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Artificial Intelligence in Medical Imaging

Opportunities, Applications and Risks

Springer

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I've Seen the Future . . .

> Scientists are people who know more and more about less and less,
> until they know everything about nothing.
> —(Konrad Lorenz? Web sources vary, so I gave up looking).

More than 50 years ago, in the turbulent spring of the revolutionary year 1968, film director Stanley Kubrick released his radically innovative science-fiction epos *2001: A Space Odyssey*, based on Arthur C. Clarke's novels. Together with a few classmates from school, I saw *2001: A Space Odyssey* at the wide-screen Rubens cinema theater in Antwerp, Belgium, in glorious 70 mm high-resolution projection.

In addition to the movie being a visually breathtaking and dazzling cinematic experience, it was also my very first introduction to the concept of artificial intelligence, and I think that this may hold true for many, if not most, people of my generation. The movie features a spaceship, the Discovery One, controlled by a computer called HAL (*H*euristically programmed *AL*gorithmic computer), a kind of artificial intelligence (AI) system *avant la lettre*, which controls the systems of the spacecraft and interacts with the astronauts on board. Throughout the movie, the presence of HAL is mostly inferred with close-ups of a red camera lens, with a central yellow dot. HAL is smart and scary and rapidly becomes the quintessential film villain, intelligent and treacherous, interacting conversationally with the crewmen in a deceptively soft, calm, and sometimes threatening voice. In this 1968 movie, the computer HAL was able to speak, recognize voices and faces, process natural language, lip-read, interpret human emotions, understand art, have discussions with the astronauts, and even play chess with the humans on board the spaceship.

When I first saw *2001: A Space Odyssey*, I was happily unaware that the term "artificial intelligence" had already been coined during the summer of 1956, when a group of researchers convened at a seminar in Dartmouth College, USA. The adjective "artificial" was meant to designate the cognitive process of "thinking machines," in contradistinction to the reasoning processes of humans. At that time, it was believed that human reasoning was "real," whereas machine thinking was "artificial." The 1960s were a period of optimism and confidence in the increasing computational speed of man-made machines, and many scientists in the field of AI were confident that computers would be capable of doing any work a man can do. Progress was, however, not meant to be linear. The heady decade of the 1960s was followed

by what is now sometimes referred to as the "AI winter," a period of disenchantment, stalled progress, and rapidly dwindling research funding. But, like a cat with nine lives, AI came back with a vengeance in the 1980s, 1990s, and especially in the twenty-first century. In 1997, for the first time, a computer chess-playing system called Deep Blue successfully defeated Garry Kasparov, the reigning world chess champion. In 2011, Watson, a question-answering system developed by IBM, beat human champions of the television quiz game *Jeopardy!* in an exhibition match. And in 2016, a computer Go-playing system called AlphaGo became the first nonhuman system to triumph over Lee Sedol, a 9-dan professional master at the game of Go. This proves that machines can be instructed to think like humans, and even exceed their creators, especially since Go is an extremely complex game, more so than chess. But, of course, chess and Go are merely board games, and they are very, very different from real-life situations.

Today, more than 60 years after the "birth" of AI, we have indeed come a long way. The field of AI has continued to grow and to evolve in many different directions. Significant breakthroughs in artificial intelligence have occurred as the result of ongoing advances in data collection and aggregation, processing power, deep learning algorithms, and convolutional neural networks. Some of the most promising applications of AI have been in image processing and image analysis, which brings us to radiology. In just a few short years, AI applications in radiology have "exploded" and AI has become "big business." This is largely due to progress in artificial neural networks, the availability of cloud computing infrastructure, and the increased interest of medical professionals to pursue research in this field. It is not so long ago that image-recognition algorithms could only be used to tackle simple tasks such as differentiating cats from dogs. However, when the potential of machine learning systems is fully exploited, much more complex problems can be tackled, and this has opened up new avenues for radiology. Identifying and characterizing lung nodules on CT scans, computer-aided diagnosis of breast cancer on mammographic films, and automatic calculation of bone age by computer software on plain X-ray films of the hand are among the first such applications. Advanced segmentation techniques have opened up new avenues. Today, in diseases such as multiple sclerosis, Alzheimer's dementia, and traumatic brain injuries, AI is transforming patient care through accurate volume measurements of lesions and brain structures. Deep learning algorithms have been successfully implemented to diagnose different types of brain tumors, on the basis of multiparametric MRI data sets; in one such example, an AI system had an accuracy of 87% in predicting brain tumor neuropathology, outperforming human (neuro-) radiologists who scored only 66% accuracy. We are now pretty confident that AI software can be used to diagnose common neurological diseases with an accuracy rate of close to 90%, comparable to that of an experienced senior doctor. AI systems are proving to be faster, more reliable, and more accurate than human radiologists . . . and, obviously, they are available 24/7, they are never tired or sick, and they continue to "learn" as they analyze more cases.

So, while it would appear that AI and radiology are a match made in heaven, there actually is a lot of hysteria and apprehension around AI and its impact on the future of radiology. It is sad to see that the advent of AI systems has created so much anxiety and self-doubt among radiologists. The AI genie is out of the bottle; we cannot turn the clock back, but we do have the power to determine the future: tomorrow belongs to those who prepare for it today. It seems likely that radiologists who use AI will replace those who don't, since there are many signs indicating that AI will have a profound impact on the world of radiology. As George Bernard Shaw said: "*we are made wise not by the recollection of our past, but by the responsibility for our future*." Nevertheless, I am not afraid, since I am convinced that radiologists will embrace AI to help us manage "routine" tasks quickly and efficiently, thus giving us more time to focus on things that really matter. For that is exactly what AI software solutions will do: take over repetitive and simple tasks. I do not share the bleak and defeatist vision of the future for radiologists. History teaches us that the arrival of new technology tends to increase, rather than reduce, the need for human personnel. More than a hundred years ago, when automobiles started to replace horses as the preferred means of transportation of goods and people, some professions such as horseshoe smiths and saddlemakers became virtually extinct, but the car industry more than made up for this loss by creating new means of employment and career opportunities.

Personally, I believe that the integration of AI into existing medical workflow is a very promising trend and we should embrace this exciting new prospect, rather than fight it or run away from it. In my opinion, AI will help a radiologist like a GPS guides the driver of a car. AI will offer proposals to the radiologists and help the doctor to make a better and more accurate diagnosis. But it will be the doctor who ultimately decides, as there are a number of factors that a machine which interprets imaging data sets cannot take into consideration, such as a patient's general state of health and family situation.

AI systems offer our profession a unique opportunity to make a new beginning, to re-invent what we do, to boost productivity and accuracy. I am convinced that AI can take over time-consuming routine tasks, freeing up time and resources to focus our attention on individual patients, and thereby moving from volume-based radiology toward value-based radiology. So, regarding the implementation of AI software into radiological practice, my closing message to all radiologists is: take charge of your own future, and embrace it with confidence, courage, and determination.

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Preface

An increasing number of unanswered questions made us unsettled about the evolution of radiology and its current ability to keep up with the pace of healthcare transformation. The answers to these questions hopefully can be found in this book, which we have started in 2017 from the inside of the European Society of Medical Imaging Informatics (EuSoMII). The first EuSoMII Academy on AI in Rotterdam in November 2017 (actually the 35th annual meeting of EuroPACS-EuSOMII) attracted a plethora of bright minds and speakers who inspired us to publish a book about artificial intelligence (AI) in medical imaging. The preparation of this book originates from a brainstorm launched by Erik Ranschaert and Paul Algra immediately after the annual meeting. The idea was to provide a bright picture of existing ideas, concepts, and practical examples of AI applications in radiology and to connect professional worlds and communities of health care and data science. The work on the book progressed very well, and the harmonious whole of the authors' insightful and practical chapters has really pleased and inspired the editors.

The main activities of the EuSoMII society are centered around medical imaging informatics (MII), a.k.a. radiology informatics or imaging informatics, which is a subspecialty of biomedical informatics. Its purpose is to improve the efficiency, accuracy, usability, and reliability of medical imaging services within the healthcare enterprise. Imaging informatics covers processes for the acquisition, manipulation, analysis, storage, distribution, retrieval, and use of imaging data. Its area of interest is therefore very wide and includes topics ranging from radiology information systems (RIS), picture archiving and communication system (PACS), shared workflow, advanced visualization, and computer-aided diagnosis (CAD) to biobanks, computer vision, augmented reality/virtual reality (AR/VR), and 3D modeling. MII exists at the intersection of several broad fields: biological science, clinical services, information science, medical physics, biomedical engineering, cognitive science, and computer science. The IT solutions used in other industries are also relevant for application in the medical field, with the main intention of achieving a higher level of efficiency and safety in health care.

The role of a professional society is indisputable, as it is a driving force to bring the ideas forward and to share the early results of research for the common good. Another important role of such society is to become a guide in changes in a specialty that at the same time preserves the core of the specialism and follows ethical principles. All this precisely describes

EuSoMII's role in supporting the acceptance of advanced imaging informatics and the optimal integration in the radiological community.

The European Society of Medical Imaging Informatics (EuSoMII) is a professional healthcare organization that provides its members and the radiological community with up-to-date information on the latest innovations and achievements in medical IT by supporting education, research, development of standards, and networking related to a top tier of IT solutions in radiology, pathology, cardiology, neurology, and other imaging-based subspecialties. The guiding principles of EuSoMII are multidisciplinary and international collaboration, joining forces and efforts to make radiology stronger and increase our specialty's value. A multidisciplinary group consisting of radiologists, physicists, radiology technicians, IT experts, and other biomedical informatics professionals represents its target audience.

EuSoMII's vision is to reach an optimal integration of information and communication technologies (ICT) with medical imaging professions for increasing the quality and safety of diagnostics and therapeutics. EuSoMII aims to become a leading think tank for new developments in ICT related to medical imaging, enabling distribution of best practices within the professional community. In its current role and format EuSoMII is a driving force behind Imaging Informatics Subcommittee of the European Society of Radiology (ESR), a leading provider of training and teaching on imaging informatics in Europe, a partner of the Society for Imaging Informatics in Medicine (SIIM), Computer Applications in Radiology and Surgery (CARS), Healthcare Information and Management Systems Society (HIMSS), the Medical Image Computing and Computer Assisted Intervention Society (MICCAI), European Federation of Organizations for Medical Physics (EFOMP), and many medical subspecialty societies.

The structure of the AIMI book multi-directionally develops all aspects of artificial intelligence applications in radiology and allied specialties. It starts from the role of medical imaging computing, informatics, and machine learning in health care, proceeds into the principles of deep learning (DL) and neural networks (NN) in imaging, provides guidance on how to develop AI applications, and presents a medical imaging data readiness (MIDaR) scale for machine learning tasks in radiology. Further on the book emphasizes several significant medical imaging AI domains for developers, such as the value of structured reporting, validation of AI applications, enterprise imaging, imaging biomarkers, and image biobanks. Practical use cases of AI in radiology are outlined in detail for the areas of chest pathology, cardiovascular diseases, breast cancer, neurological diseases, and clinical trials support and for applications beyond imaging. Economic and legal aspects of AI are elaborated by presenting a regulatory infrastructure, a perspective on the market and economics, and the importance of an AI ecosystem for radiology. Finally, the book addresses advantages and risks of AI for radiologists, balancing them by presenting a "rethinking" of radiology as a medical specialty. The AIMI book is a journey along a highway of healthcare innovations where radiologists and data scientists travel in one direction guided by the principles of medical quality and safety for the patients.

Our outstanding team of authors and editors is honored and happy to welcome you to join the shaping of the future of diagnostic imaging. We deeply appreciate and value the contributions of the authors and coauthors. We would like to thank the whole AIMI book team for their ingenuity, creativity, originality, professionalism, openness for discussion, and constructive critique. Thank you, dear coauthors and coeditors, for sharing your knowledge, experience, vision, and values.

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Contents