Towards Online Universal Quality Healthcare through AI

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Curai
Being a physician is hard(er)

- Doctors have ~15 minutes to capture information* about a patient, diagnose, + recommend treatment
- Information
  - Patient’s history
  - Patient’s symptoms
  - Medical knowledge
    - Learned years ago
    - Latest research findings (70+ journal articles per day)
    - Different demographics
- Data is growing over time, so is complexity
- Manual adaptation is challenging

*Information

- Patient’s history
- Patient’s symptoms
- Medical knowledge
  - Learned years ago
  - Latest research findings (70+ journal articles per day)
  - Different demographics

When medical care is delivered in 15-minute doses, there’s not much time for caring

Source: The Washington Post

Democracy Dies in Darkness
Study: EHRs Contribute to Family Physician Stress, Burnout

January 16, 2019 12:06 pm Michael Devitt – In theory, health information technology is supposed to improve communication among health care professionals, make it easier to access and review patient data, cut through the billing and insurance bureaucracy, and enhance the overall health experience for physicians and patients alike.

But as most family physicians know, what sounds good in theory doesn’t always play out that way in the real world. In fact, increasing evidence suggests that use of electronic health records (EHRs) (www.annfammed.org) can take up a significant amount of a family physician’s workday, making it more
Cost of medical errors

- 12M misdiagnoses/y
- Errors cause 400k deaths & 4M serious health events
  - Compare to 500k deaths from cancer or 40k from vehicle accidents
- Almost half of those are preventable

<table>
<thead>
<tr>
<th>Preventability Rationale</th>
<th>Percentage of Events*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error was related to medical judgment, skill, or patient management</td>
<td>58%</td>
</tr>
<tr>
<td>Appropriate treatment was provided in a substandard way</td>
<td>46%</td>
</tr>
<tr>
<td>The patient’s progress was not adequately monitored</td>
<td>38%</td>
</tr>
<tr>
<td>The patient’s health status was not adequately assessed</td>
<td>23%</td>
</tr>
<tr>
<td>Necessary treatment was not provided</td>
<td>17%</td>
</tr>
<tr>
<td>Event rarely happens when proper precautions and procedures are followed**</td>
<td>14%</td>
</tr>
<tr>
<td>Communication between caregivers was poor**</td>
<td>8%</td>
</tr>
<tr>
<td>Facility’s patient safety systems and policies were inadequate or flawed**</td>
<td>3%</td>
</tr>
<tr>
<td>Breakdown in hospital environment occurred (equipment failure, etc.)**</td>
<td>2%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nonpreventable Events (n=155)</th>
<th>Percentage of Events*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Event occurred despite proper assessment and procedures followed</td>
<td>62%</td>
</tr>
<tr>
<td>Patient was highly susceptible to event because of health status</td>
<td>50%</td>
</tr>
<tr>
<td>Care provider could not have anticipated event given information available</td>
<td>35%</td>
</tr>
<tr>
<td>Patient’s diagnosis was unusual or complex, making care difficult</td>
<td>29%</td>
</tr>
<tr>
<td>Harm was anticipated but risk considered acceptable given alternatives**</td>
<td>14%</td>
</tr>
</tbody>
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Online search and/or Healthcare access?

“72% of internet users say they looked online for health information within the past year” [Pew Research]

25M daily
Google

Need more than Google can deliver

Less cost and friction than PCP visit

1.4M daily

More than one-third of U.S. adults use Internet to diagnose medical condition
We can do better than Google + Webmd

“Roughly 1 percent of searches on Google are symptom-related”

[Google]

74 MM

Unique Monthly Visitors

Every month, 74 million unique people go to WebMD for health information.
We have an opportunity to reimagine healthcare
We have an opportunity obligation to reimagine healthcare
Towards Online Universal Quality Healthcare

- **Online** = mobile, always on
- **Universal** = scalable, low cost, easy to access/use
- **Quality** = as good as the best doctors, based on best-known practices and scientific evidence, replicable
- **Healthcare** != URL. Healthcare = actionable recommendations + directed access to resources including human professionals when needed
How?

- Online + physicians in the loop = telehealth
- However, standard telehealth is (1) hard to scale, (2) not better quality

shortage of **120,000 physicians** by 2030

Merrit Hawkins, 2017 survey

Barnett et.al. Comparative Accuracy of Diagnosis by Collective Intelligence of Multiple Physicians vs Individual Physicians JAMA, 2018
How?

Scale + Quality = Automation (aka AI)
Part II.
Medical AI for online Healthcare
Medical AI for Online Healthcare

1. Medical knowledge extraction/representation
2. Conversational Healthcare Systems
3. Automated Triage/Diagnosis/Treatment
4. Multimodal inputs
Part II.

1. Knowledge Extraction & Representation
Medical Knowledge extraction

- Medical ontologies
- Electronic access to medical research
- Access to Electronic Health Records

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**Medical Knowledge extraction**

- Medical ontologies
- Electronic access to medical research
- Access to Electronic Health Records

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**Extracting Information from Textual Documents in the Electronic Health Record: A Review of Recent Research**

S. M. Hayes, V. K. Sameni, H. C. Kopper, J. H. Huddle

Department of Biomedical Informatics, University of Utah School of Medicine, Salt Lake City, USA

Flinders Medical Centre Research, Flinders University School of Medicine, Adelaide, Australia

**Summary**

In the biomedical domain, the rapid adoption of Electronic Health Records (EHR) has led to the parallel growth of narrative data in electronic form, electronic medical records. 

**Generating Multi-label Discrete Patient Records using Generative Adversarial Networks**

Edward Chei, Siddharth Biswal, Bradley Malin, Jon Dula, Walter E. Stewart, Jimeng Sun

Georgia Institute of Technology, Vanderbilt University, Sutter Health

**Abstract**

Access to electronic health record (EHR) data has motivated computational advances in medical research. However, various concerns, particularly over privacy, can limit access to and collaborative use of EHR data. Sharing synthetic EHR data could mitigate risk.

In this paper, we propose a new approach, medical Generative Adversarial Network (medGAN), to generate realistic synthetic patient records. Based on input real patient records, medGAN can generate high-dimensional discrete variables (e.g., binary and count features) via a combination of an autoencoder and generative adversarial networks.
Knowledge Representation: Medical ontologies

- **Snomed Clinical Terms**
  - Collection of medical terms used in clinical documentation and reporting.
  - Clinical findings, symptoms, diagnoses, procedures, body structures, organisms, substances, pharmaceuticals, devices...

- **UMLS**
  - Compendium of many controlled vocabularies
  - Enables translating between terminology systems

- **ICD-10**
  - International Statistical Classification of Diseases and Related Health Problems
Health knowledge graphs

Figure 1. Workflow Architecture. The architecture of our workflow starts with (a) patient notes that are grouped together based on their nearness in time. Given the patient timeline bins, clinical terms are recognized from the notes and recorded into (b) the clinical concept occurrence matrix, which is scanned for (c) finding patterns of the frequency and co-frequency of concepts. This data can be used to calculate (d) contingency tables and Bayesian probability estimates. For example, the concept X has a frequency of 800 and is pairwise co-frequent with concept Y exactly 300 times.
Part II.
2. Conversational Healthcare
Understanding patients and doctors

NLP & Healthcare: Understanding the Language of Medicine

Xavier Amatrawin
Nov 5, 2018 - 16 min read

At Curai we have a mission to scale the world's best healthcare for every human being. We are building an Augmented Intelligence capability to scale doctors and lower the barrier to entry for primary care. There are many Health dialog systems for patients and consumers, but MANDY: Towards a Smart Primary Care Chatbot Application

Liu N1, Chengiao Lo, Shu Liu, and Junou Liu2
Journal of Automation and Control Engineering Vol. 1, No. 2, April 2011

Pharmbot: A Pediatric Generic Medicine Consultant Chatbot

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Designing a Chatbot for Diabetic Patients

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Abstract — An Intelligent system is a technology that enables interaction between humans and computers. The system comprises of a software system that is capable of understanding and responding to natural language. The paper proposes an algorithm in which a chatbot is designed to help medical practitioners, the patient, and the doctor in making a diagnosis. The design of the proposed chatbot is based on the adoption of a multimodal approach, which means that the system can process multiple input modalities such as text, speech, and images.

Shahrol [5] asks what is the future of such a chatbot and what is its potential impact on the medical field. A chatbot can be used as a diagnostic tool to assist doctors in diagnosing diseases and conditions. The chatbot can also be used to provide education and guidance to patients on how to manage their health conditions.

A chatbot can be a valuable tool in the healthcare industry, as it can help medical practitioners in making diagnoses and providing guidance to patients. The chatbot can also be used to provide education and guidance to patients on how to manage their health conditions.
Learning a medically-aware dialog system

User : Right now my stomach hurts.
User : It feels like I need to do a clean out. If you know what I mean
Dr : Sorry for the abdominal pain Laura. When did you have last bowel movement?
User : It was yesterday
Dr : What was the consistency of stool was it soft well-formed or was it hard?
User : Right now I just went and it is watery and very loosely
User :
User : That was causing the problem with my stomach hurts
Dr : Any blood or mucus with stools? Was it foul smelling?
User : Nope for all three
Dr : Any fever?
User : P
User : Nope
Dr : I asked as blood or mucus in stool fever can be due to an underlying infection.
Dr : Any nausea/ vomiting?
User : Nope
User : Why does this happen to me
User : Is it something that I have ate
Dr : Diarrhea can often be due to indigestion or an infection. Did you eat outside food or any packaged foo
User : Yes
Part II.
3. Automated(Assisted) Triage/Dx/Rx
Medical Diagnosis

- Diagnosis (*R.A. Miller 1990*):
  - Mapping from patient’s data (history, examination, lab exams…) to a possible condition.
  - It depends on ability to:
    - Evoke history
    - Surface symptoms and findings
    - Generate hypotheses that suggest how to refine or pursue different hypothesis
  - In a compassionate, cost-effective manner
An example: Internist-1/QMR/Vddx

Internist (1971) - Dr. Jack Myers

Process for adding a disease requires 2-4 weeks of full-time effort and doctors reading 50 to 250 relevant publications
ML/AI Approaches to Diagnosis

- Early DDSS based on Bayesian reasoning (60s-70s)
- Bayesian networks (80s-90s)
- Neural networks (lately)
Our approach: Expert systems as Prior

The science of assisting medical diagnosis: From Expert systems to Machine-learned models

Cural's mission is to scale the world's best healthcare for every human being. We are building an augmented intelligence system to help scale physicians' abilities as well as to lower users' barrier to entry to care. There are many

Knowledge base → Clinical case simulator

Example of simulated case

Hepatitis acute viral
- anorexia
- jaundice
- abdomen pain epigastrium
- hepatomegaly present
- liver enlarged moderate
- liver tender on palpation
- feaces light colored
- hands palmar erythema
- skin spider angiomas
- abdomen pain acute
- abdomen pain not colicky
- vomiting recent
- constipation
- vomiting coffee ground

Arthritis acute septic
- sepsis
- myalgia
- fever
- tachycardia
- rigors

Pyrogenic shock
- coma
- cyanosis of mucous membranes
- tachycardia
- pressure arterial systolic less than 90
- skin sweating increased generalized
- pressure arterial diastolic less than 60

Leukemia chronic myelocytic

simulated cases

Machine learned models
Our approach: Incorporating data from EHR

Clinical cases simulated from expert systems

Clinical cases other sources eg. electronic health records

ML classification models for differential diagnosis

- Hepatitis acute viral
- Leukemia chronic myelocytic
- Arthritis acute septic
  - Pyrogenic shock
    - coma
    - cyanosis of mucous membranes
    - tachypnea
    - pressure arterial systolic less than 90
    - skin sweating increased generalized
    - pressure arterial diastolic less than 60
    - myalgia
    - fever
    - Tachycardia
    - rigors
Part II.
4. Multimodality
Multimodal Inputs

Prototypical Clustering Networks for Dermatological Disease Diagnosis

Viraj Prabha1, Manish Chhabra2, Anisha Kannan2, Murali Ravuri2, Xavier Amatriain1
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Figure 1: Long-tailed class distribution of Dermnet (shown here for the top-300 classes). Also shown are nearest neighbors to four of the many prototypes learned for select classes using the proposed Prototypical Clustering Network approach. This is illustrative of the huge intra-class variability in the data. For a novel test image, shown at the upper right corner, the model predicts the correct class by measuring weighted similarity to per-class clusters in the embedding space learned through a deep convolutional neural network.

Detecting heart arrhythmias using machine learning and Apple Watch data

Yancheng is an Insight alumnus from the first Health Data Science session and is now a data scientist at AthenaHealth. While at Insight, he partnered with the UCSF Health effort study to detect atrial fibrillation patients using Apple Watch heart rate data. This content originally appeared on his personal website.
Conclusions
Recap

- More people access healthcare through search than PCPs
- Doctors don’t have time and make mistakes
- We should be able to offer a better online experience than Google + Webmd
- Online Universal Quality Healthcare
  - **Online**, mobile, always on
  - **Universal** = scalable, low cost, easy to access/use (i.e conversational)
  - **Quality** = as good as the best doctors, based on best-known practices and scientific evidence, replicable
  - **Healthcare** = not only a website you need to parse and figure out on your own, but directed access to healthcare resources including human professionals when needed
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  - Scale + Quality = automation (aka AI)
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