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"LIVE FROM THE WOMB"

Historicising the Integration of Artificial Intelligence into Biomedicine

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This article introduces to a history of the integration of artificial intelligence (AI) into biomedicine, based on accounts of AI that were published in journals of biomedical, medical, scientific and engineering communities during the last half century. These accounts were full of promises about the future of each new generation of AI, but, also, assessments of how the preceding generations of AI did not manage to deliver according to what was promised. We read such accounts together in order to capture both a narrative of unbound progress and of failure regarding the use of AI (and computing in general) in virtually all medical specialties and fields. This article contributes to the historiography of AI by retrieving this contrast between a progressivist ideology and a reality defined by limits in the integration of AI into biomedicine.

Introduction

The emphasis on digitalisation that defined the course of computing in the second half of the twentieth century and the first decades of the twenty-first has been inseparable from the contemporaneous drive for biomedicalisation, which aimed to base medicine on the molecularisation of biology.[1] According to an article in the 6 November 1959 issue of *Science*, "barely 10 years" after "the first few computers were successfully operated," no less than "some hundreds of applications of computers [were] being made in the biomedical sciences."[2] For Robert S. Ledley, the article's author—faculty member of the electrical engineering department at George Washington University and principal investigator of the Survey and Monograph on Electronic Computers in Biology and Medicine at the National Academy of Science—"perhaps the greatest utilization of computers will be in biomedical applications."[3] After all, as Ledley argued in detail in the first pages of his article,

1 On the drive for biomedicalisation: Löwy, "Historiography of Biomedicine"; Clarke et al., "Biomedicalization."

2 Ledley, "Digital Electronic Computers," 1225–26.

3 Ledley, "Digital Electronic Computers," 1225. In 1960, Ledley founded the National Biomedical Research Foundation. On Ledley: November, "Early Biomedical Computing."

computer technology and human biology were fully analogous, as the drawing he provided (see figure 1) sought to explain.

"It has been suggested," started Ledley, "that perhaps we are on the threshold of a new era in the history of mankind, arising from the utilization of electronic computing machines . . . that vastly increase man's 'thinking' capabilities, using 'thinking' in the sense of planning, analyzing, computing and controlling."[4] The effects of the new era to be brought about by this thinking machine would be "great," since "not only will its influence be directly marked on the economic, political and social aspects of our civilization, but it will have a tremendous effect in the physical and biomedical sciences as well."[5]

The rhetoric and the materialities involved in the episodes that form the history of the intersection between, supposedly, "thinking" ("intelligent") computers and biomedicine are too rich to be fully addressed here. In this article, we focus on the history of the growing field of biomedical computing, and, specifically, of the integration of artificial intelligence (AI) into biomedicine. According to one of the pioneers in the field, a view in the mid-1980s was that "while AI has just recently become a popular topic, it must be recognized that the field is as old as computing."[6] We seek to capture the dynamics in the research efforts and (possible) uses of AI in biomedicine, broadly conceived. From the early years of the introduction of computing in the fields of biology and medicine, visions of developing "intelligent" systems to assist physicians, to support diagnosis and treatment, and to promote efficiency in the clinical and healthcare domains were put forward. Whether the systems are labelled AI or not, such visions and promises of the expanding use of AI systems have persisted in the medical/scientific literature, the scientific periodicals and the press.

In biomedicine, for instance, the effects of computer-based imaging technologies have been, indeed, tremendous. Being part of visualisation practices in medicine, in the context of the broader visual culture, biomedical imaging technoscientific innovations are expanding.[7] In 2002, an article in The *New York Times* by Dylan Loeb McClain, entitled "Live from the Womb," described equipment that allowed parents to "marvel at how much their child resembles Aunt Alice months before Aunt Alice sees the resemblance for herself".[8] To be sure—as Syed Omar Ishark, vice president of the ultrasound division at G.E. Medical Systems, explained in an interview to McClain—this was "largely a result of the quantum jump in computer

4 Ledley, "Digital Electronic Computers," 1225.

5 Ledley, "Digital Electronic Computers," 1225.

6 Blum, "Artificial intelligence," 5.

7 Joyce, *Magnetic Appeal*.

8 Dylan Loeb McClain, "How It Works; A Somersault! Live From the Womb, a 3-D Performance," *The New York Times*, April 11, 2002, 7.

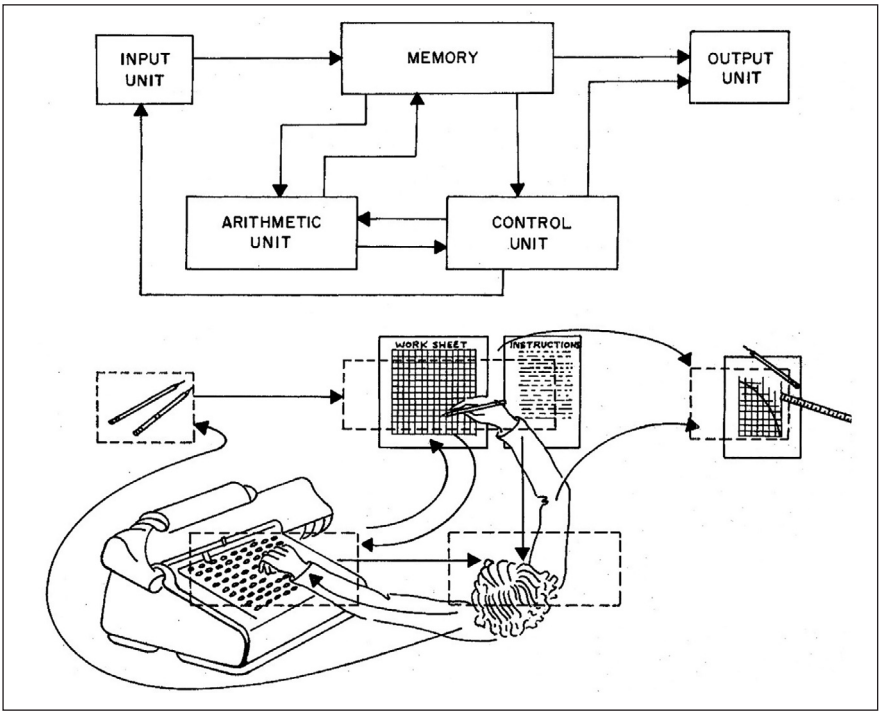

Figure 1. Original caption "Analogy between manual computing and an electronic digital computer. The arrows indicate the flow of information." (Source: Ledley, "Digital Electronic Computers," 1227. Reprinted with permission from the American Association for the Advancement of Science.)

capabilities in recent years," as "the new machine uses faster chips and software that can take advantage of the higher processing speeds."[9] Born in 1996, at least according to *The New York Times*, the "artificial womb" has since been one more technology under constant revolution because of the need to merge it with thinking machines.[10]

In what follows, we highlight the accounts of AI offered in journals of biomedical and related medical, scientific and engineering communities during the last half century. These accounts—written so as to be read by scientists, engineers and physicians—are part of a feedback loop; the work of the main actors in the introduction of AI to biomedicine, as they seek to position (and promote) their own

9 McClain, "How It Works," 7.

10 Perri Klass, "The Artificial Womb is Born," *The New York Times*, September 29, 1996, 117. For an update in 2020: Sahil Gupta, "AI will revolutionize assisted reproductive technology (if we work together)," *Fertility and Sterility Journal*, 1 July 2020, https://www.fertstertdialog.com/posts/ai-will-revolutionize-assisted-reproductive-technology-if-we-work-together.

contribution to the field informs these accounts, while, at the same time, their accounts of the past justify their own work. These actors tend to embed a narrative of the past in a progressivist discourse that includes predictions about the future. In reference to medical computing, Bonnie Kaplan has argued that, in many cases, these accounts seek to "trace developments from one great achievement to another, so that the past is portrayed simply in terms of how it unequivocally led to the present."[11] Regarding the history of computing in general, David Gugerli and Daniela Zetti have argued that accounts written by actors tend to include normative predictions about the future. As such, they are useful as starting research frameworks, but are not without "pitfalls."[12]

One way to avoid the pitfalls of actors' accounts is to historicise and contextualise them.[13] This is exactly what this article seeks to do, following studies that point to lessons to be learned from examining anticipatory discourses about technology,[14] including predictions regarding AI.[15] Furthermore, to corroborate this historicisation and contextualisation, the article introduces available works on the integration of computers in biology and medicine written by professional historians of technology. The article concludes by elaborating on the contrast between a progressivist ideology and a reality defined by limits in the integration of AI into biomedicine.

Historians' Views

In 2011, the historians of computing, Willian Aspray and Jeffrey Yost, remarked that the historical research on the contribution of computing to the biological sciences and medicine has received less attention than the contribution to other scientific fields.[16] A notable exception is the work of Joseph November, who has given us detailed pictures of the early years of biomedical computing, capturing both the ambitions and the tensions among different visions of the computerisation of medicine in the U.S.A.[17] As he notes, computing in biology and medicine was

11 Kaplan, "Computer Prescription."

12 David Gugerli and Daniela Zetti, "Computer history – The pitfalls of past futures," *Preprints Zur Kulturgeschichte Der Technik* 33 (December 2019): 1–26, 6.

13 For an example of how to do this: Tympas, "Perpetually Laborious."

14 Corn, *Imagining Tomorrow*; Messeri and Vertesi, "The greatest missions never flown."

15 Armstrong, Sotala and hÉigeartaigh, "The errors."

16 Aspray and Yost, "New Voices, New Topics." For a historical overview of the development of computing technologies and their adoption in biology and medicine in the U.S.A.: Nebeker, "Golden accomplishments"; Nebeker, "Emergence of Biomedical Engineering."

17 November, *Biomedical Computing*.

viewed as a single entity until the 1970s, when it started to split between bioinformatics and medical informatics. On the institutional side, November introduces to the negotiations for making funding available to introduce computing infrastructure in biomedical research, a great part of which came from the National Institutes of Health.[18]

Kaplan's early article (1995), gave us an account of medical computing through the early 1990s, pointing both to the scientists' technological determinist view of the ways "computers could revolutionize medicine," and, also, to "evidence of cognitive dissonance due to failure to achieve policy goals."[19] In the context of the early computerisation efforts, the use of machines described as "intelligent" was largely associated with the potential of assisting physicians and of processing large quantities of information. Despite early accounts of physicians' and engineers' visions of medical computing, detailed research on the sociocultural practices of the physicians, as well as, on their views on attempts to computerise medicine over time—views, both enthusiastic and cautious—is largely missing.[20] Jeremy Greene and Andrew Lea have identified continuities in the challenges associated with the expanding uses of computing in medicine, focusing on issues of relevance to the connection between Big Data and AI.[21] Lea moved on to argue that even before the first computerisation efforts of the 1950s, "a genealogy of biomedical computing and computerized medicine" should take more seriously the "continuities between computer-based digital practices and paper-based analog ones."[22] Rampton, Böhmer and Winkler, observe that current concerns about medicine and healthcare in the digital era are neither new nor unprecedented.[23] They demonstrate that the physician-patient relationship is historically contingent by focusing on the technological materialities that mediate the clinical encounter in different eras. They argue for the necessity of the insights from the history of medicine in the attempts to interpret the digital present of medicine.

The contextualisation that we propose benefits from a history of AI that moves "beyond canonical histories."[24] As suggested by Simos et al. in this issue, a critical periodisation of the post-war history of AI contains two distinct periods.[25] Compared

18 November, *Biomedical Computing,* 18.

19 Kaplan, "Computer Prescription," 23.

20 November, *Biomedical Computing*, 6. For a sociological analysis, informed by Foucauldian insights, of physicians' discontent with AI systems for clinical decision-making: Hanemaayer, "Don't touch my stuff."

21 Greene and Lea, "Digital Futures Past," 96–98.

22 Lea, "Computerizing Diagnosis," 230.

23 Rampton, Böhmer, and Winkler, "Medical Technologies Past and Present.

24 Bory, Natale, and Trudel, "Artificial Intelligence."

25 Simos, Konstantis, Sakalis, and Tympas, "AI Can Be Analogous to Steam Power'."

to the earlier period—which overlaps with the history of computer mainframes and the early period of home and personal computers—the more recent one—defined by the massive interconnection of computers that resulted in the internet and the web—is marked by explicit references to an AI revolution. In the words of Halpern, Mitchell and Geoghegan, this AI revolution is overwhelmed by a generalised "smartness mandate."[26] As AI historian Colin Garvey recently put it, AI represents "an epochal technology now colonizing an increasing number of domains," that "may soon become ubiquitous, coextensive with technological civilization itself: a taken-for-granted feature of modernity like running water or electricity."[27]

The historical works discussed in this section provide us with a critical lens to interpret the primary sources, in the section that follows. The pursuit of the integration of AI into biomedicine, as it is exemplified in the sources we took into consideration, confirms that this is a history of ambitions and tensions.

"Largely Curiosities": Integrating AI into Biomedicine

Our primary sources in this section are publicly available articles, published in a range of publications, from specialised biomedicine and computing journals to influential general science journals and newspapers.[28] More specifically, we examined closely the leading science news journals *Nature, Science, Scientific American*. We identified additional primary sources through cross-referencing and the snowball method, as well as through detailed examination of biomedical computing journals like *Artificial Intelligence in Medicine* and *Journal of the American Medical Informatics Association*. We supplemented our material with articles from widely circulating international newspapers, *The New York Times* and the *Guardian*.[29] After removing

26 Halpern, Mitchell, and Geoghegan, "The Smartness Mandate."

27 Garvey, "Unsavory medicine," 1.

28 On the importance of studying such sources: Aspray and Beaver, "Marketing the Monster;" Martin, "Myth of the Awesome Thinking Machine"; Dietterich and Horvitz, "Rise of concerns about AI"; Carbonell, Sánchez-Esguevillas, and Carro, "The role of metaphors"; Ethan Fast, and Eric Horvitz, "Long-Term Trends in the Public Perception of Artificial Intelligence," *AAAI '17: Proceedings of the Thirty-First AAAI Conference on Artificial Intelligence* (February 2017): 963-69; Natale and Ballatore, "Imagining the Thinking Machine"; Yarden Katz, "Manufacturing an Artificial Intelligence Revolution," SSRN, 27 November 2017, https://ssrn.com/abstract=3078224; Ching-Hua Chuan, Wan-Hsiu Sunny Tsai, and Su Yeon ChoChuan, "Framing Artificial Intelligence in American Newspapers," *AIES '19: Proceedings of the 2019 AAAI/ACM Conference on AI, Ethics, and Society* (2019): 339–44; Garvey and Maskal, "Sentiment Analysis; Roberge, Senneville, and Morin, "How to Translate Artificial Intelligence?"; Sun, Zhai, Shen, and Chen, "Newspaper coverage of artificial intelligence."

29 The basic keywords were "computers AND medicine," "big data AND medicine," "algorithms AND medicine," and "AI AND medicine."

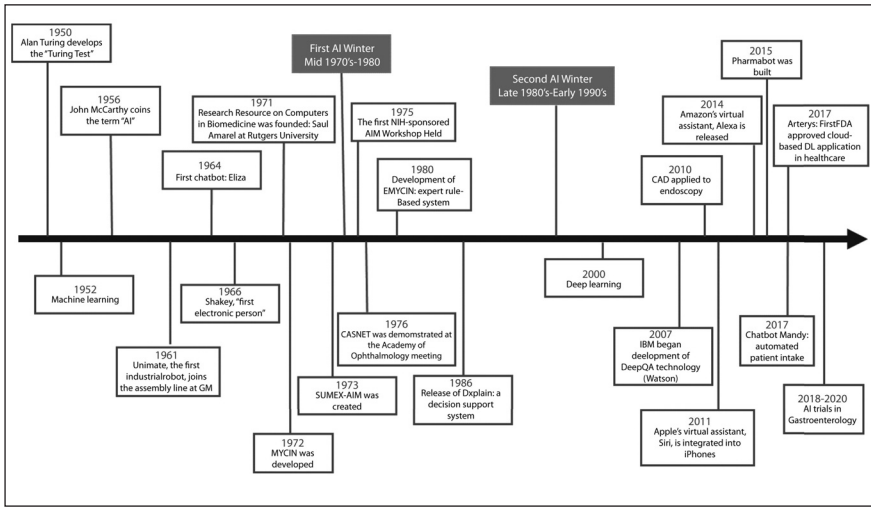

Figure 2. Original caption: "Timeline of the development and use of AI in medicine." (Source: Kaul, Enslin, and Gross, "History," 808. Reprinted with permission from Elsevier.)

duplicates and irrelevant results, we kept 296 articles from journals and periodicals, and 47 articles from the newspapers. We selected 111 and 34 respectively for detailed examination.[30]

The explicit references to an AI revolution in the second period under consideration came along with an intense interest in accounts of the history of the integration of AI in biomedicine that were published in biomedical and related journals. Suggestively, a search in PubMed using the keywords "AI AND history," returned 316 results, 286 of which were published from 2017 to March 2021, including papers on medicine and biology in general, as well as about specialised fields, spanning from dentistry and orthopaedics to neuroscience and assisted reproduction.[31] A good example of this intense interest is offered by a recent historical review by physicians that included a timeline on the history of the intersection of AI and biomedicine from 1950 to 2020 (see figure 2).

According to Kaul, Enslin, and Gross, authors of this recent review, after an early period of AI in medicine (1950s to 1970s), a longer period referred to as the "AI Winter" (1970s to 2000s) followed. This was a "period of reduced funding and interest and subsequently fewer significant developments."[32] This longer period can

30 In doing so, we used articles on the history of AI focusing on analysis of all kinds of printed media. See above, footnote 28.

31 The search was performed in 26 March 2021, with both keywords "AI" AND "History" having to appear in the title or the abstract.

32 Kaul, Enslin, and Gross, "History of Artificial Intelligence in Medicine," 808.

be divided in two shorter "winters" as depicted in the timeline (the first in the late 1970s, and the second in the late 1980s). Then, "[b]y the late 1990s, interest in ML[machine learning] was renewed, particularly in the medical world, which along with the above technological developments [meaning the decision-support systems developed during the "AI Winter"] set the stage for the modern era of AIM [artificial intelligence in medicine]."[33] In this third "boom," AI, being once again a "promising technology" according to Garvey,[34] "is likely to transform the biomedical world" as stated in a special report published in *Scientific American* in January 2020.[35]

Actors' accounts of the integration of AI into biomedicine appear from early on. Already in 1959, Ledley referred to a past of uses of "thinking machines" in this field. Detailed accounts devoted to the subject started to appear by the early 1980s, authored by practitioners in the field of biomedical computing, who sought to consolidate the emerging discipline of "medical informatics."[36] In his 1986 account, biomedical engineer Bruce Blum referred to the 1950s as "primarily a decade of experimentation with new equipment and concepts."[37] According to a 1986 account by the engineer and physician Morris Collen, computing technologies—mainframes at that time—were to be gradually adopted in biology and medicine, for research purposes. In the early 1960s, research endeavours grew, for instance with the development of the special-purpose Laboratory Instrument Computer (LINC).[38] For Blum, in the 1970s, computing capabilities grew with "commercialized multiprogramming, data base technologies and interactive computing."[39]

Throughout the 1960s and 1970s, uses of biomedical computing expanded, both in research and in patient administration and healthcare. In the context of the latter, electronic computers began to be used in hospital administration, while patient records started to be digitised and stored in databases. For Collen, "[u]ndoubtedly the broadest engineering applications of informatics to medicine have been in diffusing information systems into hospitals, clinics and their clinical support and

33 Kaul, Enslin and Gross, "History of Artificial Intelligence in Medicine," 809.

34 Garvey, "Broken Promises and Empty Threats."

35 "Innovations In: AI and Digital Health," *Scientific American*, 14 January 2020, https://www.scientificamerican.com/custom-media/innovations-in-ai-and-digital-health/.

36 Their output included stand-alone articles, special issues, conference proceedings and edited volumes. For instance, Shortliffe, Buchanan, and Feigenbaum, "Knowledge engineering for medical decision making"; Shortliffe and Clancey, *Readings in Medical Artificial Intelligence*; Blum and Duncan, *A History of Medical Informatics*. For the coinage of the term "medical informatics": Collen and Shortliffe, "Creation of a New Discipline."

37 Blum, "Artificial," 8.

38 Collen, "Origins of Medical Informatics," 780.

39 Blum, "Artificial," 8.

ancillary services."[40] Sustained computerising efforts in the U.S.A. took place at the National Library of Medicine, which digitised bibliographic material and developed its Medical Literature Analysis and Retrieval System (MEDLARS). In 1971, MEDLINE (MEDLARS on line) was instituted, which Collen described as "a monumental contribution to computerized medical literature retrieval."[41] According to Harold Schoolman and David Lindberg, pioneers in medical computing at the National Library of Medicine, the aim was to support "research in information management—medical informatics—to try to make as rapid as possible the applications at the bedside of the results from the research laboratories."[42] At the same time, as they explained, specific efforts were directed at exploring the use of computerised systems in medical education.[43]

In research projects in medical AI, the focus was on using AI to computerise medical decision-making. According to a 1984 account by Edward Shortliffe and William Clancey—biomedical computing and AI research pioneers, based at Stanford University—the research efforts in the 1960s

> emphasized the use of the computer to deal with probabilistic information, to recognize patterns using numerical techniques, to model physiological processes that were amenable to mathematical simulation, or to encode algorithmic approaches to routine clinical chores. The [medical AI] field was then in its first decade as an identifiable area of research, and the emphasis was on how to get machines to make decisions that were both accurate and reliable.[44]

A vast array of research projects was undertaken in pursuit of what was then called "expert systems," in which "medical AI researchers [were] helping to formalize medical knowledge".[45] Examples of efforts in computer-aided diagnosis include the MYCIN program for infectious disease diagnosis and therapy, the CASNET consultation program for the diagnosis and long-term treatment of the glaucoma, the INTERNIST system assisting with test selection for the diagnosis of all diseases in internal medicine, and the Present Illness Program (PIP) that aimed at information gathering and diagnosis for oedema.[46]

40 Collen, "Origins of Medical Informatics," 783.

41 Collen, "Origins of Medical Informatics," 781.

42 Schoolman and Lindberg, "The Information Age," 124.

43 Schoolman and Lindberg, "The Information Age," 121–22.

44 Shortliffe and Clancey, "Anticipating the Second Decade," 465.

45 Clancey and Shortliffe, "Introduction," 3.

46 Clancey and Shortliffe, "Introduction"; Miller, "Medical Diagnostic Decision Support Systems."

The development of such systems and their possible uses were described by Clancey and Shortliffe:

> As early efforts, they are prototypes directed at two questions: What are the issues involved in designing a consultation program (e.g., what would make such a program acceptable to physician users)? What is the nature of the expertise to be formalized (e.g., how can factual and judgmental knowledge be integrated)?[47]

According to Collen, "[a]lthough sometimes achieving excellent diagnostic performance," these research projects "were constrained in scope and not sufficiently consistent with traditional clinical practice to be accepted by clinicians."[48] For Collen, it was in the 1970s that "approaches more closely emulating the usual clinical decision-making process were sought and artificial intelligence methods began to be used for differential diagnosis and specialty medical consultation."[49] Accounts of the 1980s held that "[m]edical artificial intelligence is primarily concerned with the construction of AI programs that perform diagnosis and make therapy recommendations,"[50] or, in other words, "the use of expert systems to process medical knowledge."[51]

According to Collen, the principal funding source for introducing biomedical computing and undertaking research projects in the U.S.A. was government grants and contracts, mainly from the National Institutes of Health.[52] These funds were funnelled to the building of computing infrastructure in universities and research centres, as well as in some hospitals, where the research endeavours flourished.[53] An exceptional case was the research undertaken at Stanford University, which led, in 1973, to the development of the Stanford University Medical Experimental Computer-Artificial Intelligence in Medicine (SUMEX-AIM) network. Stanford was one of the four American AI in medicine research centres, along with MIT, Rutgers, and the University of Pittsburgh.[54] The SUMEX-AIM, a "national resource," exploited ARPANET's networking capabilities and provided access to processing power to related projects (at and outside Stanford).[55]

47 Clancey and Shortliffe, "Introduction," 2.

48 Collen, "Origins of Medical Informatics," 783.

49 Collen, "Origins of Medical Informatics," 783.

50 Clancey and Shortliffe, "Introduction," 2.

51 Blum, "Artificial," 5.

52 Collen, "Origins of Medical Informatics," 783.

53 Clancey and Shortliffe, "Introduction," 3.

54 Shortliffe, "The adolescence of AI in Medicine," 94.

55 For the history of biomedical computing in Stanford University: November, *Biomedical Computing*, 220–68.

As mentioned above, many research projects were launched in the 1980s. They did not, however, advance at the pace anticipated. According to a 1986 article by Reed Gardner—medical informatics pioneer at the University of Utah—while the "aura of AI magic has taken over as the hottest technology breakthrough since genetic engineering," "[s]uccessful applications of AI in medicine represent only a handful of projects which deal with relatively simple and mundane tasks, not the glamorous and life saving variety."[56] Gardner moved on to argue that "AI applications in general and for medicine in particular have been neither widely accepted nor applied."[57]

In a similar vein, in 1990, Robert Greenes and Shortliffe claimed that "despite years of research and development, computer-based aids for diagnosis and treatment still remain largely curiosities and demonstration projects, rather than tools for routine use."[58] Also in 1990, Randolph Miller and Fred Masarie—medical informatics experts at the University of Pittsburgh—argued that the limited adoption of medical diagnostic systems was due to their being based on the "monolithic, paternalistic Greek Oracle model."[59] In their view, such an authoritative model was not acceptable to physicians; thus, they pursued a system in which the "physician-user and the consultant program should interact symbiotically."[60]

In 1996, in light of views like the ones above, Enrico Coiera, an expert in medical informatics, then based at the Hewlett-Packard Research Laboratories in Bristol, U.K., argued that AI in medicine "was not successful—if success is judged as making an impact on the practice of medicine."[61] He moved on to explain why by noting that "despite the emphasis of much early research on understanding and supporting the clinical encounter, expert systems today are more likely to be used in laboratories and educational settings, for clinical surveillance, or in data-rich areas like intensive-care setting."[62]

For Miller, by the late 1980s and certainly by the 1990s, the commonplace use of computers reinforced research on medical decision-making systems "to improve the performances of both the user and the machine over their native (unassisted) states."[63] A multitude of ongoing, at that time, projects included general-purpose, broad-spectrum consultation systems both for general diagnosis and for specialised domains

56 Gardner, "Artificial intelligence in medicine," 133.

57 Gardner, "Artificial intelligence in medicine," 133–34.

58 Greenes and Shortliffe, "Medical Informatics," 1116.

59 Miller and Masarie, "The Demise of the 'Greek Oracle'," 1.

60 Miller and Masarie, "The Demise of the 'Greek Oracle'," 1–2.

61 Coiera, "Artificial Intelligence in Medicine," 364.

62 Coiera, "Artificial Intelligence in Medicine," 363.

63 Miller, "Medical Diagnostic Decision Support Systems," 14.

(for instance, in the interpretation of electrocardiographs).[64] Against these views, Collen thought that the adoption of new diagnostic technologies based on computing, such as computed tomography (CT), did have an impact on medical practice.[65]

European researchers meanwhile were working on integrating artificial intelligence into biomedicine as early as the 1980s, developing medical knowledge-based systems to advance the use of computing in healthcare.[66] Since 1985, a biannual conference on AI in medicine has been organised in Europe. According to a review of the conference contributions during its first 30 years (1985–2015), the main research themes—at least from the mid-1980s to the mid-1990s—concerned computer aided medicine, decision models and medical records, followed in the next years by an additional focus on telemedicine, and, after 2000, a further focus on machine learning, natural language processing, and deep learning.[67]

A good indication of these growing research efforts is the launch of the journal *Artificial Intelligence in Medicine* in 1989, amidst a period marking the beginning of the second "AI Winter." According to its first editorial, the journal would serve as an international forum for interdisciplinary studies in medical AI, "a useful aid that might help physicians utilize available scientific knowledge and thereby enhance their expert performance for the patient's and society's good."[68] The American Medical Informatics Association—established in 1988 by bringing together previously active organisations in medical informatics—launched in 1994 the journal *JAMIA (Journal of the American Medical Informatics Association)*.[69]

As the field grew, Shortliffe argued in 2009 that an important issue regarding the possible impact of AI in medicine is that it would

> depend on the development of integrated environments that allow the merging of knowledge-based tools with other applications. The notion of stand-alone consultation systems had been well debunked by the late 1980s, and thus we must be looking for ways to combine 'backend' AI notions with such ubiquitous systems as electronic medical records, provider order-entry systems,

64 Miller, "Medical Diagnostic Decision Support Systems," 14-15.

65 Collen, "Origins of Medical Informatics," 783.

66 Stefanelli, "European research efforts." According to Stefanelli, the research projects focusing on AI in medicine were mainly funded by the Commission of the European Communities, through different Research and Development Programmes. Their aim was that "users and consumers, the health care professionals and the citizen, could benefit from services similar to those that informatics and communications technology offers in other sectors such as transportation, banking, and distribution." ("European research efforts," 119).

67 Peek et al., "Thirty Years."

68 Sadegh-Zadeh, "Machine over mind," 3.

69 Shortliffe, "Dehumanization of Patient Care."

> results reporting systems, e-prescribing systems, or (on the biological side) tools for genomic/proteomic data management and analysis. This reality creates challenges for researchers, because the implication is that we need breadth of knowledge and collaborations that go beyond our immediate AI roots.[70]

He also claimed that "although AI issues are ubiquitous in biomedicine, many people who are doing AIM [artificial intelligence in medicine] research do not label it as AI." What, to him, "was once a catchy, respected label has lost much of its luster—a casualty of AI winter and the general societal sense that AI had somehow over-promised and failed to deliver."[71]

Optimism and enthusiastic accounts did not, in fact, disappear. In the following decade, AI would be discussed as "bringing a paradigm shift to healthcare, powered by increasing availability of healthcare data and rapid progress of analytics techniques."[72] The interdisciplinary team of authors of this review, published in the journal *Stroke and Vascular Neurology*, referred to the recent past of AI, and, namely, only to its "boom" after the 2000s. For Kaul, Enslin, and Gross, the authors of the 2020 timeline of AI in Medicine (figure 2), the "modern era" came with a series of advancements: IBM's open-domain question-answering system, named Watson; natural language processing resulting in chatbots and automated patient intake process; deep learning research in image processing and diagnosis.[73]

In a 2018 article in *Nature Digital Health*, Alexander Fogel, from the Yale School of Medicine, and Joseph Kvedar, from the Harvard Medical School—physicians specialising in digital health—argued that "previously, machine-driven predictions relied on algorithms designed to extract specific features provided by a human expert," while now a machine "collects more data" so that "it can continue to improve its predictions."[74] They further suggested that "current AI creates an uncomfortable situation for physicians and patients: we cannot tell which features the machine uses to generate its predictions," it's a "black box."[75]

Conclusion

We started this article with Ledley's 1959 *Science* account and predictions, according to which "perhaps the greatest utilization of computers will be in biomedical

70 Patel et al., "Coming of Age," 6 (Comments by Edward H. Shortliffe).

71 Patel et al., "Coming of Age," 7 (Comments by Edward H. Shortliffe).

72 Fei Jiang et al., "Artificial Intelligence in Healthcare."

73 Kaul et al., "History," 809.

74 Fogel and Kvedar, "Artificial Intelligence Powers Digital Medicine."

75 Fogel and Kvedar, "Artificial Intelligence Powers Digital Medicine," 1.

applications."[76] Six decades later, in 2019, Shortliffe, a key actor in medical AI, remarked, "that what we embrace today did not suddenly appear from a commercial company but was the result of decades of research, typically with slow progress and a visionary set of scientists and government funding agencies who advanced the field."[77] In a review of AI research efforts over the last 50 years, published in the *Yearbook of Medical Informatics* of the International Medical Informatics Association, he noted that "some fear that AI could worsen health disparities, and some argue that AI is simply being overhyped and has a long way to go." Indeed, between 1959 and 2019, each new generation of actors sought to promote its own contribution by offering accounts and predictions that pointed to what the previous generation of AI did not manage to deliver. These accounts served the growth of the field of (bio)medical informatics by entrenching a progressivist ideology. While assessing the failing promises, we agree with Kaplan, that such accounts "present developments as shaped by factors outside the control of those doing research and development."[78]

This contrast between a progressivist ideology and the reality of undelivered (broken) promises becomes apparent in the view held by the actors of the physicians' "acceptance" as external to the development of AI technologies. In 1969, John Mayne—a physician in Mayo Clinic—argued in the *Editorial* of the *Annals of Internal Medicine*, that

> A symbiosis that would unite the memory and processing speed of computers with the judgment and "pattern recognition" ability of physicians—making more available the human qualities of respect, concern, sympathy, and understanding that characterize the physician—would be a significant step in reducing some current health-care problems.[79]

For Mayne, it was "up to physicians to decide" on the role of computers, not computer scientists.[80] The passive role of physicians and clinicians, obvious in the accounts of the field's past presented until the early 1990s, is contradicted by the active role envisaged in other enthusiastic accounts about the future of biomedical computing. Physicians were reportedly reluctant to use early computer-aided diagnostic systems. According, for example, to a 2010 *Scientific American* article, for "these programs to gain wider use they must supplement human expertise, not

76 Ledley, "Digital," 1225.

77 Shortliffe, "Artificial Intelligence in Medicine," 260.

78 Kaplan, "The Computer Prescription," 28.

79 Mayne, "Computers in Medicine," 642.

80 Mayne, "Computers in Medicine," 642.

replace it."[81] Nonetheless, the "fear" has remained that AI "will overtake jobs and disrupt the physician–patient relationship."[82] From the mid-1990s, AI endeavours sought a more "symbiotic relationship" through interaction and collaboration of interested parties. At the same time, digitalised data and computing infrastructure were already in place in many domains of the healthcare systems. These contributed to the recent boom of AI in medicine.

This article has introduced to a history of the integration of AI into biomedicine, based on actors' accounts of AI that were published in journals of biomedical, medical, scientific and engineering communities during the last half century. Central to our aim has been the suggestion to treat with caution the enthusiasm and progressivism that accompanied these accounts. This is crucially important for a critical reconstruction of the history of the integration of AI into biomedicine. At the same time that AI seems to still have a promising potential in medicine, it has become mundane in certain biomedical domains. We attempted to demonstrate that the complexities apparent in the past efforts to integrate AI in biomedicine remain relevant to the current challenges identified in the biomedical literature, the scientific periodicals and the press. We proposed a possible way to historicise the relations between AI and biomedicine, while we pointed to the need of nuanced historical studies to contextualise further these relations in reference to the historical transformations in biomedicine and computing.[83]

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81 Allison Bond, "Reality Checkup: Medical Artificial Intelligence Still a Hard Sell in the Clinic," *Scientific American*, January 12, 2010. https://www.scientificamerican.com/article/artificial-intelligence-medical-tests-software-diagnosis/

82 Fogel and Kvedar, "Artificial Intelligence Powers Digital Medicine."

83 In this direction: Greene and Lea "Digital Futures Past"; Rampton, Böhmer, and Winkler, "Medical Technologies Past and Present."

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