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AUTOMATED
MACHINE LEARNING

Foreword

"*I'd like to use machine learning, but I can't invest much time.*" That is something you hear all too often in industry and from researchers in other disciplines. The resulting demand for hands-free solutions to machine learning has recently given rise to the field of automated machine learning (AutoML), and I'm delighted that with this book, there is now the first comprehensive guide to this field.

I have been very passionate about automating machine learning myself ever since our Automatic Statistician project started back in 2014. I want us to be really ambitious in this endeavor; we should try to automate all aspects of the entire machine learning and data analysis pipeline. This includes automating data collection and experiment design; automating data cleanup and missing data imputa- tion; automating feature selection and transformation; automating model discovery, criticism, and explanation; automating the allocation of computational resources; automating hyperparameter optimization; automating inference; and automating model monitoring and anomaly detection. This is a huge list of things, and we'd optimally like to automate all of it.

There is a caveat of course. While *full* automation can motivate scientific research and provide a long-term engineering goal, in practice, we probably want to *semiautomate* most of these and gradually remove the human in the loop as needed. Along the way, what is going to happen if we try to do all this automation is that we are likely to develop powerful tools that will help make the practice of machine learning, first of all, *more systematic* (since it's very ad hoc these days) and also *more efficient*.

These are worthy goals even if we did not succeed in the final goal of automation, but as this book demonstrates, current AutoML methods can already surpass human machine learning experts in several tasks. This trend is likely only going to intensify as we're making progress and as computation becomes ever cheaper, and AutoMLis therefore clearly one of the topics that is here to stay. It is a great time to get involved in AutoML, and this book is an excellent starting point.

This book includes very up-to-date overviews of the bread-and-butter techniques we need in AutoML (hyperparameter optimization, meta-learning, and neuralarchitecture search), provides in-depth discussions of existing AutoML systems, and

thoroughly evaluates the state of the art in AutoML in a series of competitions thatran since 2015. As such, I highly recommend this book to any machine learning researcher wanting to get started in the field and to any practitioner looking to understand the methods behind all the AutoML tools out there.

Preface

The past decade has seen an explosion of machine learning research and applications; especially, deep learning methods have enabled key advances in many application domains, such as computer vision, speech processing, and game playing. However, the performance of many machine learning methods is very sensitive to a plethora of design decisions, which constitutes a considerable barrier for new users. This is particularly true in the booming field of deep learning, where human engineers need to select the right neural architectures, training procedures, regularization methods, and hyperparameters of all of these components in order to make their networks do what they are supposed to do with sufficient performance. This process has to be repeated for every application. Even experts are often left with tedious episodes of trial and error until they identify a good set of choices for a particular dataset.

The field of automated machine learning (AutoML) aims to make these decisions in a data-driven, objective, and automated way: the user simply provides data, and the AutoML system automatically determines the approach that performs best for this particular application. Thereby, AutoML makes state-of-the-art machine learning approaches accessible to domain scientists who are interested in applying machine learning but do not have the resources to learn about the technologies behind it in detail. This can be seen as a *democratization* of machine learning: with AutoML, customized state-of-the-art machine learning is at everyone's fingertips.

As we show in this book, AutoML approaches are already mature enough to rival and sometimes even outperform human machine learning experts. Put simply, AutoML can lead to improved performance while saving substantial amounts of time and money, as machine learning experts are both hard to find and expensive. As a result, commercial interest in AutoML has grown dramatically in recent years, and several major tech companies are now developing their own AutoML systems. We note, though, that the purpose of democratizing machine learning is served much better by open-source AutoML systems than by proprietary paid black-box services.

This book presents an overview of the fast-moving field of AutoML. Due to the community's current focus on deep learning, some researchers nowadays mistakenly equate AutoML with the topic of neural architecture search (NAS);

but of course, if you're reading this book, you know that – while NAS is an excellent example of AutoML – there is a lot more to AutoML than NAS. This book is intended to provide some background and starting points for researchers interested in developing their own AutoML approaches, highlight available systems for practitioners who want to apply AutoML to their problems, and provide an overview of the state of the art to researchers already working in AutoML. The book is divided into three parts on these different aspects of AutoML.

Part I presents an overview of AutoML methods. This part gives both a solid overview for novices and serves as a reference to experienced AutoML researchers.

Chap. 1 discusses the problem of hyperparameter optimization, the simplest and most common problem that AutoML considers, and describes the wide variety of different approaches that are applied, with a particular focus on the methods that are currently most efficient.

Chap. 2 shows how to *learn to learn*, i.e., how to use experience from evaluating machine learning models to inform how to approach new learning tasks with new data. Such techniques mimic the processes going on as a human transitions from a machine learning novice to an expert and can tremendously decrease the time required to get good performance on completely new machine learning tasks.

Chap. 3 provides a comprehensive overview of methods for NAS. This is one of the most challenging tasks in AutoML, since the design space is extremely large and a single evaluation of a neural network can take a very long time. Nevertheless, the area is very active, and new exciting approaches for solving NAS appear regularly.

Part II focuses on actual AutoML systems that even novice users can use. If you are most interested in applying AutoML to your machine learning problems, this is the part you should start with. All of the chapters in this part evaluate the systems they present to provide an idea of their performance in practice.

Chap. 4 describes Auto-WEKA, one of the first AutoML systems. It is based on the well-known WEKA machine learning toolkit and searches over different classification and regression methods, their hyperparameter settings, and data preprocessing methods. All of this is available through WEKA's graphical user interface at the click of a button, without the need for a single line of code.

Chap. 5 gives an overview of Hyperopt-Sklearn, an AutoML framework based on the popular scikit-learn framework. It also includes several hands-on examples for how to use system.

To the best of our knowledge, this is the first comprehensive compilation of all aspects of AutoML: the methods behind it, available systems that implement AutoML in practice, and the challenges for evaluating them. This book provides practitioners with background and ways to get started developing their own AutoML systems and details existing state-of-the-art systems that can be applied immediately to a wide range of machine learning tasks. The field is moving quickly, and with this book, we hope to help organize and digest the many recent advances. We hope you enjoy this book and join the growing community of AutoML enthusiasts.

Acknowledgments

We wish to thank all the chapter authors, without whom this book would not have been possible. We are also grateful to the European Union's Horizon 2020 research and innovation program for covering the open access fees for this book through Frank's ERC Starting Grant (grant no. 716721).

Contents

Part I
Auto ML Methods
Chapter 1
Hyper parameter Optimization

Abstract
Hyper parameter optimization has recently seen a revival in attention due to the growing popularity of computationally intensive and hyper parameter-rich machine learning models such as automated machine learning (AutoML) frameworks and deep neural networks (HPO). This chapter provides a synopsis of the most common methods used in HPO nowadays. We begin with a discussion of model-free approaches and Bayesian optimization for optimising black box functions. Since pure blackbox optimization is prohibitively expensive for many contemporary machine learning applications, we then turn our attention to state-of-the-art multi-fidelity approaches that employ (much) cheaper variants of the black box function to approximatively evaluate the quality of hyper parameter settings. Finally, we suggest further areas of investigation and open questions for further study.

1.1 Introduction

The most fundamental duty in automated machine learning (AutoML) is the automatic setting of hyperparameters to improve performance, which is a feature included in all machine learning systems. The architecture, regularisation, and optimization of contemporary deep neural networks are highly hyperparameter dependent. There are several compelling applications for automated hyperparameter optimization (HPO), including: • reducing the amount of manual labour required to implement machine learning. With regards to AutoML, this is of paramount significance.

This has resulted to new state-of-the-art results on key machine learning benchmarks across a number of research (e.g. [105, 140]).

• increase the reliability and transparency of scientific research. It's obvious that automated HPO is more repeatable than human search. Since approaches can only be evaluated properly if they are all tuned to the same degree for the situation at hand [14, 133], this allows for more objective comparisons to be made.

Hyperparameter overfitting (HPO) is an issue that has been there since at least the 1990s (e.g., [77, 82, 107, 126]), and it was also shown early on that various hyperparameter configurations tend to function better for different datasets [82]. In contrast, the idea that HPO may be used to tailor general-purpose pipelines to particular application domains is a very recent one [30]. It is now well accepted that customised hyperparameters are preferable to the default value offered by most machine learning frameworks [100, 116, 130, 149].

Since machine learning is becoming increasingly popular in businesses, HPO is also of considerable commercial interest and is playing an increasingly important role in those settings, whether in in-house tools [45], as part of machine learning cloud services [6, 89], or as a standalone service [137].

Several obstacles make HPO difficult to solve in practise.

Enormous models (for example, in deep learning), sophisticated machine learning pipelines, and large data sets may make function evaluations prohibitively costly, and the configuration space is typically complex (comprising a mix of continuous, categorical, and conditional hyperparameters). What's more, it's not always obvious which hyperparameters of an algorithm need to be tuned, much less across what ranges.

• Typically, we cannot get a gradient of the loss function with respect to the hyperparameters. Additionally, classical optimization generally disregards target function qualities such as convexity and smoothness.

Because training datasets are often small, optimising for generalisation performance is not a viable option.

Readers interested in learning more about this subject are directed to previous evaluations of HPO [64, 94].

The following is the outline for this chapter. In this paper, we first provide a formal definition of the HPO issue and then explore its many forms (Sect. 1.2). As a further step, we talk about how to solve HPO with blackbox optimization techniques (Sect. 1.3). Following this, we zero in on cutting-edge multi-fidelity techniques that make HPO accessible even for prohibitively costly models by taking use of approximation performance measurements that are less expensive than complete model assessments (Sect. 1.4). The chapter concludes with a discussion of outstanding issues and a survey of the most prominent hyperparameter optimization methods and their applications to AutoML (Section 1.5). (Sect.1.6).

1.2 Problem Statement

Let's say that there's an N-hyperparameter machine learning method denoted by. One might think of the hyperparameter configuration space as h = h1 + h2 +... + hN, where n is the nth hyperparameter's domain. The notation for a vector of hyperparameters is h, and the notation for a vector of hyperparameters with their values instantiated to a given value is.
For example, the learning rate is a real-valued hyperparameter, whereas the number of layers is an integer-valued hyperparameter, and the usage of early halting is a binary-valued hyperparameter (e.g., choice of optimizer). For convenience, the domains of integer and real-valued hyperparameters are typically limited, with a few exceptions [12, 113, 136].
In addition, conditionality may be included in the configuration space; for example, a hyper-parameter may only be of interest if a different hyper-parameter (or set of hyper-parameters) takes on a certain value. The structures of conditional spaces are directed acyclic graphs. For instance, in the Full Model Selection (FMS) or Combined Algorithm Selection and Hyperparameter optimization problem (CASH) [30, 34, 83, 149], the decision between various preprocessing and machine learning methods is described as a categorical hyperparameter. The number of layers, for instance, may be a numeric hyperparameter, and the per-layer hyperparameters of layer I are only active if the network depth is at least I [12, 14, 33].

Our objective is to discover, given a data set D,

$$\lambda^* = \underset{\lambda \in h}{\operatorname{argmin}} \; E_{(D_{train}, D_{valid}) \sim D} \, V(L, A_\lambda, D_{train}, D_{valid}), \quad (1.1)$$

where the loss of an algorithmically-generated model with hyperparameters on training data Dtrain and validation data Dvalid is quantified by the function V(,, Dtrain, Dvalid). In practise, we only have access to a limited dataset D, so we need to make approximations to the expectation in Eq. 1.1. The holdout error and the cross-validation error for a user-provided loss function (such as the misclassification rate) are two common options for the validation protocol V(,,,); for a more comprehensive overview of validation protocols, see Bischl et al. [16]. Several methods have been suggested to speed up the judging process: We will go over some of these methods in further depth in Sect. 1, including the possibility of testing machine learning algorithms solely on a limited sample of folds, data, or iterations. Fourth, further research on multi-task [147] and multi-source [121] optimization provides additional low-cost, auxiliary tasks that may be queried in place of Eq. 1.1. These may be a low-cost source of data for HPO, but they don't always train a machine learning model on the dataset of interest, therefore they don't always provide a model that can be put to good use.

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1.2.1 Alternatives to Optimization: Ensembling and Marginalization

Most of the methods in this chapter for solving Eq. 1.1 involve fitting the machine learning algorithm with a vector of hyperparameters t that contains more than one hyperparameter. You may avoid using the argmin-operator by either constructing an ensemble (which seeks to minimise the loss for a particular validation methodology) or by integrating out all of the hyperparameters (if the model under consideration is a probabilistic model). For a comparison of frequentist versus Bayesian model selection, see Guyon et al. [50] and the references therein.

When multiple promising hyperparameter configurations have been found by HPO, it may be inefficient to choose only one; instead, it may be more effective to combine these configurations into an ensemble in order to maximise performance [109]. The potential benefits from ensembling [4, 19, 31, 34] are maximised in AutoML systems with a wide configuration space (like FMS or CASH), where optimal configurations may be quite different. Automatic Franken- steining [155] takes use of HPO to train a stacking model [156] on the outputs of the models discovered using HPO; the 2nd level models are then merged using a conventional ensembling technique, significantly enhancing performance.

All the approaches outlined so far worked in unison after the HPO operation. Base models are not designed for ensembling, although they do increase performance in practise. However, one may also explicitly optimise for models that would boost an existing ensemble by the greatest feasible amount [97].

Finally, the hyperparameters of the machine learning algorithm may frequently be integrated out when working with Bayesian models by using techniques like evidence maximisation [98], Bayesian model averaging [56], slice sampling [111], or empirical Bayes [103].

1.2.2 Optimizing for Multiple Objectives

It is common in real-world scenarios to have to balance competing goals, such as model performance and resource utilisation [65] (also see Chapter 3) or various loss functions [57]. There are two routes that may lead to a workable answer.

First, the issue may be framed as a restricted optimization problem if a restriction on a secondary performance measure is specified (such as the maximum memory usage). In this section we will go over how to deal with constraints in Bayesian optimization.

As a second, more general option, multi-objective optimization can be used to seek out the Pareto front, a collection of configurations that represent optimal tradeoffs between the objectives, in the sense that there is no other configuration that performs better for at least one and at least as well as all other objectives. The Pareto front then allows the user to choose an optimal setup. For further information, we suggest [53, 57, 65,134].

ARTIFICIAL INTELLIGENCE

AND MACHINE LEARNING

K. KIRAN KUMAR
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Preface

COVID-19, or Coronavirus Disease 2019, was firstly found in animals, and later it has been transferred to humans. The primary source for the transmission of the disease, detection and treatment methods are still unknown. A lot of details about this virus are still missing. Its spread, prevention measures and vaccination issues need to be further investigated. In this field, artificial intelligence (AI) and cloud computing solutions can play a key role, especially the machine learning (ML) sub-field of AI, which can be applied over distributed cloud systems because of its learning-from-samples capability. The trend is to apply deep learning (DL), which is an advanced form of ML techniques considering the advantages of more than one technique. However, complexity, accuracy, fidelity and other critical computing issues are still a challenge. Current cloud-assisted infrastructure includes a number of smart devices having the sensing and data analysis capabilities to allow updates about epidemic diseases to be accessed anytime from anywhere. It has the potential to provide innovative services which could not be possible without the progress made in the cloud and Internet of Things (IoT) field. Owing to their advanced technical capabilities, intelligent computing paradigms are making the way into the treatment and detection of COVID-19 and similar diseases. COVID-19 and similar crisis reaction and coordination, open or private infrastructure control, coordination or support to astute computing systems are a portion of the spaces in which intelligent cloud systems may end up key in the medical diagnosis very soon. Moreover, these computing infrastructures will turn into a critical component of the urban monitoring and treatment systems. And thus, there exists a need for merging their traditional usage that gathers data with the existing/forthcoming computing technologies.

This book aims to provide an overview of original ongoing research attempts, which contributes to the current state of the art by reporting results for the used ML techniques in the problem scope of cloud-assisted COVID-19 and similar diagnosis. It will shed light on potential cloud computing, big data, artificial intelligence, IoT and other modern information processing technologies that can build the required online and cost-efficient medical service platforms. These platforms will be able to provide online services for people such as COVID-19 intelligent screening, characteristic symptom monitoring and screening, online consultation, drug distribution, psychological consultation and epidemic prevention.

Contents

Chapter 1
Smart Technologies for COVID-19: The Strategic Approaches in Combating the Virus

1.1 Introduction

COVID-19 is an infectious disease caused by a coronavirus—SARS-COV-2. It was first discovered in Wuhan, China, in 2019 and is now a pandemic [1, 2]. It transfers from a person to another via cough and sneeze droplets exiting from the patient [3]. The known signs and symptoms of the infected patient are similar to those of the common flu which could potentially lead to lethal conditions like severe acute respiratory syndrome (SARS) [2, 4]. As a novel infection, there are still much that the medical community does not know about this virus [1]. So far, millions have been infected worldwide; some have recovered, while others have died. Presently, there is no specific vaccine or drug for COVID-19 treatment. Supportive therapy has been the primary treatment, and it has prevented some patients from complications and death [5]. Early detection of the virus and the quick response are the right measures adopted so far in preventing the virus from spreading and in managing the cases [1, 3].

The pandemic has affected all aspects of human lives, creating an unprecedented global economic downturn. At the peak of the crisis, virtually the governments of every nation imposed lockdown. This was the course of action taken to stop the spread of the virus and to contain it. It was not palatable for billions of people, but they had to accept staying indoors and practice physical distancing and turning to technology to adapt the new normal. The lockdown and physical distancing worked well in preventing the spread of the virus, but there is a price to pay. The continuation of the lockdown means keeping many people out of jobs and leaving them with little or no financial income to carter for themselves and their families. The world economy will suffer, because it will not only lead to global recession as experienced in 2008 or great depression of 1929 to1933 but could lead to global economic paralysis.

As a result of these developments, we have two options: to continue with the lockdown and starve to death or to open up the economy and face the pandemic. Well, no nation will continue with the lockdown because of its severe effects on the society, but the reopening of any economy will depend crucially on the mass testing for the virus, tracing persons who have had contacts with the infected patients, and treating them. The day the virus was declared a pandemic, the WHO director general outlined four key areas for urgent international actions against the infection as—prepare and be ready, detect, protect and treat, reduce transmission, and innovate and learn [6]. COVID-19 has come to stay. We have no option than to accept it and live with it, just like other known diseases that have been in existence before COVID-19. All we have to do is to accept its existence in our midst as an invisible enemy but to fight and contain it using smart technology.

At the peak of the global lockdown and in keeping to physical distancing, people had no other alternative than to resort the digital technology in all their human interactions. Technology stood in the gap and played a crucial role. We became inseparable with our smartphones, pads, computers, and televisions in our interaction with the outside world. Apps offering video meetings like Zoom, Skype, Google Hangouts, WhatsApp, and Facebook become sources of our interactions. Autonomous vehicles became means through which items are delivered to people. Drones were used by the law enforcement agencies for monitoring. As some countries and regions open for human activities to return to normalcy, our normal way of life will not be the same again, as this infectious disease will totally alter our usual way of life. The pandemic has brought a turning point that will speed up digital revolution. This chapter discusses the digital technological approach in fighting the virulent and highly contagious virus.

1.1.1 Scope of the Study

This survey reviews previous studies on the use of smart technology in the healthcare system. How digital technology and IoT have been utilized in the fight against infectious diseases. It evaluates how intelligent systems can be deployed in meeting up with the WHO's four key areas of actions in containing SARS-CoV-2, the virus that causes COVID-19 [6]. This chapter outlines and thoroughly explained the strategic approaches to combat and contain the pandemic. Being a highly contagious virus, physical distancing is vital, but healthcare workers must attend to the infected patients. This is where smart and connected health system plays a major role. It is beneficial in healthcare because of its flexibility to use, high precision, and continuous monitoring of patients. This chapter examines the various smart technologies that can be used to fight and contain the infectious disease and also their comparison for quick and better understanding.

The COVID-19 pandemic has caused hospitals to be over-crowded. Health workers are over stretched with the influx of people seeking medical attentions. How will they cope with other patients previously under their care before the pandemic, and whose medical conditions are not like this novel virus? Artificial intelligence and biosensor enabled digital health technology proffer solutions that will take the pressure off the overworked healthcare givers. This survey investigates the various smart health systems that can be applied in easing off the work strain on medical practitioners. Must persons with health problem be physically present in hospitals before they will be attended to? This issue is addressed by the application of various intelligent systems because they accommodate remote health monitoring, smart nursing homes, in-home assistance, telemedicine, and Wireless Body Area Network (WBAN) [7–9].

1.2 Related Works

1.2.1 Radio Frequency Identification

Technological innovations and developments arise anytime there is need to address a matter, especially an issue that negatively affects man and his environment. The motivation for the development of smart systems in healthcare was as a result of the need to solve the health challenges before humanity. Song et al. [7] stated that wireless sensor technology, Internet technology in clinical medicine, RFID, and AI are the major developments in medical IoT. Robots embedded with RFID reader are used to distribute drugs in hospitals, keeping healthcare givers away from frequent contacts or close proximity to patient with SARI. Health experts have used implanted RFID to observe a patient with a prolonged illness [10]. Miller et al. in their survey explained that installed RFID system is used to track and manage patients and staff in hospital [11].

1.2.2 Wireless Sensor Network

Stankovic [9] sated that Ubiquitous Monitoring (UbiMon), one of the applications of WSN, provides patients' monitoring in real time and supports the framework for data collection and analysis from wearable and implantable biomedical sensors. The paper pointed out that Smart Attire (Satire), a wearable personal monitoring system, would allow its user to record their daily activities using motion and location sensors. Khan et al. [7] in their paper, "An Overview of the Impact of Wireless Sensor Networks in Medical Health Care," cited how a cardiac monitoring system, CardioNET, is used to remotely monitor the human heat to prevent heart attack. The system sensor node gathers ECG signals and transits it to a local PDA device via a WLAN, and the PDA then sends the data to the remote monitoring system for interpretation and decision taken. They outlined the various WSN applications which provide caring environment for patients in their homes and elderly people assistance as smart nursing, medicine and meal reminder, and object location.

1.2.3 Contact Tracing

In their study, Dar et al. [12] pointed out that as a result of the unavailability of test kits for mass diagnostic laboratory tests and the vaccine for COVID-19, the best and effective step in containing the pandemic is to trace the contacts of infected persons. WHO [3] defines contact tracing as the process of identifying, assessing, and managing people who have been exposed to an infectious disease to prevent the spread of the infection. Considering how common portable devices with GPS are in present time and how frequent we make use of them in our daily lives, they provide the capabilities of been used for tracing [13]. Hernandez-Orallo et al. [14] pointed out that detecting and controlling the spread of COVID-19 are important in managing its cases. The use of smartphone contact tracing application will help to trace an infected person's previous locations and the persons he might have come in contact

1.2 Related Works

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- GSM cell—every mobile phone has a registered cell, and whenever it is in any new cell, it can also be identified. Telecom providers can determine the location of very mobile phone in its network.
- Wi-Fi—every device in a local communication network like Wi-Fi is identified by its physical address. Hence, the MAC address can help in contact tracing.
- GPS—every smartphone is equipped with a GPS app and allows for location tracing.
- Bluetooth—this technology are also used to trace contacts.

1.2.4 COVID-19 Laboratory Tests

In their study "Safety management of nasopharyngeal specimen collection from suspected cases of coronavirus disease 2019," Yan Qian et al. [15] stated that nucleic acid detection is the gold standard for diagnosis of COVID-19, and the nasopharyngeal swab is the main method of sampling. There are many techniques to detect or predict if someone is infected with COVID-19, but the most reliable technique is diagnostic testing because it is important in identifying someone who actually has the virus [16]. The virus signs and symptoms are like that of many flu infections, and flu infections could be misinterpreted as coronavirus infection. COVID-19 tests detect the presence of the causative organism of the disease or the antibody of the virus. There are two main categories of testing for the novel virus—the diagnostic tests and the serologic tests [8, 17].

The diagnostic tests detect the current infection. The US Food and Drug Administration [17] stated that the diagnostic tests are of two types – the molecular diagnostic tests and the antigen tests. The serologic test is used to detect the antibodies of SARS-CoV-2. It takes time for COVID-19 antibody to be created; hence this test is not used in confirming if someone has the virus in the first few days of getting infected [8]. The antibody levels in patients with severe COVID-19 case are higher than patients with mild cases [17]. As a result of these, different individuals have differences at which their antibody responds to the virus. The test is carried out on someone who has already had the infection and has recovered. In their paper, Scarpetta et al. [8] classified serologic tests into enzyme-linked immunosorbent assay (ELISA) immunochromatographic assay (ICGA). Carter et al. [18] revealed that serological testing has been expanded, from blood serum or plasma as sample to include saliva and sputum or other biological fluids as sample to test for the presence of SARS-Cov-2 antibodies. Table 1.1 below shows the comparison of the various laboratory tests.

1.2.5 Thoracic Imaging

Maghdid et al. [2] agreed that clinical analyses of chest computed tomography (CT) and blood test result and the nucleic acid test (NAT) are techniques that can be used to detect COVID-19. NAT is used to detect the specific nucleic acid sequence and species of SARS-CoV-2, the virus that causes the disease. CT gives positive results in determining the infection severity and its effects on the lungs. They propose a four-layer framework using on-board smartphone sensors and machine learning. The layers are input, configuration, symptoms prediction, and COVID-19 prediction layers. Jacobi et al. [19] used chest X-ray (CXR) and CT analysis to detect COVID-19. They stated that CXR is less sensitive to COVID-19 detection than CT but cited the disadvantages of CT. Rubin et al. [16] evaluated the use of CT and CXR in COVID-19 diagnosis and management under three scenarios—varying risk factor, community conditions, and resource constraints. They affirmed that thoracic imaging techniques are good for pulmonary disease diagnosis and management, but for COVID-19 detection, results from the images can be used to sort out patients for further diagnoses. CXR is comparatively inexpensive and commonly used in ICU centers for diagnosis than CT. In their study, Weinstock et al. [18] stated that there is no tangible prove that CXR can detect the novel virus but CT has shown high sensitivity in the detection of the virus. Using CXR as a visual indicator with other health signs and symptoms can be used to diagnose COVID-19 [1].

NUMERICAL MODELLING AND DESIGN OF ELECTRICAL MACHINE AND DEVICES

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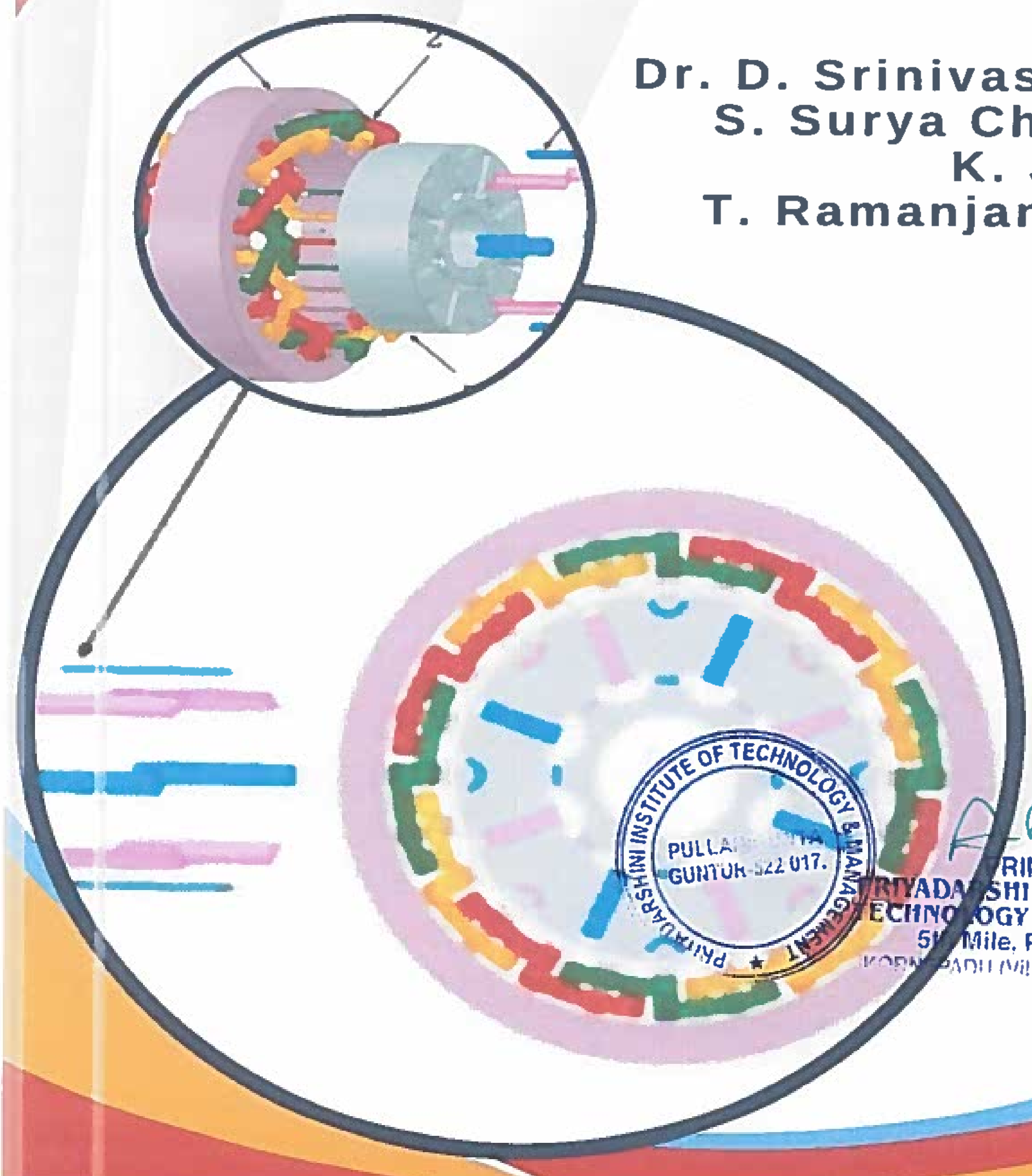

Preface

This book provides an overview of numerical field computational methods. Particular attention is paid to the finite element method (FEM) for the design of electrical machines and other magnetic devices.

II is based on the authors' experience in teaching numerical techniques to undergraduates, graduates and doctoral students in courses at their own and at various international universities, e.g. guest courses at COPPE Universidade Federal do Rio de Janeiro (Brazil), Univorsité do Batna (Algeria) and the RWTH Aachen (Germany). The numerical techniques are introduced to engineers from industry in an aiuiua! *Short Course in Magneticx* organised at the Katholieko Universiteit Leuven.

This book is intended to be the basic reading material for such courses on numerical field computations as given nowadays at the theatrical Energy division in the Electrical Engineering Department of the Katholieke Universiteit Leuven and as guest courses at other univarsities.

The book describes the theory and techniques of modelling and simulating electromagnetic devices. While its primary focus is on the techniques applicable to the modelling of electrical machines and the electmmechanical energy transducers, it also illustrates the usefulness of knowing the physical background of the specific problems. Accordingly, the right problem definitions can be applied and computed results can be interpreted and verified in a proper way.

Particular attention is paid to the FEM in designing electromagnetic devices, suoh as motors, actuators and transformers. This means that only frequencies below 10 kHz are considered. Several aspects of coupled fields are discussed in sections where the physical problem urges coupled solutions. The book has been written as a text book for undergraduates, graduates and engineers in practice who want to learn how to apply the fundamentals to solve electromagnetic design problems. Selected examples to develop skills to define and solve a field pmblem accurately are given at tha end of this book. In parallel with the tent for this book, an in-house software package for two dimensional and

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Numerical Modelling and Design of Electrical Machines and Devices

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