Bernard Nordlinger
Cédric Villani
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Healthcare and Artificial Intelligence

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Editors

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Foreword

This book is the result of a meeting between the mathematical Fields Medalist Cédric Villani, the brilliant surgeon Bernard Nordlinger, and the MacArthur Genius award-winning roboticist and computer scientist Daniela Rus. A priori, there was little to suggest they would ever work together: Cédric Villani was promoting mathematics as the head of the Raymond Poincaré Institute, Bernard Nordlinger was trying to improve the prognosis of cancers through ambitious therapeutic trials, and Daniela Rus was trying to create widely available robots and AI systems to support people with physical and cognitive work.

However, their meeting was not purely fortuitous since their trajectories crossed at an event in support of innovation and research. Bernard Nordlinger whose concerns extended beyond surgical procedure had extensive experience in controlled therapeutic trials. He was well aware of methodological requirements and the most appropriate means of exploiting the results. Cédric Villani whose interests went well beyond the world of mathematics was seeking advances that had the potential to be enabled across many fields (particularly, health). Daniela Rus was looking for advances having a societal impact (particularly, addressing significant challenges around curing disease).

Although their complementarity was obvious, it was necessary to provide a means of establishing exchanges between those who accumulated data and those who actively worked in particular fields. Cédric Villani and Bernard Nordlinger set up a joint working group between the French Academy of Sciences and the French Academy of Medicine. The working group comprised a number of highly qualified members of the two academies and many other experts. The objective of the working group was to meet to gather information, listen to presentations, and exchange ideas. Daniela Rus joined later and brought an American viewpoint and expertise.

A joint meeting of the two academies on “Mathematics, Big Data, and Health: The Example of Cancer” took place on November 28, 2017. By presenting examples from health insurance databases pertaining to results already obtained in imaging and genetics, they provided us with the first opportunity to highlight the prospects that mathematics could offer to the progress of science and technology in health.

The characteristics of health sciences and their "structural wounds" as Cédric Villani put it (more particularly, the complexity of phenomena, the variability of conclusions, the complexity of funding, and human interpretative bias) must find a new dynamic of progress by mobilizing mathematical sciences. By making it possible to exploit Big Data and, more generally, artificial intelligence, medicine will increase its means of action. No field of activity will be able to escape this evolution. The very special resonance that artificial intelligence will have in the health field should be obvious to all.

Renewing and perfecting the interpretation of images; increasing performance in radiology, pathological anatomy, and dermatology; taking advantage of genetic data; and developing precision medicine all will become possible thanks to artificial intelligence. It will enable the collection of data of a previously inaccessible richness to make possible the most careful clinical examinations. It will make an irreplaceable contribution to diagnostic and therapeutic choices.

Such a development presupposes the retraining of doctors and, more broadly, of health professionals. Such a change in practices also requires consideration of the evolution of responsibilities and their legal consequences. If the robot and the algorithm acquire such a critical role in the decision, will they assume a legal personality? The hopes raised by artificial intelligence raise questions and even concerns. These concerns are justified. The basic precaution is to be careful as we move toward the fantastic predictions of the "augmented man" that on the basis of adventurous extrapolations suggest a totally uncontrolled evolution.

We must thank Bernard Nordlinger, Cédric Villani, and Daniela Rus for getting some of the top experts to participate and gathering a series of solidly argued clear articles that should allow readers to learn calmly without reserve and without passion about the prospects for the development of artificial intelligence in health.

Let us hope that this book will convince its readers that "there is no question of replacing the doctor with the machine and that the challenge is to organize the natural and collaborative interactions between human expertise and the contributions of artificial intelligence in the daily practice of medicine."[1]

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[1] Villani C., *Donner un sens à l'intelligence artificielle*, p. 197.

Introduction

Artificial intelligence (AI) is a revolution for some people, fashion for others, and a reality for many aspects of our lives. All areas scientific and otherwise are preparing to experience the upheavals it will inevitably bring.

At the forefront of scientific fields awaiting this impact is health. On the one hand, there are the usual problems such as diagnostic errors, variability of situations, fallibility of experts, and great difficulties in transmitting research information to practitioners. On the other hand, AI excels at digesting piles of literature, finding rare correlations, and analyzing images and other data that are ever more numerous produced by medicine, a field in which the stakes are of course literally vital.

This book provides an overview of AI in medicine and, more generally, looks at issues at the intersection of mathematics, informatics, and medicine. It reaches out to AI experts by offering hindsight and a global vision, and to non-experts intrigued by this timely and important subject. It provides clear, objective, and reasonable information on issues at this intersection avoiding any fantasies that the AI topic may evoke. The book provides a broad kaleidoscopic viewpoint rather than deep technical details.

The book was gradually compiled by the Artificial Intelligence and Health working group created by the National Academy of Medicine and the Academy of Sciences of France at our suggestion. The sessions of the working group were an opportunity for us to explore the questions we had asked ourselves during our meeting at the Ethics Council of the Epidemium competition. Above all, they were a means of inviting recognized specialists to contribute and collaborate such as mathematicians, modelers and analysts, data scientists, statisticians, oncologists, surgeons, oncogeneticists, sociologists, hospital administrators, and lawyers.

For the applications of AI to be impactful a multidisciplinary approach is required. This is the reason we set up a multidisciplinary working group with specialists from various fields of medicine, mathematics, and computation. Our conversations were fruitful because we were able to discuss topics that are intrinsically multidisciplinary with experts representing all their medical and computational aspects. The dialogue of this think tank made us realize that the doctors of the future will have to be “multilingual” in medicine, data, and computation. This will require new approaches to training medical students, something we believe should be done early in medical training.

The road ahead is full of challenges, but the journey is worth it. The "mechanical" medical doctor (MD) is certainly not for tomorrow and certainly not desirable. The doctor of the future should be "augmented," better equipped, and well informed to prevent, analyze, decide, and treat disease with empathy and the human touch. The aim will be to improve diagnoses, observations, therapeutic choices, and outcomes.

Imaging and, more generally, the analysis of medical data will benefit from AI and machine learning advances. Medicine is an area of choice for the full exploitation of images because medical image details are too fine or subtle to be picked up by the naked eye. Additionally, when image resolution is poor, algorithms can identify the missing data and enhance image quality. Mathematical models can then be used to predict future outcomes given the current images.

Modeling can be used as an enhanced tool for the evaluation of chemotherapy treatments. Right now tumor response to chemotherapy is estimated using approximate measurements of the diameter of the tumor. New advances in tumor growth modeling processes make it possible to predict tumor response to treatments that take into account macroscopic features. Equally important is the consideration of tumor genomic data or modeling. In the future these predictions will take into account information at both the molecular and the macroscopic scale and will be a significant challenge.

The correspondence between genotype and phenotype remains the most vexing of the mysteries of biology, but new statistical learning methods offer a workaround. They enable the analysis of extraordinary molecular datasets to be self-mathematized to better identify the regions of the genome associated with tumor progression and determine the most appropriate treatment. This same machine learning approach can help to overcome the imbalance between the large number of variables studied and the small sample sizes available by selecting the most relevant data. The future of clinical research will be enabled by tumor databanks. Combining clinical and biological data stored in tumor banks will likely become standard practice for clinical research. Clinical trials are in the process of being renewed: the platforms that make it possible to record and cross-reference large clinical and molecular data suggest new trial formats. Studies target molecular abnormalities more than organs. When strong pilot alterations are identified, molecular information will gradually enter into common practice.

Pathology will also be renewed by AI. Today pathologists depend on physical slides that cannot be shared. Imaging the slides will in future lead to pathology databanks. Such virtual slides will allow remote analysis without a microscope. Multiparametric analysis makes it possible to search for increasingly complex information. New technologies for organ exploration that are extremely promising are beginning to emerge yielding large amounts of data, in addition. The microbiota, the environment, and now entire ecosystems can be identified by statistical tools.

Finally, and perhaps most importantly, medical data are becoming accessible, especially to young multidisciplinary teams working in open mode (open science, open data).

Such developments will have to face up to major challenges associated with the race for the three major ingredients that are the object of unbridled competition worldwide: human expert brains, high-performance computer equipment, and very large multiparameter datasets.

First of all is the challenge of finding human expert brains. AI is mainly carried out by experts endowed with a spirit of collaboration, ready to take on a challenge, and with expertise in interdisciplinary contacts. Dual-competency profiles for new jobs (health and Big Data, algorithms and medicine, etc.) are very popular, yet the talent pool is scant. Training a new generation of scientists ready to occupy these interfaces is a major challenge. There are not enough trainers or programs; we will have to start new experimental training programs.

Next is the challenge of producing high-performance computer equipment. Europe lags behind the United States and China in terms of investment. The AI of health in the future will require large storage and computing centers, some of which will be internal and some will be outsourced.

Last but not least is the search for machine learning algorithms to identify correlations, regularities, and weak signals. This will require very large multiparameter datasets, labeled data, and cross-referencing the data of various sources (private and public) whose marriage can only be accomplished with governmental support. In France the largest existing public health databases are interlinked such as SNIIRAM (National Information System Inter Plans Health Insurance), SNDS (National Health Data System), and hospital platforms such as the platform of the AP-HP (Administration of Paris Public Hospitals). They are all intended to be part of a larger entity aimed at facilitating their access for research purposes.

The construction of such large medical datasets presents a triple challenge. First, the technical and technological challenge posed by the size of the data has to be resolved. This includes rapid access to data, handling a variety of formats, addressing the considerable number of imperfections in the data, and the need for enhanced cybersecurity. Second, the ethical and legal challenge relating to the protection of personal data requires solutions that ensure public confidence. Third, trust in sharing data is difficult to come by in practice since it requires convincing data owners to overcome their reluctance to join forces. In the French context the State is playing a key role in all these areas. France has set up the Health Data Hub to facilitate research.

Finally, patients will have to play their part in such developments. This includes giving informed consent, participating in the development of tools, and contributing to the evolution of practices and mentalities. While physicians retain responsibility for contact with and explanations to patients, an interaction between humans and algorithms in medicine that is appropriate and constructive is likely to emerge (especially defined for the human dimension).

Today, all nations aspiring to be part of the global innovation scene are embarking on AI and health programs. The United States and China have announced national strategies to stimulate the development and applications of AI with medicine and healthcare as important pillars. France is no exception as shown by releasing the report “Giving meaning to artificial intelligence” (by Cédric Villani) in March 2018. The findings in the report are the result of six months of interdisciplinary work including many hearings. This report outlines a strategy for a coordinated AI policy in France and, more broadly, in Europe. The President of the French Republic adopted most of the recommendations in his speech on March 29, 2018.

The multidisciplinary working group responsible for the genesis of this book contributed some of the background and reflections that shaped the report sent to the government; it also influenced details of the Data Protection Act that adapts French law for the purposes of the EU General Data Protection Regulation (RGPD). It is intended to provoke advance thinking of both specialists and the merely curious. This book brings together a variety of very brief contributions proposed by stakeholders to the working group. All the themes already outlined are included.

The last part of this book examines breakthroughs that connect medicine and society such as the ambivalent role of new modes of information (particularly, social networks that disrupt communication and spread fake news and conspiracy theories), the emotional and sometimes misleading dialogue between humans and machines, and humanity’s temptation to push ahead without safeguards. Throughout the book, contributors emphasize directions and dominant themes more than details.

The purpose of this book is to give the reader an overview of the state of the art of AI in medicine by providing examples and suggestions of how the medical field will change. Machines supporting and augmenting doctors should not be seen as scary. Rather, the future “augmented” doctor will provide patients with better and more personalized treatments.

Bernard Nordlinger
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Artificial Intelligence and Tomorrow's Health

Cédric Villani and Bertrand Rondepierre

The potential of artificial intelligence (AI) in the field of health is immense and has been, from the very beginning of the discipline, subject to significant work since the beginning of the 20th century. The 1970s saw an explosion in the scientific community's interest in biomedical applications helped by the availability of distributed computing resources such as SUMEX-AIM (Stanford University Medical Experimental Computer for Artificial Intelligence in Medicine) from Stanford University and Rutgers University. Among the first practical applications to be identified was the MYCIN project. Developed in the 1960s and 1970s at Stanford University it used an expert system to identify bacteria that cause serious infections and then provided appropriate treatments.

In addition to the obvious benefits for society as a whole, the field of health has always exercised a particular fascination in the scientific community in addition to being a natural playground for artificial intelligence. The general increase in the volumes of data available in extraordinary proportions and the complexity, number, and variety of phenomena involved make health an almost infinite and extremely diversified subject of study. This complexity, which a priori defeats any attempt to fully model human biology and the mechanisms at work, is precisely the privileged place of expression for AI. Like a doctor, AI techniques are based on observations that produce information that can be used by the practitioner when confronted with theoretical and empirical knowledge. In a context where it is increasingly difficult to replicate the results of community-driven studies and where, as in many other areas, the transition from discovery to a product or new practice is rarely frictionless, AI is an exception because it is perceived as a capacity that can be directly activated and used in the field.

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However, the need for theoretical knowledge is sometimes challenged by recent approaches, such as neural networks and deep learning, that manage to discover for themselves how to accomplish certain tasks without a priori information on the phenomenon under study. Based on the observation of many examples, these methods establish correlational links between the patterns observed and the ability to perform the task requested. However, such discovered links can be misleading because of the well-known difference between correlation and causality that mathematicians know well, on the one hand, and because data can carry biases that distort the relevance of the result obtained, on the other hand. Such weaknesses are not critical when it comes to recommending a movie but can have particularly disastrous consequences in the field of medicine. Autonomous discovery by algorithms is not a necessity, however, because centuries of study and deepening our knowledge of medicine have enabled us to produce a wide spectrum of models applicable to human biology unlike in some fields where human beings are perfectly incapable of explaining the cognitive processes at work to translate data into usable information. If these models exist, it must be noted that medicine as a whole remains to be based on observation and its practice is therefore extremely dependent on the experience of the practitioner whose diagnosis is based on a priori knowledge, as well as on a history of previous situations with which the new one is compared. Two practitioners in health and AI with different experiences will therefore potentially and naturally arrive at two different diagnoses from the same observation.

Like some therapeutic or epidemiological discoveries whose explanation escapes the current state of our knowledge some phenomena are only understood through an empirical process. Thus, it is at the intersection between the blind approach and full formal modeling that AI can reveal its true potential and, for example, avoid gross errors that are incomprehensible to a human being.

The importance of empirical information leads to the observation that the data that express it, even more than elsewhere, constitute the core of the practice of medicine in its relationship with the patient. It is therefore not surprising that there is an exponential increase in the quantity and diversity of available data as part of a global digitization of all medical practice and the use of ever more numerous and varied sensors. Reports written by health professionals, analytical results, genomics, medical imaging, biological signal recordings, and drug use history are examples of data sources that can be the raw material for AI research. Their diversity is an expression of the multiplicity of possible applications for health some of which can be cited as recurrent examples: diagnostic assistance, pharmacovigilance, materiovigilance, infectiovigilance, personalized medicine, patient follow-up, clinical research, and medical–administrative uses. However, the data are not in themselves an "open sesame" whose possession alone will allow the development of AI. Data in themselves are only of interest if they are clean, neat, and well labeled. It is for this reason that any AI approach necessarily involves a work step on these data to extract the essence of the data and thus enable them to be exploited at their true value.

The state of the art of AI for these various applications is highly heterogeneous. Like other fields, neural networks have made significant progress in the exploitation of biological signals as evidenced by the success of young French companies such as

Cardiologs, which specializes in the automatic analysis of electrocardiograms. On these issues the combination of data availability and algorithm refinement has made it possible to match, if not sometimes exceed, the level of performance obtained by a human to detect pathologies from these signals. Similarly, use of such signals related to vigilance have been made possible with initial successes (particularly, in the correlation of pathologies) thanks to the depth of public databases. One example is the work published in February 2018 in *The Lancet Public Health* showing that excessive alcohol consumption is associated with a tripling of the risk for dementia, in general, and a doubling of the risk for developing Alzheimer disease. Advances in natural language processing have made it possible to make progress in the extraction of information (particularly, from reports written by doctors) and one hopefully to capitalize on medical information in the long term by simplifying the upstream work of qualifying and enriching data. The AI revolution for health has only just begun, and the coming years should be rich in new developments.

Key to the success of this revolution is the confluence of three types of resources: human, empirical (through databases), and computational (since it is primarily about large-scale computing). The human resource is the most critical of this triptych and the most protean. It is primarily critical to expertise in the field of AI and in the field of health and exerts real tension on profiles displaying this double competence. Experts with such competence are particularly valued not only for their ability to inject medical knowledge into AI methods, but also for the reciprocal aim of bringing AI closer to the medical professions by matching them to the most relevant needs and uses. Human resources are also critical to getting professionals and patients fully involved. Since data and their qualification are a major concern, as well as materializing the link between machines and the real world, they cannot do without those who produce data, those who enrich data to associate data with a business value, or those who exploit data in their medical practice.

The battle for AI is being fought on many levels. This is especially true of the health sector where many countries are trying to address the issue and position themselves as leaders. First, a battle for human resources is being fought in parallel between countries, between companies and the State, and between companies. Second, there is a struggle for leadership in AI for health. At first glance, the United States appears to be in front with a definite lead, while Canada, the United Kingdom, and Israel are positioning themselves as very serious competitors. Israel's case is particularly interesting in this regard. Gathering its own data through a systematic and authoritative campaign involving doctors and the entire hospital community means the initial resource necessary for a larger scale AI approach to health has already been constituted. Moreover, research teams have been developed within a few large insurance funds that are leading the entire social security apparatus and capable of setting up ingenious models based largely on interdisciplinarity and cooperation between specialties.

French Strengths and Weaknesses

For its part France is already in a privileged position to play an important role internationally in the field of AI for health. French higher education and research have always occupied a prominent place at the international level, particularly because of the recognized excellence of scientific training in France. Excellence, particularly in mathematics and computer science, gives France a competitive advantage as confirmed by the presence of many French people at the head of many prestigious companies and teams working on AI. Yann LeCun is the most famous of them and a leading figure on neural networks. He is currently working at both New York University and Facebook AI Research (FAIR). Expanding the definition of the French community to include the Francophone community we must also mention Yoshua Bengio, another leading figure in the field playing a major part in the Canadian strategy. While this academic excellence is the sine qua non condition necessary to occupy an advantageous position in a tough international competition, it is not sufficient to guarantee it. Globally, the current rigidity of medical training remains a problem today since it will not be able to meet the need for multidisciplinarity that will only increase. The integration of AI and, more broadly, digital technology into curricula is a must for professions that will be at the forefront of such technological developments.

Downstream of research and contrary to certain preconceived ideas innovation in France remains very dynamic despite little publicity and visibility. While a significant proportion of the scientific publications of digital giants are relayed both in the specialized press and in national and even international dailies, some French successes, such as Therapixel (winner of a world competition against teams from the world's largest laboratories), remain unpublicized. Even if France is not the base of any digital giant, it is not deprived from an industrial point of view since it is home to heavyweights in the field such as Sanofi or Atos (which have a more transverse position) and OVH (which provides advanced cloud-computing services).

Academic, entrepreneurial, and industrial forces are therefore well represented and can rely on data resources that are unique in the healthcare field all over the world. Indeed, France's Jacobin tradition has led it over time to set up a health system that collects, but not exclusively, the data necessary for the performance of medical and administrative tasks in a mode that is essentially centralized and managed by the State. Moreover, more than 65 million French people participate in this system giving it the critical size necessary. So, it is conceivable that the use of already capitalized data will lead to short-term successes. These data are grouped together in the National Health Data System (NSDS), which now has as its primary objective the organization and implementation of healthcare reimbursement.

The sensitivity of the domain and the information that is manipulated raises the question of trust in a more singular way. In this context the fact that the public health task is essentially carried out by the State or by structures that report directly to it makes developing AI in health and structuring organizations for this purpose a legitimate intermediary of trust. The challenge here is to ensure that the need for such developments is accepted and to guarantee the framework within which they will be carried out without the use of intermediaries, although the latter are not exempt from obligations either. Indeed, the existence of French and European regulations (the EU General Data Protection Regulation or RGPD) as a spearhead contributes to creating a framework of trust favorable to the development of AI systems that respect and protect individuals and are therefore all the more likely to be successful and accepted by French citizens.

These comparative advantages will not be the only determinants of French success. Competition for human resources could lead to French research laboratories and companies drying up and becoming a breeding ground for non-European players. As a result, the dynamics of innovation would be jeopardized permanently undermining French ability to excel in this area. Moreover, because of the difficulty of conducting research projects in the health sector due to administrative and regulatory complexities there remains an entry barrier that does not allow major players, whether academic or industrial, to emerge.

While the NSDS is considered an immense asset, it is nonetheless limited and insufficient to allow the development of a real French force for AI and health on its own. A system that has been designed solely for medical and administrative purposes cannot be expected to be naturally equipped to support and promote an efficient research and innovation approach in the field of AI. To this end there is a very pragmatic lack not only of the necessary hardware and software resources to implement such an approach, but also of the governance and organization necessary to ensure coherence at the national level. This is evidenced by customer data available in hospitals to date still not being shared with national data. Even under the first NSDS implementation it may take months or even years for data to be capitalized within the system when it has not yet been coded for reimbursement. As data quality is essential it must be borne in mind that a great deal of work will be needed to make data directly usable by AI approaches and that data management will have to be accompanied by governance that is currently structurally lacking.

Finally, excellence in AI, health research, and innovation on their own is not enough to create economic champions. Whatever the quality of upstream work it must be associated with the existence of a large market that does not yet exist either within the State, with private companies, or with French citizens. If we agree that the market is at a minimum European and even possibly international, then there is still a chasm to be crossed to transform innovation into economic success (especially with French venture capital remaining insufficient to face international competition).

A Project for France

Whatever the plan to be implemented it is important to keep in mind the three main types of challenges that any approach will face: technical; legal and ethical; and trust and organization. Technical challenges essentially constitute the ability to deploy new technologies in adapted systems while ensuring the continuity and recovery of existing systems. These challenges exist whatever the underlying technology and are the result of meticulous architectural work. However, the legal and ethical challenges raised are much more specific to AI and to the field of application of health because the criticality and sensitivity of the application require a particular investigation. Finally, the challenges of trust and organization reveal that the first obstacle to the development of AI is not so much technological or regulatory as it is human. AI cannot develop without the trust of its users and the support of organizations that are often ill-equipped to deal with such a broad and cross-cutting issue. Contrary to popular belief it would seem that technical challenges are often easier to meet than anticipated, while trust and organizational challenges are much more difficult to address than expected. This is certainly explained by the fact that a technical challenge usually requires a technical solution, while a human challenge requires much more in-depth work, reflection, and pedagogy.

To organize French action in this area the report "For a meaningful artificial intelligence" proposes a global approach aimed at establishing a system of both academic and industrial scope in the field of AI and health by capitalizing on French strengths. The first requirement for such an approach is to set a direction with some ambitious objectives of general interest to maintain and structure the system effort over time. Clearly identifying these objectives is also a prerequisite to equipping them since such action will certainly not be the same if we are interested in reducing the risk of nosocomial disease or in personalized medicine. Setting a direction is also an opportunity to lead upstream reflections on ethics and trust by integrating them into concrete projects thus avoiding the pitfall of overly theoretical discussions that could lead to decisions to the detriment of progress, even though the apparently contradictory dimensions of these projects were reconcilable.

Before others do it for the country it is essential to reorganize the French health system along the lines of the one that led to the success of the digital economy (i.e., the platform model as an intermediary in accessing information, content, services, and goods published or provided by third parties). Such a platform is an opportunity to deploy state-of-the-art computing and data storage resources compatible with the uses of AI. This technical aspect is more a prerequisite and an update of the existing system than a breakthrough in itself. However, it is the vector that will have to collect the data relevant to the uses of AI in health, to instrument their collection, and to capture data in real time. In doing so this platform is intended to be deployed from the central level to the local level (hospitals, health professionals, and patients) thus bringing together systems that have historically been disconnected from each other. From an economic point of view it is a means of changing the situation by allowing third parties (researchers, contractors, large companies, and public authorities) to develop and experiment with new functionalities that are directly based on the health system and the data it contains. Thus, the platform opens up a new way of creating and distributing added value.

Emphasis should be placed on research and experimentation. Complaints are recurrent as a result of too heavy regulatory obligations and too long delays in the investigation of cases. While the situation has improved considerably in recent years, to be compatible with the pace of innovation the introduction of "sandboxes" in the health sector that are open to experimentation would temporarily ease the constraints on stakeholders, support them in fulfilling their obligations, and carry out experiments under real conditions. Research will also be the first beneficiary of this policy. Thanks to privileged access to data and flexible experimental conditions, such public research laboratories as the interdisciplinary institutes for research in artificial intelligence (3IA institutes) proposed to free the forces of our academic fabric, should find fertile ground here for the development of AI for tomorrow's health.

Finally, the most significant difficulty will be posed by organizational challenges that will involve setting up a governance system with a cross functional data policy whose objective would be to think upstream in terms of data collection, data capitalization, and governance of the health platform, as well as organization of the effort around the development of AI. A project such as the Shared Medical Record should be accompanied by an AI dimension to be explored in the project so that data are no longer capitalized only for documentary purposes, but also for subsequent research, innovation, and exploitation within the scope of AI. Such a possibility requires specific structuring so that the patient's history can be followed, an operation made difficult today since the use of NIR[1] is not systematic. Of the conditions necessary for success it should be stressed that development of the AI skills of organizations (companies, administrations, regulatory authorities, doctors, and health professionals) is essential. The same is true of patients where the need to demystify AI is becoming increasingly important to avoid a feeling of mistrust or refusal to take advantage of the opportunities offered by these technologies. Acculturation, acceptance, and trust must each be a primary concern since the development of AI depends mainly on patient involvement.

European Tracks

It is generally accepted that France has not reached the level in terms of AI needed to compete against such giants as the United States or China and must look instead to Europe. In the health field, working directly at the EU scale is a hard task to undertake. Although it would have been natural to cooperate with Germany, it has a much more heterogeneous and disparate health system than that of France and therefore does not offer the same opportunities in the short term. There seem to be so many different situations in the various Member States that now would be a good time to carry out a survey, map the different European health systems, and establish the potentialities in terms of AI. Depending on the results of such a study the desirability or otherwise of developing a European health system deploying the logic of the French plan on a European scale could be evaluated. That could support the French academic and industrial policy of AI applied to health.

[1]Registration number or social security number in France.

It will only be as a result of major changes that France will be able through the European Union to seize the position it wishes to occupy in the world in terms of AI and health.

Advancing Healthcare Through Data-Driven Medicine and Artificial Intelligence

Ran D. Balicer and Chandra Cohen-Stavi

If it were not for the great variability among individuals, medicine might as well be a science, not an art.
Sir William Osler, 1892.

Introduction: The Status Quo and Its Toll

Health systems have been facing escalating challenges in recent decades since the increase in demand and costs cannot be met by a similar rate of increase in human resource and invested capital. The rise in demand is the result of several key trends: the population is growing older, and the relative proportion of the population over the age of 65 is rapidly increasing. As the average healthcare needs of the elderly population are far greater than those of the younger population this trend is straining healthcare systems. In parallel, chronic disease morbidity in all age groups is becoming increasingly more prevalent. A majority of people above the age of 50 years have chronic disease comorbidity or multimorbidity (i.e., two diseases or more), and this multimorbidity has a synergistic impact on their healthcare needs.

Such strained systems and individual providers are working in an ineffective and error-prone traditional model of reactive care. In the current state of affairs the intuitive and experience-based art of medicine is failing us and allows for substandard care to be the norm, even in the most advanced healthcare systems. It has been estimated that 45% of the evidence-based interventions required in routine care are missed, and

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many deaths are the result of medical errors or inappropriate care,[1] despite clinical professionals doing their best to deliver the right care. Increased complexity in the options of care models, medical treatments, and medical technologies bring about intensifying challenges in disentangling the evidence for effectiveness, with almost 2.5 million English-language articles per year published in scientific journals.[2] The providers themselves bear severe professional and personal cost for this continuous increase in workload and inappropriately designed work setting, with recent surveys suggesting that up to 50% of physicians reporting severe burnout signs and symptoms.[3]

The Promise of Artificial Intelligence in Transforming Healthcare for the Better

It has been suggested that healthcare systems must adapt and profoundly change in their operating model to allow sustainable effective care to their members in view of these basic inadequacies and escalating challenges. One way to navigate rising healthcare demand and exponentially increasing complexity in care and treatment options is to proactively anticipate future demand, risks, and health needs and use this knowledge for better care allocation and patient-centered treatment decisions. The ability to understand the dynamic factors affecting health through data analytics, pattern detection, and prediction is paramount to creating more intelligent healthcare.

Effective and efficient models of care must strive to be proactive and prevention focused rather than reactive and treatment focused; integrated rather than divided into detached care silos; precise and tailored to the specific patient's unique set of characteristics and needs rather than based on average population observations. It is a common wisdom that the smart use of data in healthcare is both a key requisite and driving force to allow such changes to be implemented on a large scale.

The expansion of embedded information technology (IT) systems across healthcare settings provides an increasing wealth of data that can be harnessed through advanced analytics in a systematic transformation to narrow key gaps for the healthcare systems of the future. These include the widespread implementation of electronic health record systems, the availability of health-related data from personal

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[1] Makary M.A., Daniel M., "Medical error—the third leading cause of death in the US," 2016. BMJ 2016;353:i2139; Hogan H., Healey F., Neale G. et al., "Preventable deaths due to problems in care in English acute hospitals: A retrospective case record review study," *BMJ Quality and Safety,* 2012.

[2] Ware M., Mabe M., *The STM Report: An Overview of Scientific and Scholarly Journal Publishing*, 2015, The Hague: International Association of Scientific, Technical and Medical Publishers. Retrieved August 7, 2017 from: https://www.stm-assoc.org/2015_02_20_STM_Report_2015.pdf.

[3] Shanafelt T.D., Hasan O., Dyrbye L., Sinsky C., Satele D., Sloan J.O. et al., "Changes in burnout and satisfaction with work-life balance in physicians and the general US working population between 2011 and 2014," *Mayo Clinic Proceedings,* 2015, 90(12), 1600–1613. Medscape survey of 15,000 physicians. Report accessed at: https://www.medscape.com/slideshow/2018-lifestyle-burnout-depression-6009235?faf=1.

and healthcare devices, and the increasing use of genetic testing which produce massive patient-specific datasets. Continuous improvement in computing power and widespread implementation of AI in other daily domains of life increase the drive to implement similar systems in healthcare as well.

Among many opportunities that data and advanced analytics offer for healthcare advancement there is the potential for preventing complications and improving prognosis (to preempt), supporting patient-focused treatment decision-making (to individualize), integrating patient involvement in navigating their care (to align expectations between patients and providers), and the automation of clinical tasks and service allocation to improve the efficiency and safety of health institutions (to make repetitive technical tasks redundant, reduce errors, and reduce clinical variability).

Multiple advanced data analytics techniques are being increasingly used in academic and commercial innovation platforms to develop data-driven tools for the healthcare setting, from basic algorithms based on straightforward regression statistics to the most complex *machine learning* tools based on multiple layers of artificial neural networks. Indeed, most of the computerized solutions in current clinical practice do not rely on independent computer intelligence, but rather on human-generated algorithms based on expertise and research. Still, in this chapter we will loosely use the term artificial intelligence (AI) to denote the wide range of tools that allow computers to perform tasks just as well as if not better than humans.

The National Health Service in the United Kingdom has outlined the ways AI can and is expected to improve and help transform healthcare by allowing for the prediction of individuals who are at risk for illness to target treatment more effectively toward them; the development of AI diagnostic and treatment decision tools tailored to individual need supporting health professionals and patients; and the automation of clinical tasks and service allocation to improve the efficiency and safety of health institutions.[4]

The potential for improvement is profound. It has been shown, for example, that by combining *deep learning* AI techniques with pathologists' diagnoses for identifying metastatic breast cancer an 85% reduction in the human error rate resulted.[5] Such automated analysis has also been shown to find and match specific lung nodules on chest computed tomography scans nearly twice as fast as a panel of radiologists. The power of AI algorithms to diagnose by means of imaging results has been demonstrated in a study in which the performance of algorithms to identify skin cancers was on par with a panel of 21 experts.[6]

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[4]Harwich E., Laycock K., *Thinking on Its Own: AI in the NHS, 2018*, Reform Research Trust, London, UK.

[5]Wang D., Khosla A., Gargeya R., Irshad H., Beck A.H., "Deep Learning for Identifying Metastatic Breast Cancer," arXiv preprint arXiv:1606.05718, 2016: https://scholar.harvard.edu/humayun/publications/deep-learning-identifying-metastatic-breast-cancer.

[6]Esteva A., Kuprel B., Novoa R.A., Ko J., Swetter S.M., Blau H.M., Thrun S., "Dermatologist-level classification of skin cancer with deep neural network," *Nature,* 2017, 542(7639), 115–118.