ins`	English and Swedish names of schools and the programs
`custom_configuration.tex`		macros and values for configuring a project
`main.tex`		an example of the thesis itself
`kth_logo.png`		the KTH logo for use on the cover
`KTH_ROYAL_INSTITUTE_OF_TECHNOLOGY_logotype.png`		KTH logotype for use on the English language cover
`kththesis.cls`		the kththesis class file
`README_notes.tex`		these notes
`references.bib`		references that may be cited in the thesis

E.4 Expected users and their differences

This template is relevant to several different sets of users:

Users 1 Author or Authors (see Appendix D.1),

Users 2 Those working together with the author(s) during the degree project process (see Appendix E.5),

Users 3 Administrative staff working with the document after it has been approved by the examiner (see Appendix E.6), and

Users 4 The (hopefully) many (human) readers of the final document (see Appendix E.7).

Users 5 The (hopefully) many computers reading the metadata and the full text of the final document (see Appendix E.7.1).

Users 6 Those who are maintaining or updating this template (see Appendix E.7.2).

Each of these different sets of users has different needs and perspectives. The following subsections describe these needs and perspectives.

For information for authors, see Appendix D - located in the file `README_author.tex`.

E.5 Those working in parallel with the authors(s) during the degree project

Those working together with the author(s) during the degree project process include the examiner, supervisor(s), and the opponent(s).

E.5.1 Supervisor

If a degree project is done in industry, there is generally an industrial supervisor in addition to the academic supervisor(s). The template supports up to 3 supervisors (typically an academic supervisor, an industrial supervisor, and sometimes an additional academic or industrial supervisor). The choice of up to three reflects my experience and observation of prior theses in DiVA. Note that there is expected to be at least one supervisor. The supervisors are enumerated as A, B, and C. For each of A, B, and C as appropriate, replace the "X" in the following macros:

`\supervisorXsLastname{}`	the last name of the supervisor
`\supervisorXsFirstname{}`	the first name of the supervisor
`\supervisorXsEmail{}`	e-mail address of the supervisor

If the supervisor is from within KTH, then add their KTHID, School, and Department info:

`\supervisorXsKTHID{}`	the supervisor's kthid
`\supervisorXsSchool{}`	the school of the supervisor
`\supervisorXsDepartment{}`	the department of the supervisor

If the supervisor is from outside of KTH, then add their organization with:

`\supervisorXsOrganization{}`	the supervisor's organization

E.5.2 Examiner

I assume that there is only a single examiner for a given thesis*. For this examiner, the relevant macros are:

`\examinersLastname{}`	the last name of the examiner
`\examinersFirstname{}`	the first name of the examiner
`\examinersEmail{}`	e-mail address of the examiner

If the examiner is from within KTH, then add their KTHID, School, and Department info:

`\examinersKTHID{}`	the examiner's kthid
`\examinersSchool{}`	the school of the examiner
`\examinersDepartment{}`	the department of the examiner

*Statistically, there are very few theses with multiple examiners, and this generally occurs for students either in a double degree program or when there are two students in a 1st cycle degree project from different schools, then there might be one examiner for each student. As the case of more than one examiner occurs very infrequently, I have left it for future work. The pseudo-JSON structure is set up to handle multiple examiners, but additional macros would be needed in a similar fashion as used for multiple supervisors, and this metadata would have to be conditionally added where appropriate.

If the examiner is from outside of KTH, then add their organization with:

\examinersOrganization{} the examiner's organization

I assume that someone (such as the examiner) will generate the file: `custom_configuration.tex`. This assumption is based upon the fact that the examiner knows who the student or students are who will be working on a given degree project, who the supervisor or supervisors are, what program the student is in, course code, ... Ideally, this file should be generated automatically by some computer program so that each student or pair of students in a group gets a customized template automatically via the Canvas course. However, currently, the file is generated using a command line program (`create_customized_JSON_file.py`) to generate a JavaScript Object Notation (JSON) file. Subsequently, a separate program (`customize_LaTeX_project.py`) takes this JSON data and creates the appropriate LaTeX commands and inserts this information into the file and then inserts this file into a ZIP file, either replacing or augmenting the `custom_configuration.tex` within this ZIP file (if one exists). There is an option for this second program `-initialize` that causes the program to simply replace the file rather than appending the new information to the end of the file.

The above programs are available from https://github.com/gqmaguirejr/E-learning. The README file for this GitHub contains information about how to run the programs, their options, and gives examples.

E.5.3 Opponent(s) and oral presentation

Unlike the supervisors and examiner, the macros related to the opponent and oral presentation are in the `main.tex` file. The macro for the opponent(s) is:

\opponentsNames{} the names (in normal name order) of the opponent or opponents

When there are multiple opponents, separate their names with '\&'; for example, A. B. Normal \& A. X. E. Normalè.

For the oral presentation, the following macros are filled in once the examiner has scheduled your oral presentation:

\presentationDateAndTimeISO{} date and time of the presentation is ISO format, for example: 2022-03-15 13:00

`\presentationLanguage{}`	three letter abbreviation for the language of the presentation according to three letter ISO 639-2 Code – specifically the "B" (bibliographic) variant of these codes (note that this is the same language code used in DiVA), generally eng or swe
`\presentationRoom{}`	a room name and/or "via Zoom https://kth-se.zoom.us/j/ddddddddddd"
`\presentationAddress{}`	location of the room, for example: Isafjordsgatan 22 (Kistagången 16)
`\presentationCity{}`	city where the presentation occurs, generally: Stockholm

E.6 Administrative staff

Once a thesis is approved by the examiner we need to add the TRITA number. The TRITA number is assigned by the student affairs office of the school from an annual series of numbers.

E.6.1 What is a TRITA number and why does each approved thesis get assigned one?

TRITA stands for Transactions for the Royal Institute of Technology, with the letter 'A' appended to it. The TRITA definition is the 1971 report, "Mall för publikationsserier vid Kungl. Tekniska högskolan i Stockholm", TRITA-LIB-1001, `http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-127656`.

The format for TRITA numbers for degree projects is TRITA-⟨school acronym⟩-EX-YYYY:nnnn, where nnnn is a sequential number starting from 1 each year with the numbers assigned in chronological order to approved theses ("numren delas ut kronologiskt först när examinatorn godkänt arbetet." - according to one of KTH's archivists). Note that the list of assigned TRITA numbers is archived each year*. The year, YYYY, is based on the year that the

*It seems that this archiving is done twice a year.

thesis was *approved*.

The TRITA number value can be set with a macro that takes two arguments: series and year:number as shown below:

```
% for entering the TRITA number for a thesis
\trita{TRITA-EECS-EX}{2022:00}
```

E.6.2 Where does the TRITA number go?

The TRITA number will appear on the back cover of the thesis. It is also stored as part of the metadata entered into DiVA.

E.6.3 What does this mean in practice?

Currently, at EECS the TRITA number is only assigned to the thesis when the examiner has approved the thesis and submitted the PDF of the approved thesis (with cover) to the student affairs office. Of course, this does not make much sense because the back cover is already on the thesis! This means that someone in the student affairs office must either (*i*) edit the sequential number part of the TRITA number (using some PDF tool) or (*ii*) they need to make a new back cover and replace the existing back cover. A better solution would be to inform the examiner of the TRITA number and the examiner can see that this number is inserted into the macro shown above and this can enable the number to appear on the back cover and as an added bonus be included in the metadata for DiVA.

Note that it is expected that in 2023, this process will change – thus the assignment of the TRITA number and the application of the back cover would be done by the student affairs office (as only they have the relevant information)*.

E.6.4 Entering the metadata into DiVA

If a thesis has used this template the "For DIVA" page contains the metadata for DiVA and an administrator can cut and paste this data into DiVA. Alternatively, this metadata can be extracted with a program from the PDF file to produce a JSON file that can subsequently be used to create a MODS file for import into DiVA. The LaTeX compiler can in many cases produce a file called "fordiva.json" that contains the metadata.

*Note to maintainers: This means that the back cover can be removed from this template.

The programs that can be used to extract data and to take a JSON file and create a MODS file are available from `https://github.com/gqmaguirejr/E-learning`.

Note that the import of the MODS file does **not import the collaboration data**, even though this is in the file. This is a limitation of the DiVA import function. Therefore, this information has to be manually entered along with uploading of the PDF file itself.

E.7 (Human) Readers of the thesis

Some theses have very few downloads from DiVA, while some have had hundreds of thousands of downloads. Therefore, you should remember that you have a wide range of human readers of your thesis. The readers include other students looking for information related to their own thesis or because they are interested in the future work that you have suggested to work on for their own degree project. Additionally, researchers who are looking for your results may find your thesis relevant to them. In many cases, companies will look at theses for ideas about what the state of the art is - in several cases, theses have been important as “prior art” and this invalidated patents that had been issued if the patent was submitted after the thesis became public (hence it pays to get theses public as soon as possible). Other human readers are the UKÄ review teams that examine the degree programs offered at KTH. Finally, as KTH is a public agency, it is important that the general public know what is done at KTH*.

E.7.1 Machines reading the metadata or full text of the thesis

The file `pdf_related_includes.tex` contains LaTeX code that stores the title, author(s), and keyword information into the PDF document in such a way that if you ask for the properties of the PDF file you will get this data. This information makes it easier for machines to get this information from the PDF file.

Additionally, many search engines (such as Google’s search engine) mine DiVA for the metadata and if the full text of the thesis is published via DiVA then they also process the full text of the thesis. The result is that search engines can find the content in these theses. This is likely to increase the

*This is an important part of the Swedish Offentlighetsprincipen.

probability that someone will download your thesis if they think it is relevant to them – increasing the number of your human readers (see Appendix E.7).

E.7.2 Template author and maintainers

KTH periodically changes the cover design for theses, introduces new programs of study, eliminates programs of study, reorganizes administratively, and faculty move between schools, departments, and divisions. It can be expected that this template will need to evolve with these changes.

For example, if there is a change in schools or programs then there needs to be changes made to the file `schools_and_programs.ins`. While the current file was extracted from KOPPS, the program that does this will need to be replaced because further development of KOPPS has been terminated by KTH's central IT unit which plans to transition all of this information to Lokalt adb–baserat dokumentationssystem (LADOK).

As another example, on 13 December 2021 there was a change in the KTH cover for 1$^{\text{st}}$ and 2$^{\text{nd}}$ theses, and the cover generator web service was shutdown. The initial draft version of the cover used a proprietary font (TheSans B4 SemiLight and TheSans B6 SemiBold). The version that was publicly introduced uses another proprietary font (Arial) and officially only existed as a DOCX file for a thesis in Swedish. The result is that I had to make my own version in LaTeX to try to emulate the DOCX cover. This lead to a lot of effort, but one can get a reasonable cover with the correct font as described in Appendix D.2.

E.8 While writing

As was noted in Appendix D.1, the thesis template contains lots of examples, notes, and comments. One method to provide additional information is the use of \todo. Several different types of `todo` notes have been used in the thesis. These are described in Appendix E.8.1.

E.8.1 Conventions for todo notes

The example thesis text includes extensive comments, directions, and warnings. These follow the form shown below:

```
\generalExpl{Comments/directions/... in English}
\sweExpl{Text p svenska}
\engExpl{English descriptions about formatting}
```

```
\warningExpl{warning}
```

and appear as:

Comments/directions/... in English

Text på svenska

English descriptions about formatting

warning

Each of the above is a macro, so as usual in LaTeX you can redefine it - even defining it to produce nothing! Several previous students have placed these re-definitions in the `custom_configuration.tex` file.

E.8.2 Turning on and off the README_notes

As the various README notes are targeted at different readers, you may or not want to see them. It is very easy to turn them on or off by adding or removing a percent ('%') character before the relevant \begin{comment} and \end{comment} comments around each set of notes.

For example, if you are a student writing a thesis, I suggest turning off everything except for the `README_author.tex` and `README_notes.tex` sets of notes. However, I would suggest keeping the other README files around (at least for a little while) as a source of examples of how to do things. Despite having spent a very large number of hours working on the template and drafts of students' theses, I find some of the README files very helpful as a reminder of how to do things.

E.8.3 Removing the README_notes

At some point you will no longer want this README information. You can remove it by removing the line \include{README_notes/README_notes} – from the `main.tex` file. If you have removed the other README* files from the **README_notes** directory, you can then remove the **README_notes** directory.

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E.8.5 Removing unused fonts

This version of the template may also have some font information, in the form of Opentype Font files (with the extension ".otf") and TrueType Font font files (with the extension ".ttf"). If you are not using these fonts (and no longer are using any of the README files), then you can delete these font files.

README acronyms

This document is incomplete. The external file associated with the glossary 'readme' (which should be called `main.tld`) hasn't been created.

Check the contents of the file `main.tdn`. If it's empty, that means you haven't indexed any of your entries in this glossary (using commands like `\gls` or `\glsadd`) so this list can't be generated. If the file isn't empty, the document build process hasn't been completed.

Try one of the following:

- Add `automake` to your package option list when you load `glossaries-extra.sty`. For example:

  ```
  \usepackage[automake]{glossaries-extra}
  ```

- Run the external (Lua) application:

  ```
  makeglossaries-lite.lua "main"
  ```

- Run the external (Perl) application:

  ```
  makeglossaries "main"
  ```

Then rerun LaTeX on this document.

This message will be removed once the problem has been fixed.

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€€€€ For DIVA €€€€

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An abstract is (typically) about 250 and 350 words (1/2 A4-page) with the following components:

- What is the topic area? (optional) Introduces the subject area for the project.
- Short problem statement
- Why was this problem worth a Bachelor's/Master's thesis project? (*i.e.*, why is the problem both significant and of a suitable degree of difficulty for a Bachelor's/Master's thesis project? Why has no one else solved it yet?)
- How did you solve the problem? What was your method/insight?

- Results/Conclusions/Consequences/Impact: What are your key results/
  conclusions? What will others do based on your results? What can be done now that you have finished - that could not be done before your thesis project was completed?

€€€€,
"Keywords[eng]": €€€€
Nonlinear Optimization, Medical Imaging, Digital Image Processing €€€€,
"Abstract[swe]": €€€€
Enter your Swedish abstract or summary here!
€€€€,
"Keywords[swe]": €€€€
Canvas Lärplattform, Dockerbehållare, Prestandajustering €€€€,
}

acronyms.tex

```
%%% Local Variables:
%%% mode: latex
%%% TeX-master: t
%%% End:
% The following command is used with glossaries-extra
\setabbreviationstyle[acronym]{long-short}
% The form of the entries in this file is \newacronym{label}{acronym}{phrase}
%                                   or \newacronym[options]{label}{acronym}{phrase}
% see "User Manual for glossaries.sty" for the details about the options, one example is shown below
% note the specification of the long form plural in the line below
\newacronym[longplural={Debugging Information Entities}]{DIE}{DIE}{Debugging Information Entity}
%
% The following example also uses options
\newacronym[shortplural={OSes}, firstplural={operating systems (OSes)}]{OS}{OS}{operating system}

% note the use of a non-breaking dash in long text for the following acronym
\newacronym{IQL}{IQL}{Independent Q^^e2^^80^^91Learning}

\newacronym{KTH}{KTH}{KTH Royal Institute of Technology}

\newacronym{LAN}{LAN}{Local Area Network}
\newacronym{VM}{VM}{virtual machine}
% note the use of a non-breaking dash in the following acronym
\newacronym{WiFi}{Wi^^e2^^80^^91Fi}{Wireless Fidelity}

\newacronym{WLAN}{WLAN}{Wireless Local Area Network}
\newacronym{UN}{UN}{United Nations}
\newacronym{SDG}{SDG}{Sustainable Development Goal}
```