Euclid Seeram
Vijay Kanade

Artificial Intelligence in Medical Imaging Technology

An Introduction

Springer

Artificial Intelligence in Medical Imaging Technology

Euclid Seeram • Vijay Kanade

Artificial Intelligence in Medical Imaging Technology

An Introduction

Springer

Euclid Seeram
Medical Imaging, Faculty of Health
University of Canberra
Burnaby, BC, Canada

Vijay Kanade
Research & Development
AI Researcher, Intellectual Property Research
Kolhapur, Maharashtra, India

ISBN 978-3-031-64048-3 ISBN 978-3-031-64049-0 (eBook)
https://doi.org/10.1007/978-3-031-64049-0

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

This book is dedicated to my two smart, and beautiful granddaughters,
Claire and Charlotte
with love and blessings to you both forever.
*(**Euclid Seeram**)*

This book is dedicated to my beloved parents,
late Dr. A.S. Kanade (Lt. Commander) and Prof. Jaya A. Kanade,
whose wisdom, guidance, and love continue to inspire me every day.
With heartfelt gratitude and everlasting affection, this work is a tribute to your unwavering support and enduring legacy.
*(**Vijay Kanade**)*

Foreword (*For Euclid Seeram*)

In the rapidly evolving landscape of healthcare, where technology is revolutionizing diagnostics and treatment paradigms, the intersection of Artificial Intelligence (AI) and medical imaging stands as a beacon of innovation and promise. AI is currently finding success in healthcare data integration, workflow optimization, diagnostic assistance, image reconstruction, and treatment planning to name a few. With AI integrating into so many aspects of the radiography department, technologists and therapists are and will be forefront healthcare providers in the training, validating, and implementing of different AI applications. Within this aspect, Dr. Euclid Seeram's work, "Artificial Intelligence for Medical Imaging Technology: An Introduction," emerges as an indispensable guide.

Dr. Seeram's extensive expertise, coupled with his visionary insights, has yielded a comprehensive resource that addresses the pressing need for integrating AI into the domain of medical imaging. As a distinguished authority in both medical imaging and AI, Dr. Seeram navigates the intricate terrain of this field with clarity and precision. Dr. Seeram has published 31 textbooks on various subject matters in medical imaging and has more than 60 papers published in peer-reviewed journals. Dr. Seeram has served as a consultant and guest lecturer to some of the most prestigious imaging societies on an international scale. Dr. Seeram is revered in the medical imaging community for his unwavering expertise and dedication to high standards in quality imaging focused on improving patient care. He is globally renowned as both a distinguished educator and a pioneering researcher. Professionally, we consider ourselves privileged to have collaborated with him on the forefront of the evolving field of AI, particularly within the realm of Computed Tomography (CT). Personally, our CT imaging careers began reading and learning from Dr. Euclid Seeram's "Computed Tomography: Physical Principles, Clinical Applications, and Quality Control." His unwavering dedication to the profession is unmistakably evident in the breadth and depth of his work.

Artificial Intelligence for Medical Imaging Technology: An Introduction is not merely a technical manual; it is a testament to the transformative potential of AI in healthcare. Dr. Seeram elucidates the intricate concepts of AI algorithms, machine learning, and deep learning in a context that demystifies these complex topics for medical imaging technologists and therapists. By providing practical applications and real-world examples, he empowers technologists and therapists to harness the power of AI in enhancing diagnostic accuracy, streamlining workflows, and ultimately, improving patient outcomes.

Artificial intelligence is finding its way into all aspects of life, and medical imaging and radiation sciences are just one area finding ways to utilize it in numerous ways. Crucially, Dr. Seeram recognizes the pivotal role of medical imaging technologists in the integration of AI technologies. As frontline practitioners, technologists are uniquely positioned to leverage AI tools to augment their capabilities, optimize image acquisition protocols, and collaborate effectively with radiologists and clinicians. Dr. Seeram's meticulous scholarship and dedication to advancing the field shines through in every chapter, making this book an invaluable resource for technologists, educators, and healthcare professionals alike offering insights, strategies, and best practices for navigating the AI-driven landscape of medical imaging.

In an era characterized by exponential growth in data complexity and healthcare demands, the need for proficient AI integration in medical imaging has never been more pressing. Dr. Euclid Seeram's work heralds this new era in medical imaging—one defined by collaboration, ingenuity, and the relentless pursuit of excellence. Let us embark on a collective journey toward a future where AI empowers us to deliver the highest standard of care to every patient, in every corner of the globe.

Associate Professor, Weber State University School of Radiologic Sciences
Taylor Ward,
Ogden, UT, USA

Assistant Professor, Arkansas State University Medical Imaging and Radiation Sciences Program
Kendall C. Youngman,
Jonesboro, AR, USA

Foreword (*For Vijay Kanade*)

Medical Imaging industry is already one of the early adopters of the Artificial Intelligence. It is imperative to trace trends and the future of AI deployment in the Medical Imaging domain.

I have known Vijay A. Kanade for several years and I admire his expertise in "Intellectual Property Research." As a versatile academician, his research spans cutting-edge areas such as AI, Bio-inspired computing, IoT, Wireless technology, Neuroscience, Biophysics, Biomedicine, BCI, and so on. With a portfolio of more than 50 research papers published in prestigious journals like Springer, ACM, IEEE, and other renowned Scopus indexed journals and international conferences, Vijay stands at the forefront of innovation and knowledge across multiple disciplines.

His research work has taken him to prestigious universities worldwide, including Massachusetts Institute of Technology (Cambridge, USA), Columbia University (NY, USA), University of California (Santa Barbara, California), Central Michigan University (Michigan, USA), Manchester Metropolitan University (Manchester, UK), National University of Singapore (Singapore), and several others.

I must highlight that Vijay A. Kanade embarked on his research journey at Raman Research Institute, Bangalore, where he involuntarily assumed the role of a "research scholar" for a concise duration of 6 months. During his tenure, he was actively engaged in projects revolving around Brain Computer Interface (BCI). Subsequently, he transitioned into the corporate sector, delving into the realm of "Intellectual Property (IP)," where he served various IP firms for over 8 years. During his tenure as an IP professional, Vijay conducted independent research endeavors, garnering international recognition from universities worldwide, who extended invitations for him to present his work.

Vijay's mission is to advance humanity into as-yet-undiscovered or underexplored scientific realms. He maintains a constant enthusiasm for learning new things and expanding his expertise to diverse subject areas, including medical imaging. His innovative approach to thinking is greatly valued in his research pursuits.

Presently, Vijay serves as an autonomous researcher, dedicating part of his time as an "AI researcher" to corporate firms. Additionally, he remains engaged in addressing IP-related matters whenever required. Owing to his prowess in science and technology, Vijay has been sought after as a seasoned AI expert by media platforms such as Spiceworks.

Vijay belongs to a family of academicians; I am aware that his father, Late Dr. A. S. Kanade was a principal at a renowned college in Goa, a province on the west coast of India and his mother has retired after a long career as a teacher. Thus, spreading knowledge for the greater good is encoded in the DNA of Vijay A. Kanade.

I am glad that Vijay A. Kanade has decided to co-author this book on "Artificial Intelligence in Medical Imaging Technology" which is a timely reference to students studying medical imaging, radiologists, doctors, and medical imaging professionals. This book delves into the basic construction blocks of AI as well as its future and my personal favorites are the chapters that detail out "Principles of Machine Learning" and "Principles of Deep Learning." I am sure that the medical imaging practitioners as well as the researchers in the domain will find this very helpful.

I wish this book all success, which it so richly deserves.

Principal, New Education Society's Arts, Commerce and Science College
Arvind Samb Kulkarni,
Ratnagiri, Maharashtra, India

Intellectual Property Attorney
Priyank Gupta,
Pune, Maharashtra, India

Preface

Artificial Intelligence (AI) is everywhere and has entered the realm of Medical Imaging, and applications range from Computer-Aided Detection (CAD), Disease Detection and Classification; Radiomics; Imaging Biobanks; Dose Optimization; Structured Reporting; Workflow; to Interventional Fluoroscopy; Computed Tomography (CT); Image Reconstruction; and Image Processing. The literature is replete with articles and various tutorials describing not only these applications but also the technical aspects of AI including its subfields Machine Learning (ML) and Deep Learning (DL) as a means of introducing important and significant concepts and principles to medical imaging personnel, including radiologists and technologists, biomedical engineering technologists, and administrators. Additionally, the literature has identified the attitudes of these personnel to the notion of AI in applications in Medical Imaging.

A Guest Editorial on *Artificial Intelligence and the Radiographer/Radiological Technologist Profession: A joint statement of the International Society of Radiographers and Radiological Technologists and the European Federation of Radiographer Societies,* published in Radiography 26 (2020) 93–95, states that: *It is of critical importance that radiographers and radiological technologists, as medical imaging and radiotherapy experts, must play an active role in the planning, development, implementation, use and validation of AI applications in medical imaging and radiation therapy, reinforcing the need for the technology to be targeted to the most pressing clinical problems. The optimal integration of AI into medical safety, clinical imaging and radiation therapy can only be achieved through appropriate education of the current and future workforce10 and the active engagement of radiographers and radiologic technologists in AI advancements going forwards.* In a similar vein, the American Society of Radiologic Technologists (ASRT) published a comprehensive white paper in 2020, on *The Artificial Intelligence Era: The Role of Radiologic Technologists and Radiation Therapists*. A summary statement identified several points relating to the preparation for future change, most notably: "Radiologic technologists and radiation therapists should participate in or lead efforts to maintain quality of AI-based devices and to incorporate AI into quality programs, particularly for patient radiation dose…..and should become involved in laying the groundwork for ethical, practical, patient safety, and clinical aspects of AI in their responsibilities and for the betterment of patient care."

The major purpose of this book *Artificial Intelligence for Medical Imaging Technology* is to provide a useful resource to meet the developing educational requirements of the personnel identified above, not only in the United States and Canada, but also in the United Kingdom, Continental Europe, South America, Africa, Asia, Australia, and New Zealand.

The contents in this book are described in 10 Chapters and 4 Appendices as follows:

Chapter 1: Artificial Intelligence in Medical Imaging Technology at a Glance provides a brief orientation to the nature of Artificial Intelligence (AI) and its applications in Medical Imaging Technology. Chapter 2 elaborates on the ideas introduced in Chap. 1 by presenting a comprehensive exploration of Artificial Intelligence (AI) in healthcare, and tracing the historical evolution of AI, the chapter offers insights into machine learning and deep learning. Focusing on clinical decision support systems, and interpretation and validation of AI results for clinical decision-making. Chapter 3 presents a comprehensive overview of machine learning, covering supervised learning techniques like linear regression and decision trees, with applications in medical image analysis. Furthermore, the chapter explores unsupervised learning, reinforcement learning in medical imaging, and outlines critical machine learning components, including data acquisition, model architecture, loss functions, optimization algorithms, and evaluation metrics such as classification, receiver operating characteristic (ROC) analysis, precision-recall curves, and metrics like Intersection over Union (IoU) and Dice Coefficient. Chapter 4 offers a comprehensive exploration of deep learning principles, spanning neural networks like Convolution Neural Networks (CNNs), Recurrent Neural Networks (RNNs), autoencoders, Generative Adversial Networks (GANs), and attention mechanisms. It delves into CNN specifics for image classification, covering convolutional layers, filter sizes, activation maps, and transitions. Crucial topics like dropout, regularization, transfer learning, data augmentation, and CNN interpretability are highlighted, as well as specialized architectures for segmentation, object detection, and image generation, emphasizing their significance in deep learning applications. Chapter 5 delves into the realm of medical image manipulation and comprehension through an exploration of preprocessing techniques, such as noise reduction and image enhancement. Additionally, segmentation methods, feature extraction, and representation within medical images are addressed and image post-processing techniques crucial for obtaining high-quality medical images are reviewed followed by image interpretation and visualization.

Chapter 6 elaborates on several topics introduced in Chap. 1 and outlines the essentials of eight applications of AI in Medical Imaging. These include radiology workflow; computer-aided detection/diagnosis; radiomics; imaging biobanks; disease detection and classification; dose optimization; structured reporting; and image processing. Chapter 7 deals with the elements of image reconstruction algorithms in Computed Tomography (CT), namely, the filtered back projection algorithm and Iterative Reconstruction (IR) algorithms, and their limitations, and finally, a description of how DL algorithms are used in CT image reconstruction. Chapter 8 addresses major elements of Computer-Aided Detection (CADe) and Computer-Aided Diagnosis (CADx). In particular, the main stages of a CAD system are reviewed followed by a brief description of the major elements characteristic of a Deep Learning-based CAD system, highlighting three components are essential in order to provide a useful output to assist with decision making and accurate diagnosis: mass detection; mass segmentation; and mass classification. Chapter 9 delves into the crucial ethical and regulatory aspects surrounding AI in healthcare. It navigates through the regulatory frameworks, such as FDA regulations, UK's Medicines and Healthcare products Regulatory Agency (MHRA), and global agencies that govern AI's integration into healthcare. The chapter explores the concerns regarding privacy and security surrounding medical imaging data. Moreover, it meticulously examines the intricate subjects of bias, fairness, and transparency ingrained within AI algorithms. Lastly, it underscores the imperative of responsible AI use in healthcare, outlining the pivotal considerations for its ethical implementation. Finally, Chap. 10 explores the horizon of possibilities and challenges that define the future of AI in medical imaging. It unfolds a comprehensive exploration of recent breakthroughs in AI for medical imaging, showcasing how cutting-edge technologies are reshaping the diagnostic landscape. From the advent of explainable AI to the promise of federated learning, the chapter navigates through emerging technologies that are steering the trajectory of healthcare innovation. Moreover, the chapter carefully analyzes the potential ramifications of integrating AI into clinical practice and its future in healthcare, providing insights into the opportunities and the hurdles that need to be tackled for responsible incorporation. There are four Appendices related to Chap. 3. The primary aim of these appendices is to offer additional details on specific technical aspects, aiding in the comprehension of the workings of machine learning.

Enjoy, study, and learn from the pages that follow and remember—your patients will benefit from your wisdom.

Burnaby, BC, Canada Euclid Seeram

Kolhapur, Maharashtra, India
Vijay Kanade

Acknowledgments

By Euclid Seeram

An important satisfying task in writing a book of this nature is to thank those medical physicists, biomedical engineers, computer scientists, and manufacturers who have done the original work on the various topics included in this book. First, I would like to thank my co-author Vijay Kanade, BE (CS), who holds a Bachelor of Engineering Degree with a specialization in Computer Science, and who is an Artificial Intelligence (AI) researcher with expertise on a wide range of topics that span the subject matter of AI. I have learned a great deal on AI by just reading and studying his well described and detail chapters on AI included in this book. Furthermore, I have gained additional knowledge on AI from the University of Helsinki's Open Learning course on The Elements of AI. The course features a wide range of topics ranging from Why AI Matters, Probability Fundamentals, and Machine Learning to Neural Networks including Deep Learning Fundamentals.

This book deals with AI in Medical Imaging Technology as outlined in the Preface above, and in this respect, it is indeed a pleasure to express sincere thanks to all of the scientific and clinical experts, whose works have not only been cited but also provided illustrations of various concepts related to AI applications in Medical Imaging.

I am most grateful to Dr. Rob Davidson, PhD, MAppSc (MI), BBus, FASMIRT, Professor of Medical Imaging, University of Canberra, Australia. Thank you for not only assuming one of the roles of supervising my PhD dissertation but more importantly for providing me with the motivation to provide tools to educate our imaging community, and for serving as a reviewer of the initial proposal for this book. Another individual to whom I am grateful is Dr. Patrick Brennan, PhD, of the University of Sydney, Australia, who opened up doors for me to participate in the medical imaging community at the international level. Additionally, I would like to thank the *other reviewers* who provided constructive feedback to our publishers, Springer Nature, in support of this work. They are in alphabetical order, Dr. Anthony Chan, PhD, PEng, CEng, CCE, Program Head, Biomedical Engineering, School of

Health Sciences, British Columbia Institute of Technology (BCIT), and an award-winning Canadian Biomedical Engineer; Dr. Quang Vo, PhD, MSc, BEng, Instructor, School of Health Sciences, BCIT; Dr. Taylor Ward, PhD, Assistant Professor, Weber State University; School of Radiologic Sciences; and Kendall Youngman, MSRS, RT(R)(CT)(MR), Assistant Professor, Medical Imaging & Radiation Sciences Arkansas State University. Thanks for your constructive comments and positive feedback on the need for this book.

I must also acknowledge Yongjun Xu and 31 co-authors for their comprehensive review paper entitled “Artificial intelligence: A powerful paradigm for scientific research” published in *The Innovation 2*, 100,179, 2021, from which I have learned a great deal on the topic of AI, in several domains, such as in Physics and Mathematics and so forth. Another individual to whom I am grateful is Valentina Al Hamouche, MRT(R), MSc, who is the CEO/Founder VCA Education Solutions for Health Professionals based in Toronto, Canada. Valentina has provided me with recurring opportunities to provide Radiographic Imaging Sciences and CT Physics and Technology and other topics such as *AI in Medical Imaging* delivered through live webinars to further educate technologists and students across Canada and internationally as well. Thanks Valentina.

We are grateful to Merry Stuber, Senior Editor, Cell Biology & Biomedical Engineering at Springer, a part of Springer Nature, New York, NY, USA, who did all the hard work in not only reviewing the proposal herself but having it evaluated by several reviewers whose names are mentioned above, that finally led her to accept it for publication. Merry has provided the needed continuous support and encouragement to bring this work to fruition. Additionally, we appreciate the contributions of members of the production team at Springer Nature, including Amrita Unnikrishnan (Ms.), Production Editor, who has worked exceptionally hard during the production of this book, especially in the page-proof stages.

I humbly acknowledge the support from my beautiful family; first my lovely wife, Trish, a warm, smart, caring, and a very special person in my life, thanks babes. Secondly, my caring and very brilliant son David, the best Dad on the planet, to his two most precious daughters, my granddaughters, to whom this book is dedicated. Thanks for your enduring love, support, and encouragement.

By Vijay Kanade

Writing a book of this kind involves a gratifying responsibility of acknowledging the contributions of various professionals whose original work forms the backbone of its content. Firstly, I extend my gratitude to my co-author Euclid Seeram, an esteemed figure in academia, radiology technology, and a well-known author in Medical Imaging. Collaborating with someone of his caliber has been an honor, and I’ve gleaned valuable insights from his expertise, particularly in emphasizing the importance of paying attention to finer details and also tailoring the content to suit medical professionals, notably radiologists and imaging technologists.

I also want to express sincere appreciation to the multitude of researchers, authors, and experts whose work, referenced and exemplified throughout this book, illuminates the role of AI in medical imaging.

Special thanks are owed to Merry Stuber, Senior Editor at Springer, who diligently evaluated and facilitated the publication process, supported by a dedicated team at Springer Nature. Merry's continuous support was indispensable in bringing this work to reality. We also wish to acknowledge the valuable contributions and exceptional dedication of the production team at Springer Nature, particularly Amrita Unnikrishnan, Production Editor, who worked tirelessly during the book's production.

Lastly, I owe a debt of gratitude to my family for their resolute backing: my mother, Jaya Kanade, who has been a constant source of strength and encouragement; my late father, Dr. A. S. Kanade, whose remarkable professional, academic, and research accomplishments consistently drive me to push the boundaries and strive for greatness, even in his absence; and my wife, Kalyani, a computer engineer and a talented interior and graphic designer, whose artistic abilities brought the illustrations to life. I deeply appreciate their steadfast love and support.

Contents

Chapter 1
Artificial Intelligence in Medical Imaging Technology at a Glance

1.1 Introduction

Medical imaging technology has evolved from film-based imaging modalities to digital imaging modalities. These modalities include digital radiography, digital fluoroscopy, digital mammography, computed tomography (CT), diagnostic medical ultrasound, nuclear medicine, single-photon emission computed tomography, position emission tomography, and magnetic resonance imaging (MRI). These technologies produce both anatomical and functional images that can also be fused together to produce what is referred to as fused images. These images are viewed and interpreted by radiologists (who are specially trained in the art and science of image interpretation) to provide a diagnosis of the patient's medical/health condition. Since this task requires using a large knowledge base to extract various features from images as well as interpret these features, medical imaging is hence well-positioned for AI applications.

Furthermore, medical imaging involves additional tasks and processes other than image interpretation. Figure 1.1 provides examples of other areas of imaging "with potential for AI assistance and enhancement" [1]. These include processes before image acquisition, during image acquisition, following image acquisition, image interpretation, and following image interpretation.

With the above in mind, Potocnik et al. [2] point out that "radiographers, clinicians, and radiation therapists should acquaint themselves with the new technology and demonstrate readiness to actively contribute toward development, implementation, and adoption of AI-enabled solutions."

The purpose of this chapter is to introduce a broad overview of AI. First, AI and its subsets, machine learning (ML) and deep learning (DL), will be defined followed by a brief description of the major features of AI including how AI works. Furthermore, specific applications of AI in medical imaging will be reviewed, and a

E. Seeram, V. Kanade, *Artificial Intelligence in Medical Imaging Technology*,
https://doi.org/10.1007/978-3-031-64049-0_1

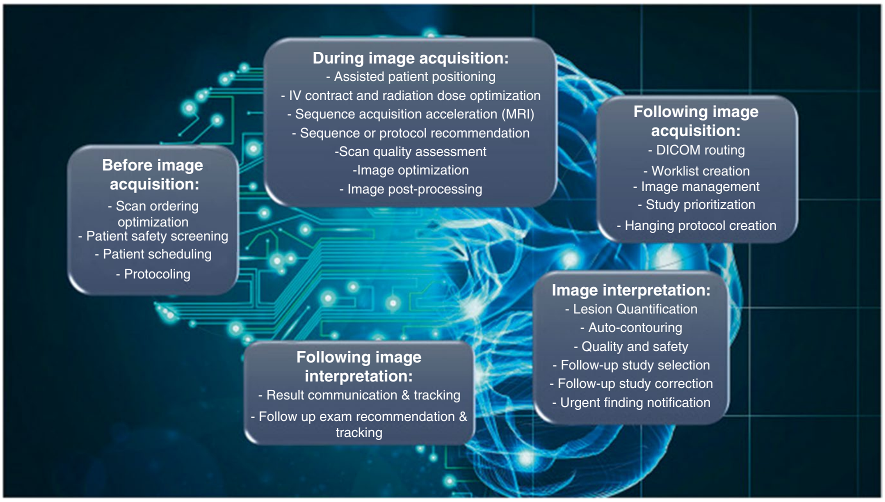

Fig. 1.1 Overview of the process cycle in radiology and major tasks with potential for AI assistance and optimization. (From Pierre K, Haneberg AG, Kwak S, Peters KR, Hochhegger B, Sananmuang T, Tunlayadechanont P, Tighe PJ, Mancuso A, Forghani R (2023). Applications of Artificial Intelligence in the Radiology Roundtrip: Process Streamlining, Workflow Optimization, and Beyond, Seminars in Roentgenology, 58 (2), 158–169. (Reprinted under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/))

case study of how AI is used in CT image reconstruction will be outlined. Finally, the chapter concludes with a glimpse of the ethics of AI in medical imaging.

1.2 A Little Bit of History

The beginnings and history of AI involve several milestones and breakthroughs, as outlined by Najjar [3] dating back to 1956 when it was formally introduced at the Dartmouth Conference [4]. These milestones and breakthroughs are sketched out in Fig. 1.2 and described by Nijjar [3]. Notable events include the creation of ELIZA, the first chatbot developed at the Massachusetts Institute of Technology (MIT), a decline in AI interest and research in the 1970s, development of neural networks in 1986, chess gaming in which International Business Machine's (IBM's) Deep Blue defeated chess champion Garry Kasparov in 1997, introduction of Google's self-driving car in 2009, and so on to the currently popular Generative Pre-Trained Transformer-4 (GPT-4), an AI model based on deep learning algorithms, which accepts image and text inputs and emits text outputs that "while less capable than humans in many real-world scenarios exhibit human-level performance on various professional and academic benchmarks" [5], which is introduced in 2023.

Today, AI has become commonplace in many areas of society, including medical imaging technologies, and applications continue to increase almost exponentially

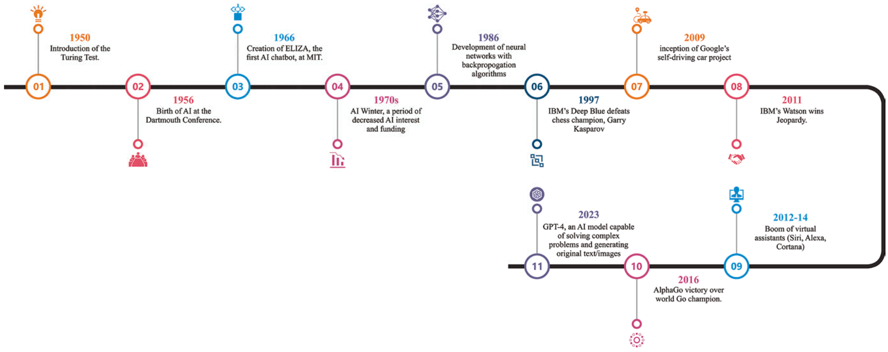

Fig. 1.2 Significant milestones in the evolution of artificial intelligence. (From Najjar, R. (2023) Redefining Radiology: A Review of Artificial Intelligence Integration in Medical Imaging. Diagnostics, 13, 2760. https://doi.org/10.3390/diagnostics13172760. Reprinted under the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/))

all over the world. For a detailed coverage of AI and its "impact on human societies," the interested reader should refer to a textbook by Dr. Christo El Morr [6].

1.3 Definitions

AI is a branch of computer science. It is an extensive subject and is based on principles and concepts related to mathematics, logic, philosophy, cognitive science, biology, and evolution. Key elements of AI include computer vision and scene recognition, robotics and sensory systems, natural language processing, neural computing, expert systems, intelligent computer-aided instruction, and neural networks. Furthermore, these elements provide AI applications in everyday life, including smart phones, smart cars, smart homes, email, banking, social networking, online shopping, sports, and the Internet of Things (IoT), to mention only a few. More importantly and within the context of this book, AI is now used in medicine and healthcare and medical imaging technologies, including computed tomography (CT) [7–10].

1.3.1 Artificial Intelligence

The literature offers a vast number of definitions of AI and its subfields, ML and DL, as illustrated in Fig. 1.3, in which ML is a subfield of AI and DL is a subfield of ML. Each of these terms is defined briefly by Pesapane et al. [11] For example, AI is defined as "a device that mimics cognitive function" (referring to human thinking and problem-solving), ML refers to "algorithms that improve as they are exposed to more data," and DL is "an artificial neural network structured in multiple

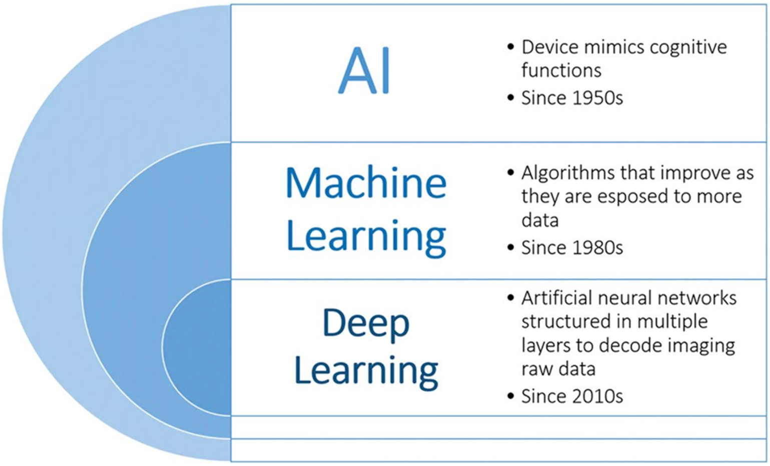

Fig. 1.3 AI and its subfields, ML and DL. While ML is a subfield of AI, DL is a subfield of ML. (From Pesapane, F., Codari, M. & Sardanelli, F. (1918). Artificial intelligence in medical imaging: threat or opportunity? Radiologists again at the forefront of innovation in medicine. Eur Radiol Exp 2, 35. https://doi.org/10.1186/s41747-018-0061-6. Reprinted under the Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/))

layers to decode imaging raw data." The word algorithm refers to a finite set of rules for solving a problem. These rules can be coded for computer processing.

A more detailed statement of the meaning of AI is offered by Nijjar [3] as "the replication of human intelligence in machines that are programmed to emulate human cognition and actions, encompassing learning, problem-solving, reasoning, and perception. AI can be classified into two major types: narrow AI, which is designed for specific tasks (e.g., facial recognition or voice commands), and general AI, which mimics a broader spectrum of human intellect. AI aims to develop systems with autonomous intelligent functionality, capable of problem-solving, decision-making, and performing tasks typically requiring human intelligence."

1.3.2 Expansion of AI

There are three fundamental elements as shown in Fig. 1.4 driving the expansion of AI in an enormous way. These include scientific breakthroughs, greater computing power, and more data. Furthermore, this expansion has been driven mostly by the application of machine learning and deep learning [12].

While scientific breakthroughs refer to discoveries that change knowledge and have a significant impact on science and technology as well as an impact on society as a whole, computing power depends on the number of processors (more processors mean more power) and the processor's speed (faster speed means greater computing power). Additionally, using graphics processing units (GPUs) for parallel

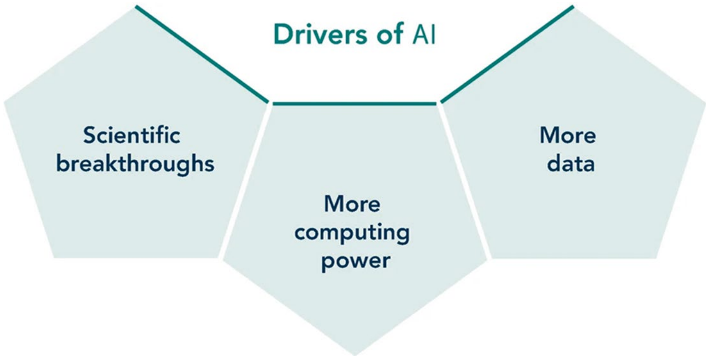

Fig. 1.4 Three fundamental elements driving the expansion of AI. See text for further explanation. (From Sheikh, H., Prins, C., Schrijvers, E. (2023). Artificial Intelligence: Definition and Background. In: Mission AI. Research for Policy. Springer, Cham. https://doi.org/10.1007/978-3-031-21448-6_2 Reprinted under the Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/))

processing increases the computing power. Medical imaging has experienced scientific breakthroughs such as dose reduction methodologies, CT image reconstruction algorithms, and more recently photon counting CT technology and now uses GPUs as part of its instrumentation architecture. Furthermore, medical imaging is now considered a big data profession, since it generates very large amounts of data. Big data is characterized by the four Vs, namely, volume, velocity, variety, and veracity. While volume refers to the amount of data, velocity addresses the speed with which new data is generated and propagated. Variety, on the other hand, refers to the fact that the data can be structured, unstructured, and semi-structured. Finally, veracity of big data examines whether the data is trustworthy.

AI is explained in a little more detail in Chap. 2.

1.3.3 Machine Learning

As shown in Fig. 1.3, ML is a subfield of AI. The literature includes several definitions of ML. For example, two such definitions include the following:

1. ML is “the use and development of computer systems that are able to learn and adapt without following explicit instructions, by using algorithms and statistical models to analyze and draw inferences from patterns in data” [13].
2. ML “is an AI technique that teaches computers to learn from experience. Machine learning algorithms use computational methods to ‘learn’ information directly from data without relying on a predetermined equation as a model. The algorithms adaptively improve their performance as the number of samples available for learning increases. Deep learning is a specialized form of machine learning” [14].

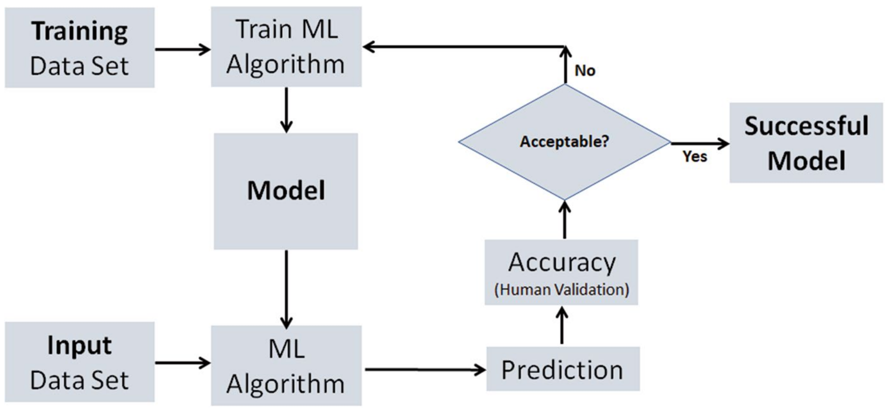

Fig. 1.5 The fundamental steps involved in ML. See text for further explanation. (From Seeram E (2023) X-Ray Imaging Systems for Biomedical Engineering Technology. Springer Nature Switzerland AG, 2023. Reproduced by permission)

The major characteristics of ML are its algorithms and learning categories. The learning categories include supervised learning, unsupervised learning, semi-supervised learning, and reinforcement learning, while the algorithms are neural networks, linear regression, logistic regression, clustering, decision trees, and random forests [14]. These topics are not within the scope of this chapter; however, they will be described in Chaps. 3 and 4.

Figure 1.5 illustrates the fundamental steps involved in ML. First, training data is needed to train the ML algorithm and the outcome of training is called a model. New data is then entered into the model, and the algorithm will subsequently make predictions on the basis of observation, experience, or scientific reason. Predictions are then validated by humans for accuracy. If the output result is acceptable, then the ML model is successful. If the output result is not acceptable, then the process repeats itself until the desired result is obtained. ML will be described in more detail in Chap. 3.

1.3.4 Deep Learning

DL is a subfield of ML (Fig. 1.3) and has been described as being more complex than ML. Numerous definitions are offered in the literature [15–17]. Two such definitions, for example, are the following:

1. DL "is essentially a neural network with three or more layers. These neural networks attempt to simulate the behavior of the human brain—albeit far from matching its ability—allowing it to 'learn' from large amounts of data. While a neural network with a single layer can still make approximate predictions, additional hidden layers can help to optimize and refine for accuracy" [15].