Special Article

Digital Health

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Abstract:

Digital health is a contemporary term that is used in attempts to encompass the terms *eHealth, mHealth,* and *telehealth* in taxonomy. In this context, digital health depends heavily upon the development of artificial intelligence (AI) technology. There are many challenging problems that need smart solutions, such as self-learning for streaming data, and collaborative AI among machines and human AI planning. People involved in some aspects of digital health and precision medicine must prepare themselves to face this new era of AI technology.

Keywords: digital health, precision medicine, artificial intelligence

Digital health[1] is the convergence of digital technologies with health to enhance the efficacy of health-care delivery and to make medicine more precise. In the near future, digital technology will change the way physicians deliver care. The questions are: how much can it do and when? In essence, artificial intelligence[2] takes the principle role in digital technology to reshape the perspectives of medicine for improving human clinical capabilities in drug discovery, epidemiology, precision medicine, operational efficiency and diagnosis.

Regarding "artificial intelligence", the word signifies the ability to solve certain complex problems in a way that the human brain could not do but the machine can, where multiple interfaces are utilized to create a "smart" system. The principal aim is to develop and to deploy safe, effective AI applications into practice for safe data-driven technology in health and care, such as the expertise ranging in applications from accident and emergency (A&E) triage to image diagnostics in radiology and development of mortality and sepsis algorithms. Currently, diagnosis regarding biochemical tests, hematological examination and radiological examination, for examples, are already based on digital technology.

One of the applications (apps) under development is a medical diagnostic tool, such as the example shown in Fig.1. Never before has there been a way to view and interact with AI results, for reading workflow to become smarter and more efficient. Now, it is an AI content-enabled medical imaging console which stands to revolutionize the way physicians incorporate the galaxy of third party AI machines into their reading workflows.[2]

Figure 1. Brain MRI on digital tablet. From: https://focusedcollection.com/227259484/stock-photo-doctor-looking-brain-mri-scan.html (cover page)

Apps on therapy are variable, such as robot doctors[3] (Fig.2), artificial pancreas[4] (Fig.3), medical micro/nanorobots[5] (Fig.4), CRISPR gene editing.[6] Advancements in medical technology are creating a world where robots may play a bigger part in healing the ill than doctors. Fifteen medical robots are changing the world. Xiaoyi, China's "Little

Doctor," became the first artificial intelligence robot to pass the China's medical licensing exam. Although the machine showed ability to learn, reason and make judgments by itself, there is a long way to go before Xiaoyi could practice independently.

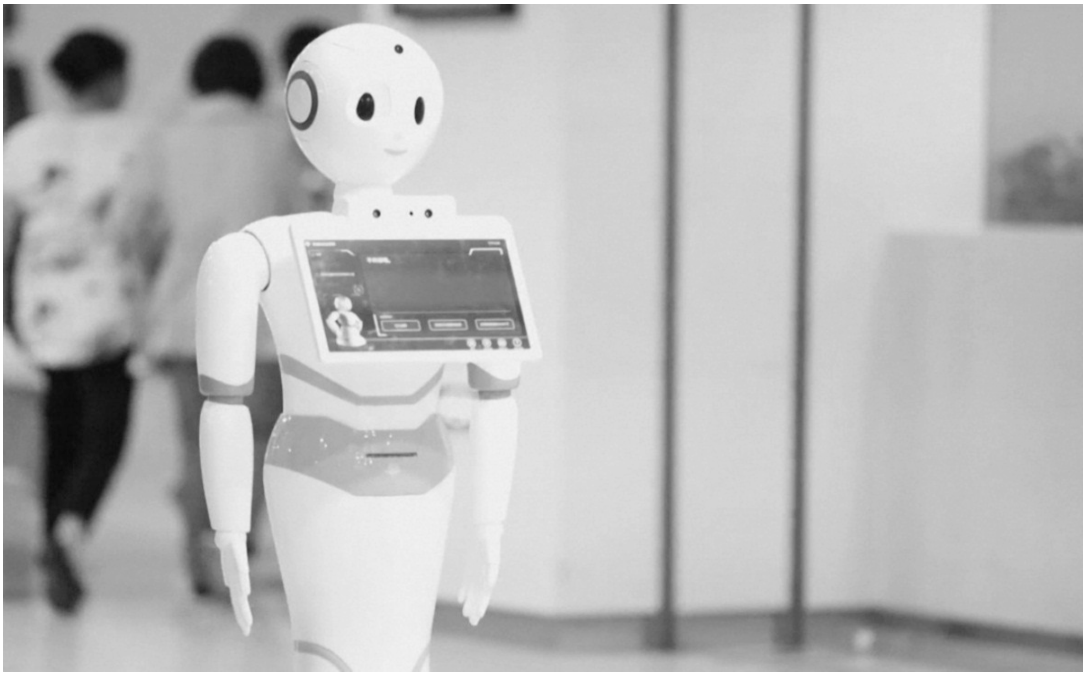

Figure 2. Xiaoyi, China's "Little Doctor" had to demonstrate more than a capacity for rote learning to get through the medical licensing exam. (cover page)

Treatment of certain cases of diabetic patients may be more comfortable than formerly. As regards the " Artificial Pancreas," currently affordable cases of type 1- diabetic patients could implant a tiny silicon transistor device under the skin to work in place of the natural pancreas (Fig. 3).[2]

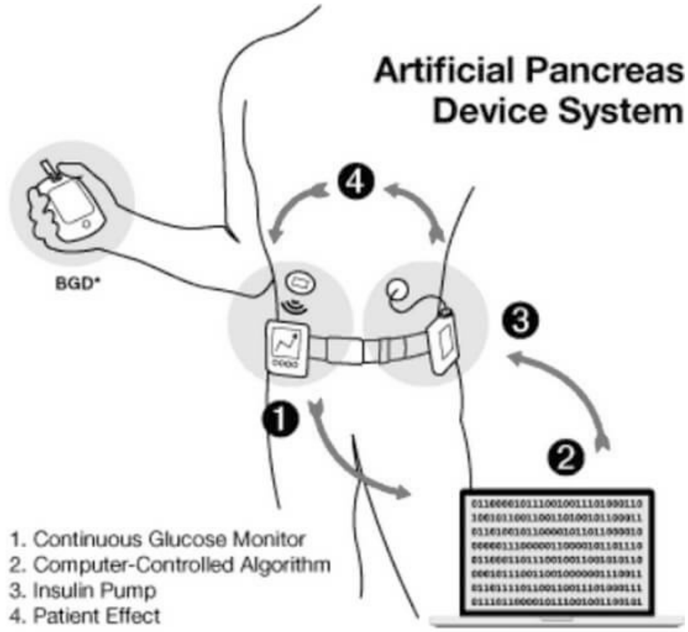

Figure 3. Artificial pancreas From: http://www.fda.gov/MedicalDevices/Productsand Medical Procedures/HomeHealthandConsumer/ConsumerProducts/ArtificialPancreas/ucm259548.htm (cover page)

The field of medical micro/nanorobotics holds considerable promise for advancing medical diagnosis and treatment due to their unique ability to move and perform complex tasks at small scales. The term medical micro/nanorobots refers to all nano-to-micron-size structures (300 nm-300 mcm) capable of converting power sources into kinetic energy. Nanorobots are devices ranging in size from 0.1 to 10 micrometers that are composed of nanoscale or molecular components. These devices (Fig. 4) can be injected into patients to perform diagnosis or treatment on a cellular level. Recent engineering breakthroughs have led to the successful *in vivo* operation of medical micro/nanorobots. Antibacterial nanorobots are tiny machines made of gold nanowires and coated with platelets and white blood cells that can clear bacterial infections directly from patients' blood, basically mimicking a bacterium as the target, then ensnaring them in their nanowire mesh when the bacterium gets near. The clearance process can even be sped up through a patient's body with targeted ultrasounds. Nanorobots can potentially be used in place of broad-spectrum antibiotics in the fight against the rise of antibiotic-resistant diseases. Also, potential uses for nanorobots in medicine include targeted drug delivery for cancer, biomedical instrumentation, surgery, pharmacokinetics, monitoring of diabetes, and health care.

Micro/nanorobots have been used to deliver stem cells to a damaged location for tissue restoration. These applications demonstrate that micro/nanorobots could serve as platforms for regenerative medicine and cell-based therapy, especially useful in the later stages of life, when organs and systems start to fail. Moreover, other applications to be developed include using helical structure to guide a sperm toward an egg for assisted fertilization. It is conceivable that micro/nanorobotics will soon play a prominent role in medicine.

AI in Digital Health and Precision Medicine

Artificial Intelligence refers to the study of how to make a computer, a digital device, look intelligent from a human perspective. Before discussing the concept and how AI solves the problems in digital health and precision medicine in general, it is necessary to dissect the hardware of a computer to see exactly what is inside the machine to make it possible for it to look intelligent. The hardware components consist of three basic logic gates: the AND gate, OR gate, and NOT gate. These gates involve the implementation of the Boolean logic concept. For the 2-input AND gate, suppose these inputs are named *a* and *b* and their values can be only true (T) or false (F). For the AND gate, the output of the AND gate is true if the following conditions: a = T, b = T. Otherwise, the output of the AND gate is false. For the OR gate, the output of the OR gate is true if the

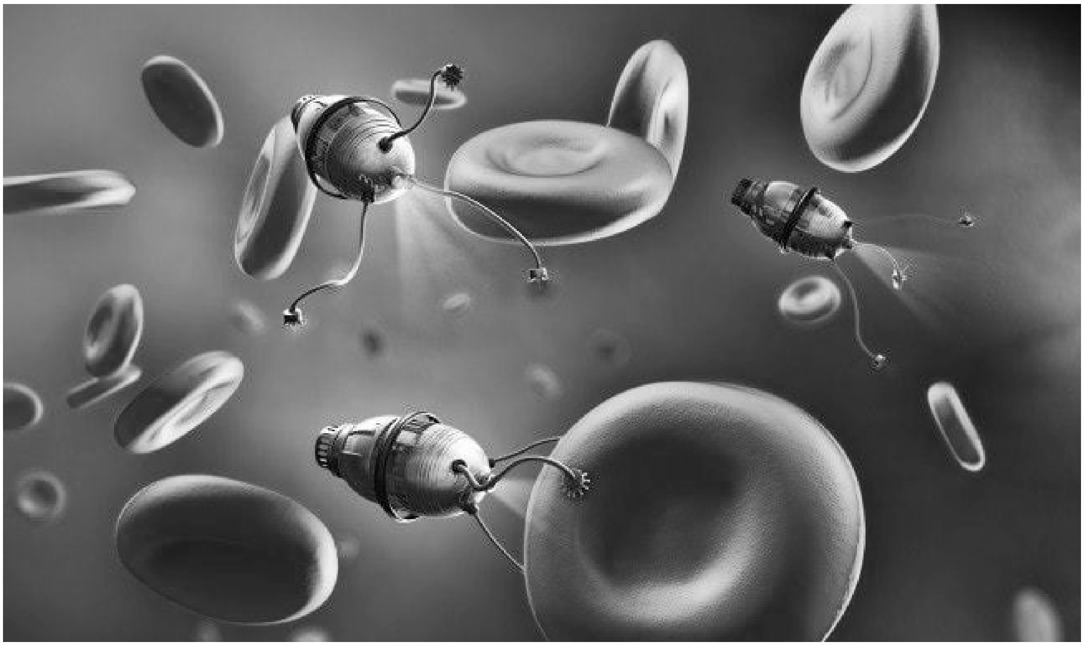

Figure 4. Nanorobot at work. From: <en.wikipedia.org>wiki> Nanorobotics. From: http://triotree.com/blog/nanorobots-introduction-and-its-medical-applications/ (cover page)

following conditions apply: (1) a = T, b = F; (2) a = F, b= T; (3) a = T, b = T. Otherwise, the output of the OR gate is false. For the NOT gate, there is only one input and output. If the input is true, then the output is false. If the input is false, then the output is true.

From the operations of the AND, OR, and NOT gates, it is obvious that a computer classifies the inputs data into two classes, either class *true* or class *false*. For the example of the AND gate, class *true* has one input datum of (a = T, b = T) and class *false* has three input data of (a = T, b = F); (a = F, b = T); (a = F, b = F). Based on this observation, any problems in digital health and precision medicine can be solved by any computer if those problems are transformable to classification problems. Once the problem is transformed into the problem of classification, some efficient algorithms to solve the problem must be developed. These classification algorithms make the machine look intelligent from the human perspective, which is called *artificial intelligence*.

There are various ways to classify a set of data according to the properties, features, or characteristics of the data. For example, the features of a patient may be his/her temperature, weight, height, blood pressure, size of waist, and symptoms measured in numeric form. Each class has a specific set of feature values. Two of the simplest approaches to classify features are by (1) tree search and (2) rule-based filtering. For tree search, the value of each feature is checked one at a time with a predefined threshold value of each class until reaching the last feature to predict the class. Playing the game Tic-Tac-Toe (Xs and Os) is a good example of tree search. A computer generates all possible answers in each move and evaluates each answer as a score. It then selects the best answer of the current move and, from this best answer, it generates the next possible answers in the next move in advance. This process is iterated until no more moves exist. The computer can gain the potential to win the game by traversing this search tree. For rule-based filtering, the approach is similar to tree search but several conditions are formed by simultaneously considering the values of features defined in terms of logic statements by using AND, OR, NOT as the conjunctions. A correct class is determined if the values of all features according to a pre-defined rule of the class is tested *true*. For example, suppose the goal is to determine whether a considered object is a box or not by testing its features of orthogonality of the dimensions, width, height, and length. The rule for this example should be:

If width > 0 *and* height > 0 *and* length > 0 *and* all dimensions are orthogonal **then** the object is a box.

To make the testing conditions more versatile to a real situation, some fuzzy words such as "very hot", or "rather chubby", can be included and transformed into a numeric value by using a membership function, such as the study of applying fuzzy rule-based classification to assess coronary artery disease.[9]

Although tree search and rule-based approaches are rather practical and understandable for several applications, there are other complex problems in digital health and precision medicine which cannot be efficiently solved by these methods, for example, locating a cataract from an optical image[10] or finding pattern of genes in microarray data.[11] The most efficient AI method to cope with these complex problems is a neural network. A neural network is a set of neurons connected in the form of network. Each neuron is a mathematical function imitating the activity of a neuron based on the model proposed by McCulloch and Pitts.[12]

The original McCulloch and Pitts (MP) model tried to answer two fundamental questions, namely (1) when will a neuron fire a signal to other connected neurons, and (2) how does a neuron learn? Their proposed model is similar to threshold logic.

A neuron acts as a classifier by using either a linear or non-linear function which makes it very versatile for any complex problems.

Many neural network models have been proposed during the past 40 years. Each later model improves on the previous models in terms of learning speed, classification accuracy, and number of neurons. However, the most current neural network models work under the assumption that all training data sets must be stored inside the computer memory during the learning process. If new data exist to be learned, then the new data must be combined with the previous training data and the learning process must be restarted. This circumstance increases the complexity of learning time. Furthermore, some models have no plasticity to adjust the structure of the neural network by either adding more neurons or eliminating some redundant neurons during the learning process. These neural models cannot be used in a big data environment where the data keep increasing and overflow the computer memory.

Recently, some new neural models have been proposed to cope with tremendous and streaming data volume.[13, 14] The models deploy the concept of discard-after-learning to learn chunks of streaming data in order to solve the problem of memory overflow and to include plasticity within the network. Each incoming chunk of data is completely discarded from the learning process after being learned.

Endnote: Remarks on the definitions of digital health vs. electronic health:

Digital health[1] is the use of information and communication technologies (ICT) to treat patients, conduct research, educate healthcare professionals, track diseases, and monitor public health. The practice is solely achieved by machine for materialistic results. The term *e-health,*[15] a relatively recent health-care practice supported by electronic processes and communication dating back to at least 1999, obtaining from the use of information and communication technology in health-care, encompasses a range of applications, including telemedicine, electronic health records, clinical decision support systems, mobile health applications, computerized physician order entry, electronic prescribing systems and web-based health services.

References and documents using for editing the paper:

1. Digital health – Wikipedia. From: https://en.wikipedia.org/wiki/Digital_health. Accessed 19/1/2020.
2. Senanarong V, Luasinsap Ch, Bovornkitti S. Artificial intelligence and precision medicine. Thammasat Med J 2018; 18: 687-94.
3. Hussain W, Goddard A, Joshi I. AI and healthcare. Commentary December 2019: pp. 10-11.
4. Himathongkam T, Luasinsap Ch, Bovornkitti S. Artificial pancreas and diabetes mellitus. Buddhachinaraj Med J 2016; 33: 152-5.
5. Soto F, Chrostowski R. Frontiers of Medical Micro/Nanorobotics: *in vivo* Applications and Commercialization Perspectives Toward Clinical Uses. From:https://www.frontiersin.org/articles/10.3389/fbioe.2018.00170/full. [Cited Mar 19, 2020]
6. Bovornkitti S. Further on CRISPR gene editing. Thamasat Med J 2020; 20: in print.
7. Dileep G. Imagine a robot capable of treating Ebola patients or cleaning up nuclear waste. From: http://www.weforum.org/agenda/2016/01/no-the-robots-are-not-about-to-rise-up-and-d... Accessed 1/30/2016
8. Northstar AI Explorer. What is a content-enabled medical imaging console? From: https://www.terarecon.com/north-star?gold=EAIalQobChMiiMuXqICQ5wl-VDA4rCh0KrQGBEAAYBCAAEgKtavD_BwE. [Cited Mar 19, 2020]
9. Mohammadpour RA, Abedi SM, Bagheri S, Ghaemian A. Fuzzy rule-based classification system for assessing coronary artery disease. Computational and Mathematical Methods in Medicine, Vol. 2015, Article ID 564867, 8 pages, http://dx.doi.org/10.1155/2015/564867 [Cited Mar 19, 2020]
10. de Castro A, Benito A, Manzanera S, Mompean J, Canizares B, Martınez D, et al. Three-dimensional cataract crystalline lens imaging with swept-source optical coherence tomography. Investigative Ophthalmology & Visual Sci 2018; 59: 897-903. doi:https://doi.org/10.1167/iovs.17-23596

11. Brunoa G, Fiori A. MicroClAn: Microarray clustering analysis. Journal of Parallel and Distributed Computing 2013;73:360-70.
12. McCulloch WS, Pitts WS. A Logical calculus of the ideas immanent in nervous activity. Bulletin of Mathematical Biophysics 1943;5:115-33.
13. Prem Junsawang, Suphakant Phimoltares, Chidchanok Lursinsap. Streaming chunk incremental learning for class-wise data stream classification with fast learning speed and low structural complexity. PLoSONE 14(9): e0220624. https://doi.org/10.1371/journal.pone.0220624 [Cited Mar 19, 2020]
14. Thakong M, Phimoltares S, Jaiyen S, Lursinsap C. Fast learning and testing for imbalanced multi-class changes in streaming data by dynamic multi-stratum network. IEEE Access 2017;5:10633-48.
15. Wikipedia. eHealth. From: https://wikipedia.org/wiki/EHealth. [Accessed Mar 21, 2020]

Further reading:

1. Eysenbach G. What is e-health. J Med Internet Res 2001; 3(2):e20.doi:10.2196/jmir.3.2.e20(http://doi.org/10.2196%2Fjmir.3.2.e20). ISSN 1438-8871 (https://www.worldcat.org/issn/1438-8871).
2. Oh H, Carlos R, Murray E, Alejandro J. What is eHealth(3): A systematic review of published definitions. J Med Internet Res 2005;7: e1. doi:10.2196/jmir.7.1.e1(https://doi.org/10.2196%2Fjmir.7.1.e1).
3. Gavin A, Nickolai T. Treating people you never see: internet-based treatment of the internalizing mental disorders. Australian Health Review 2010; 34: 144-7.
4. Taylor GMJ, Dalili MN, Semwal M, Civijak M, Sheikh A, Car J. Internet-based interventions for smoking cessation. The Cochrane Database of Systemic Reviews 2017; 9: CD007078.c/articles/PMC6703145).
5. Yassaee M, Mettler T, Winter R. Principles for the design of digital occupational health systems. Information and Organization 2019; 29: 77-90.
6. Cafazzo JA. Design for digital health. In: Rivas H, Wac K, Editors. Digital Health. Scaling Healthcare in the World. Springer, 2019; Chap. 3, p.47-65. DOI: https://doi.org/10.1016/B978-0-12-816427-3..00003-8