Curai

SCALING BEST HEALTHCARE TO EVERYONE, with AI

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Barriers to healthcare

CURAI

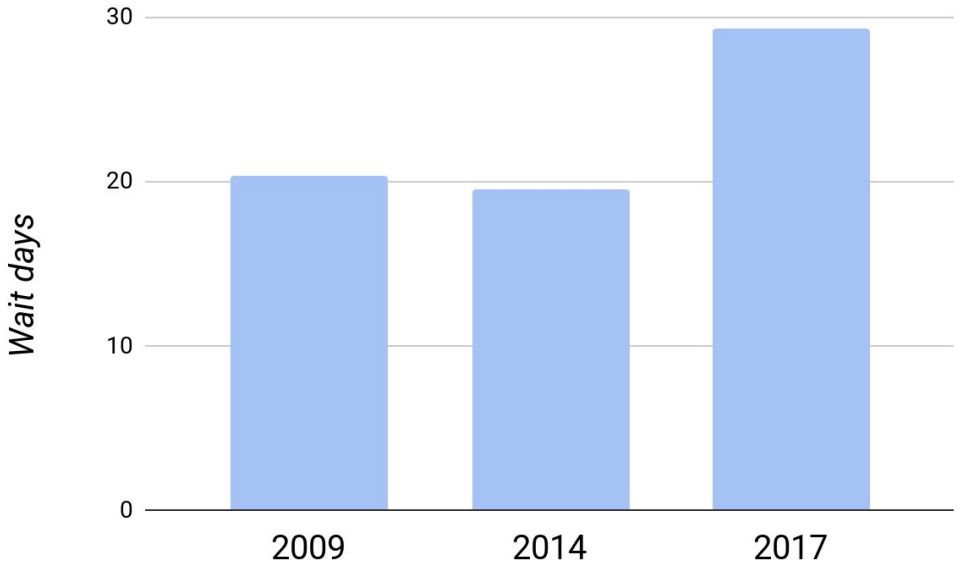
10% of adult population have **no** health insurance

28% of working adults are **under insured**

adversely affects access to care

Kaiser Family Foundation analysis of the 2017 National Health Interview Survey

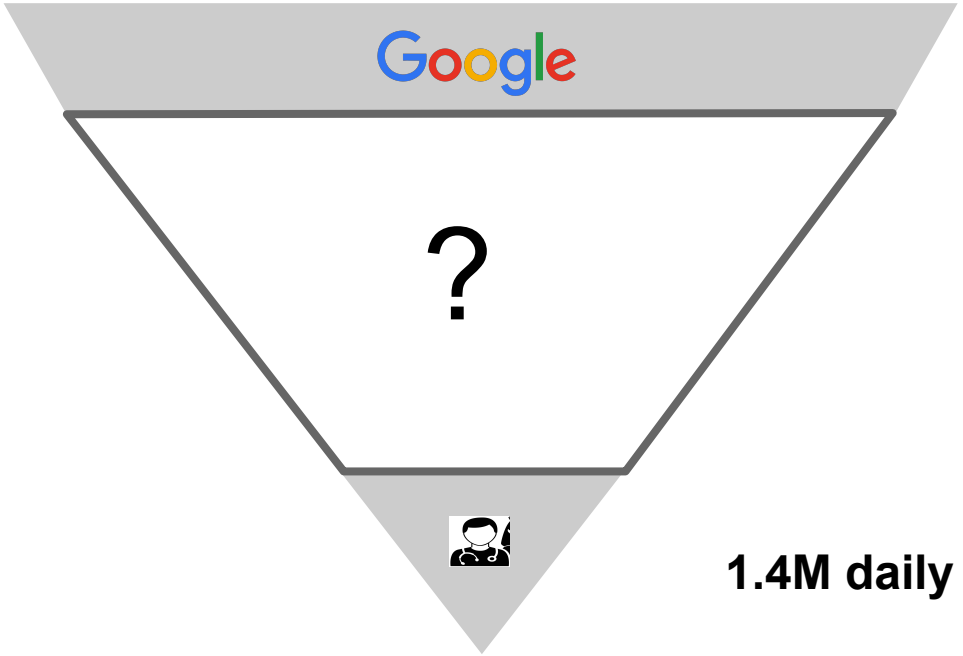
Lack of timely care



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

Merrit Hawkins, 2017 survey

Healthcare starts as a search



25M daily

1.4M daily

Rethinking user-doctor interaction

people with true medical need to visit a doctor,
visits at the right time

Part II.
Medical AI = data + models

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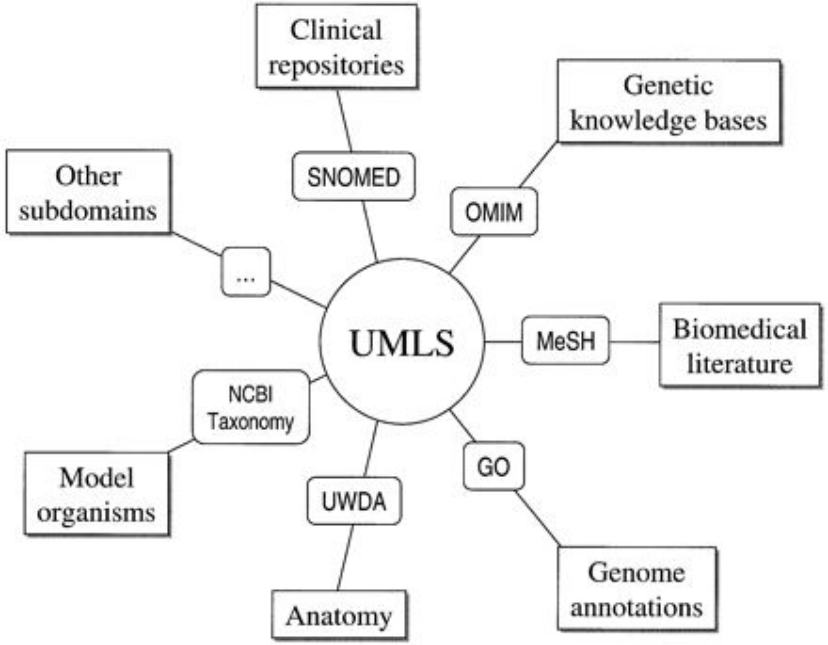
Medical AI = **data** + models

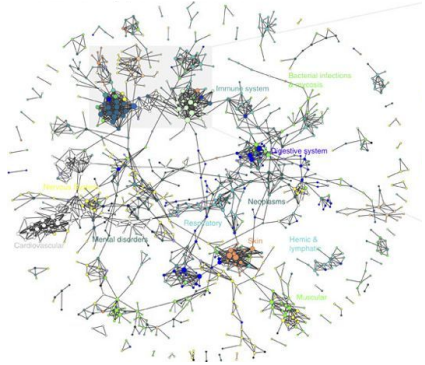
Data: Medical terminologies/ontologies

- 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

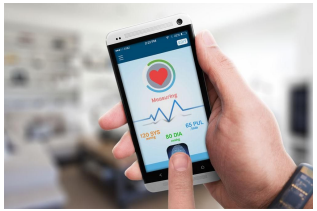


Data

- Electronic access to medical research

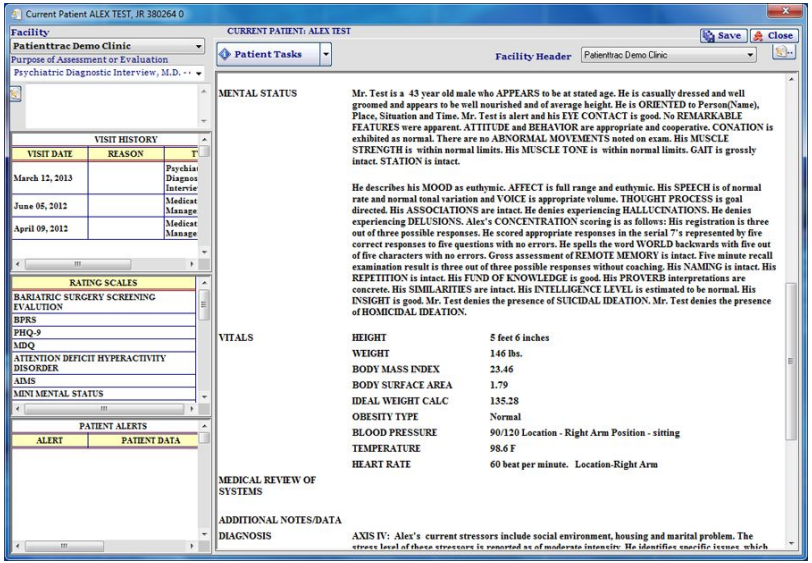


- Data from health sensors
  - Wearables
  - FDA-approved phone apps

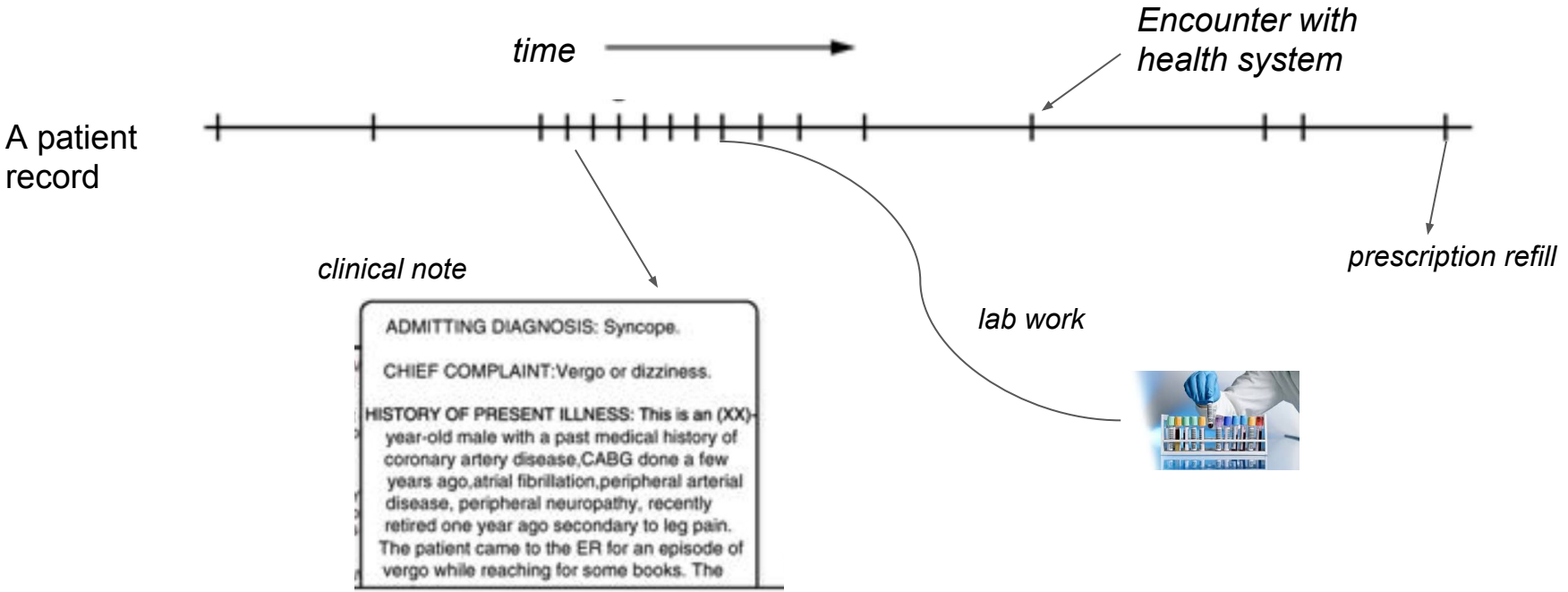


Data: Electronic health records

- Large-scale patient-level clinical data
- Digital information about patients *encounters* with doctors or the health system
- An encounter may include
  - Doctor notes, medications, procedures, diagnosis, tests and imaging
  - structured and unstructured data



A patient record in EHR



User-Doctor conversational data

- Multimodal interaction data

```
        User  : This is not sore or anything its just red and the nail i
sent ingrown either
        Dr  : Thanks for sharing the picture. Glad you reached out. Le
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        User  : Yes sure
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        User  : No
        Dr  : Alright. Does it hurt to walk?
```

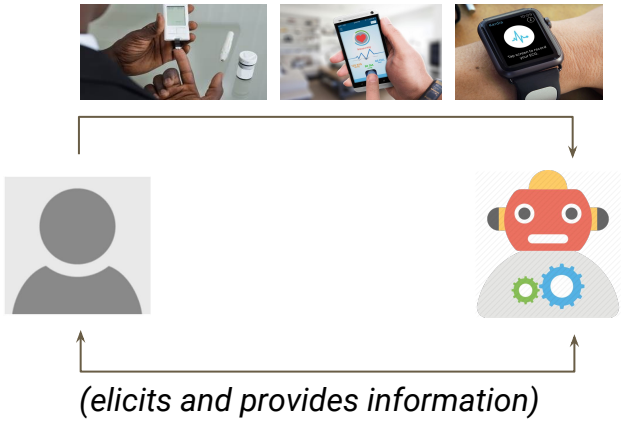
Part II.
Medical AI = data + **models**

Medically-aware dialog system

AI for the user: Medically-aware dialog system

- Personal AI health agent
  - Elicits and provides information

- “Medically aware”
  - Has medical knowledge
  - Knows about medical diagnosis
  - Gathers and reasons about multiple modality inputs
  - Translates between patient language and medical language (eg. UMLS, SNOMED)



Devlin et al. BERT: Pre-training of Deep Bidirectional Transformers for Language Understanding, 2018
Vaswani. *et. al.* Attention is all you need, 2018

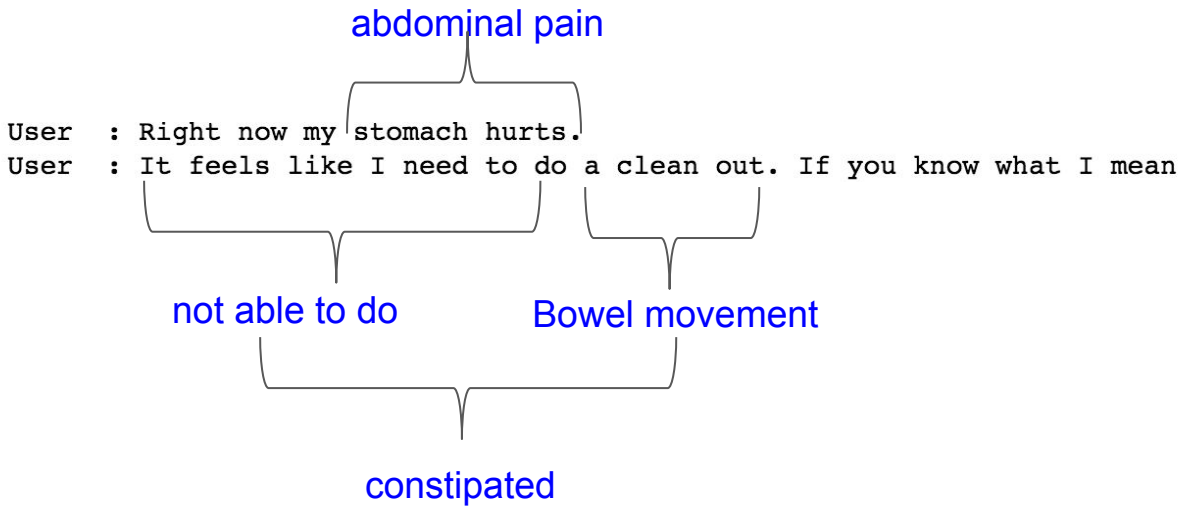
Learning a medically-aware dialog system

CURAI

```
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
```

Challenge # 1 : Understanding patient language



Challenge # 2 : Eliciting medically-relevant information

CURAI

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?

Ask more about current concern

related question

Challenge # 3 : Knowing about science of diagnosis

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?
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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

• • •

Note the progression from asking about their constipation to nausea

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.
Medical AI = data + **models**

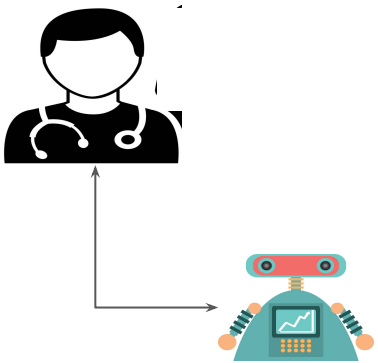
AI for medical diagnosis

Medical diagnosis

CURAI

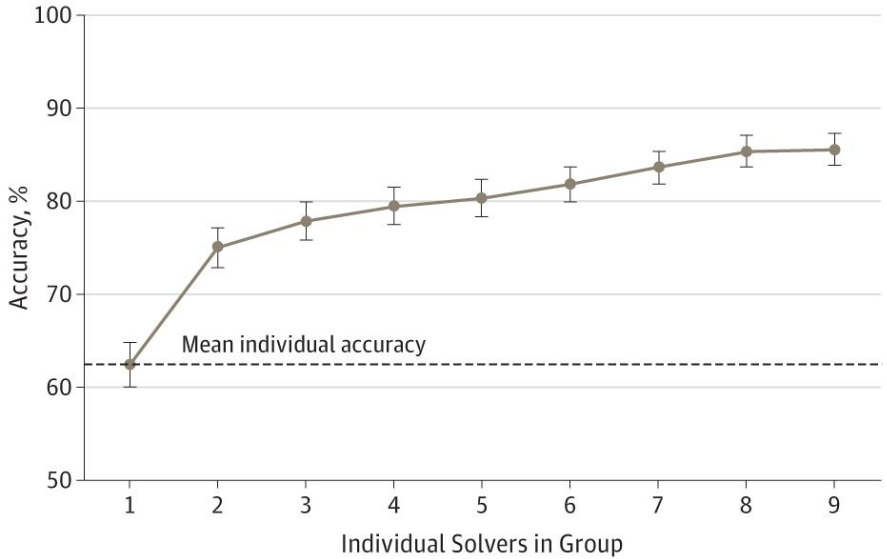
- Doctors have ~15 minutes to capture information about a patient, diagnose, and recommend treatment

- Hard for doctors to “manually” personalize their “recommendations”



Accuracy of diagnosis

2069 medical practitioners solving 1572 cases from the Human Dx data set

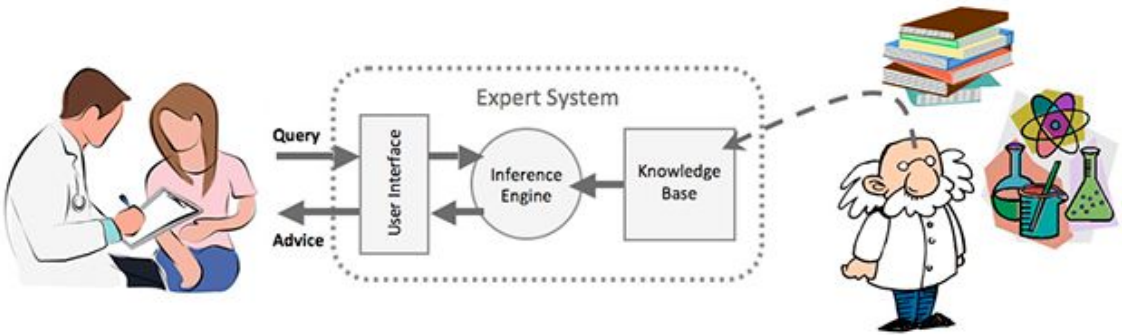


- Recency and availability bias
- Failure/delay in eliciting critical piece of information

Barnett et.al. Comparative Accuracy of Diagnosis by Collective Intelligence of Multiple Physicians vs Individual Physicians JAMA, 2018
Schiff et.al. Diagnostic Error in Medicine, JAMA Internal medicine, 2009

AI models for diagnosis (1970s-2000s)

- Examples: Mycin, Internist-1, DxPlain, VDDx, QMR
- Covers over 1000 diseases and 3500+ findings
- Expert curation based on:
  - Scientific research and evidence-based literature
  - Expert knowledge



Buchanan, B.G.; Shortliffe, E.H. (1984). *Rule Based Expert Systems: The MYCIN Experiments of the Stanford Heuristic Programming Project*

An example from Knowledge Base

DISPLAY WHICH MANIFESTATION LIST?
ALCOHOLIC HEPATITIS

AGE 16 TO 25	0 1			
AGE 26 TO 55	0 3			
AGE GTR THAN 55	0 2			
ALCOHOL INGESTION RECENT HX	2 4			
ALCOHOLISM CHRONIC HX		2 4		
SEX FEMALE	0 2			
SEX MALE	0 4			
URINE DARK HX	1 3			
WEIGHT LOSS GTR THAN 10 PERCENT		0 3		
ABDOMEN PAIN ACUTE		1 2		
ABDOMEN PAIN COLICKY			1 1	
ABDOMEN PAIN EPIGASTRIUM		1 2		
ABDOMEN PAIN NON COLICKY		1 2		

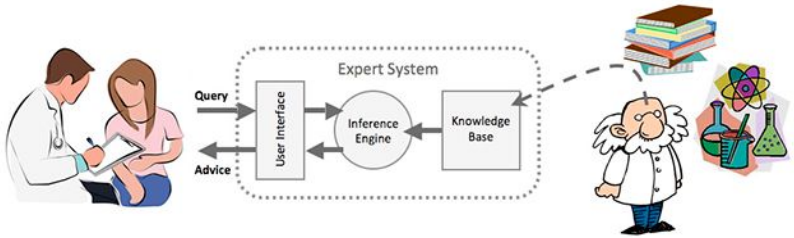
CHOLESTEROL BLOOD DECREASED			2 2	
KETONURIA	1 2			
PROTEINURIA	1 2			
SGOT 120TO 400	2 3			
SGOT 40TO 119	2 3			
SGOT GTR THAN 400	1 2			
UREA NITROGEN BLOOD LESS THAN 8			2 2	
UROBILINOGEN URINE ABSENT			1 1	
UROBILINOGEN URINE INCREASED		2 4		
WBC 14000 TO 30000			0 3	
WBC 4000 TO 13900 PERCENT NEUTROPHIL(S) INCREASED				0 3
WBC LESS THAN 4000			1 1	
ACTIVATED PARTIAL THROMBOPLASTIN TIME INCREASED			1 3	
ANTIBODY MITOCHONDRIAL			1 1	
ANTIBODY SMOOTH MUSCLE			2 3	
BSP RETENTION INCREASED			1 5	

Evoking Strength	Interpretation
0	Nonspecific—manifestation occurs too commonly to be used to construct a differential diagnosis
1	Diagnosis is a rare or unusual cause of listed manifestation
2	Diagnosis causes a substantial minority of instances of listed manifestation
3	Diagnosis is the most common but not the overwhelming cause of listed manifestation
4	Diagnosis is the overwhelming cause of listed manifestation
5	Listed manifestation is pathognomic for the diagnosis

Frequency	Interpretation
1	Listed manifestation occurs rarely in the disease
2	Listed manifestation occurs in a substantial minority of cases of the disease
3	Listed manifestation occurs in roughly half the cases
4	Listed manifestation occurs in the substantial majority of cases
5	Listed manifestation occurs in essentially all cases—i.e., it is a prerequisite for the diagnosis

Scalability issues with expert systems

- Composed of generalized disease profiles
- Upkeep: costly, time consuming and time-delayed
- Not easy to personalize



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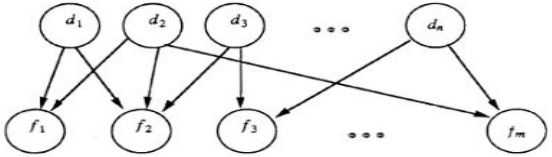
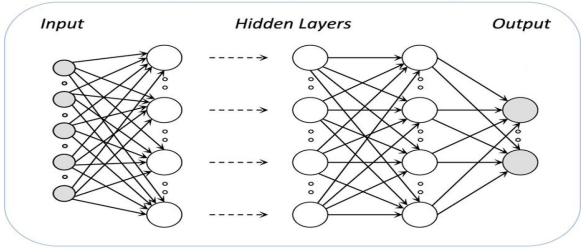
Machine-learned models for diagnosis (2010-

- Primarily driven by electronic health records

- Easier to personalize
- Flexible to combine different data sources
- Robust to noise in data



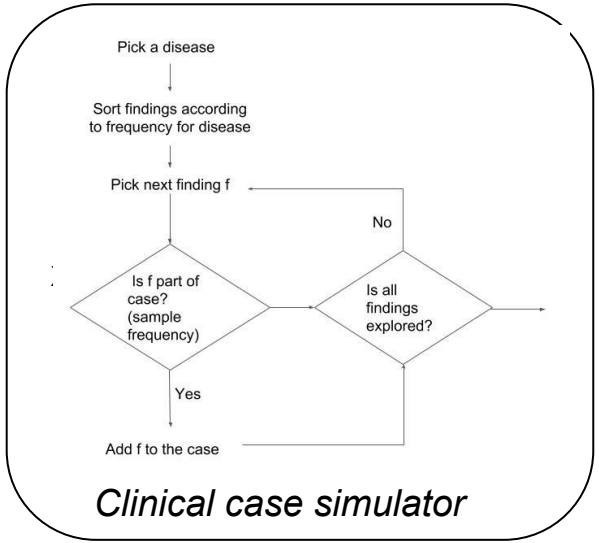


- No explicit encoding of expert knowledge

Finlayson, S. G. *et al.* Building the graph of medicine from millions of clinical narratives. *Sci. Data,* 2014
Rotmensch, M. *et. al.* Learning a Health Knowledge Graph from Electronic Medical Records, Nature 2017
Rajkomar *et.al.* Scalable and accurate deep learning with electronic health records, 2018

Insight: Expert systems as Prior

Knowledge base central to expert systems



Clinical case simulator

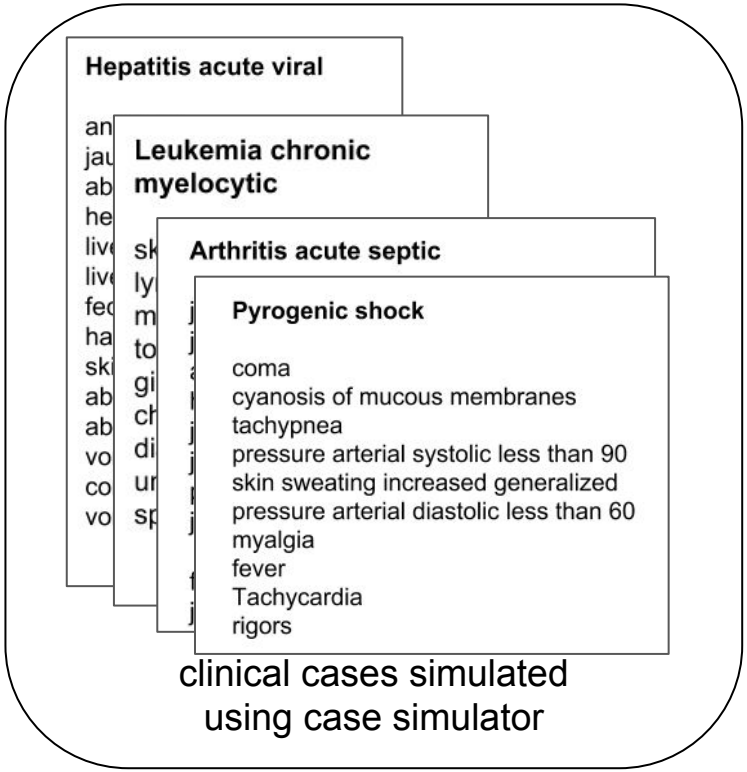
Hepatitis acute viral

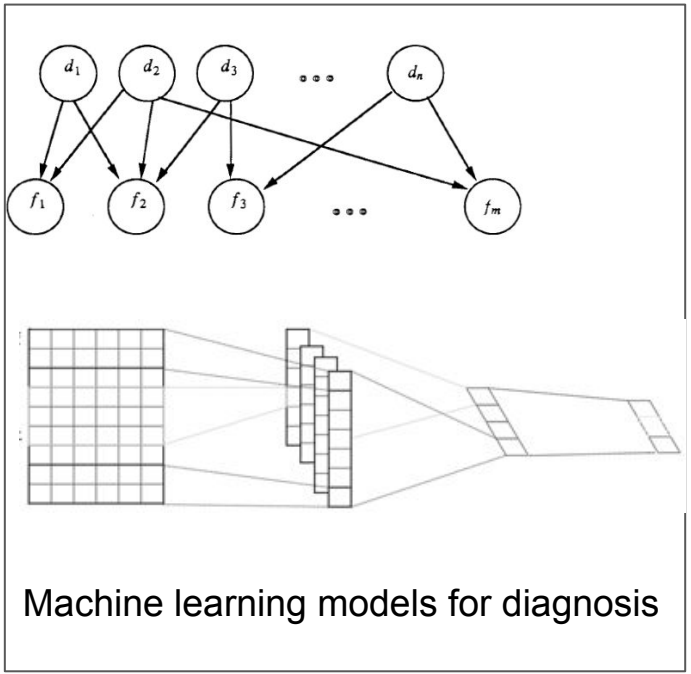
anorexia
jaundice
abdomen pain epigastrium
hepatomegaly present
liver enlarged moderate
liver tender on palpation
feces light colored
hands palmar erythema
skin spider angiomas
abdomen pain acute
abdomen pain not colicky
vomiting recent
constipation
vomiting coffee ground

Example of simulated case

Ravuri et.al. Learning from the experts: From expert systems to machine-learned diagnosis models, MLHC 2018

Our Approach

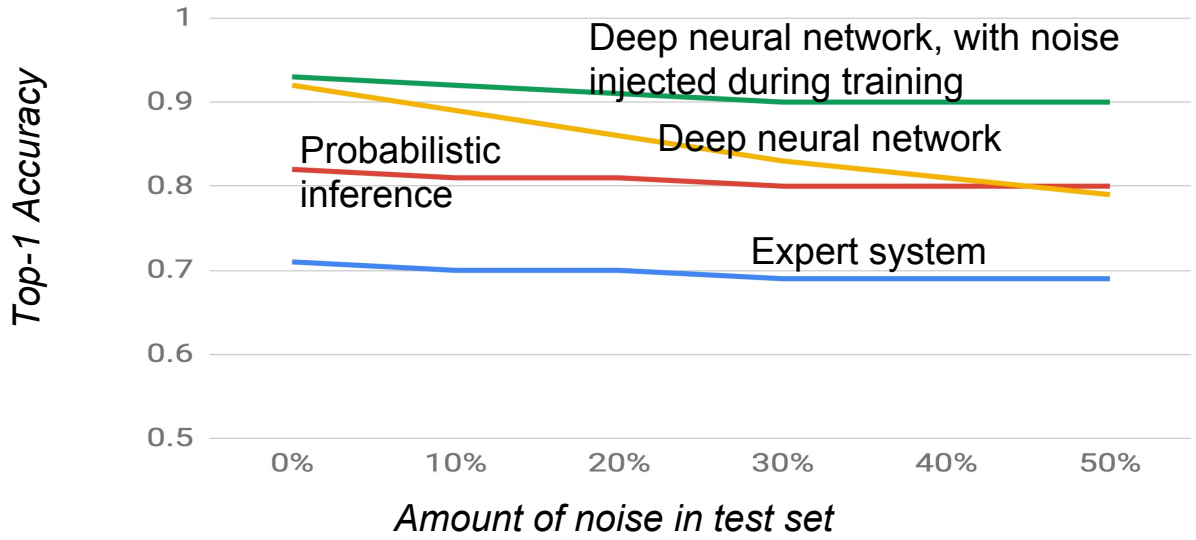




Ravuri et.al. Learning from the experts: From expert systems to machine-learned diagnosis models, MLHC 2018

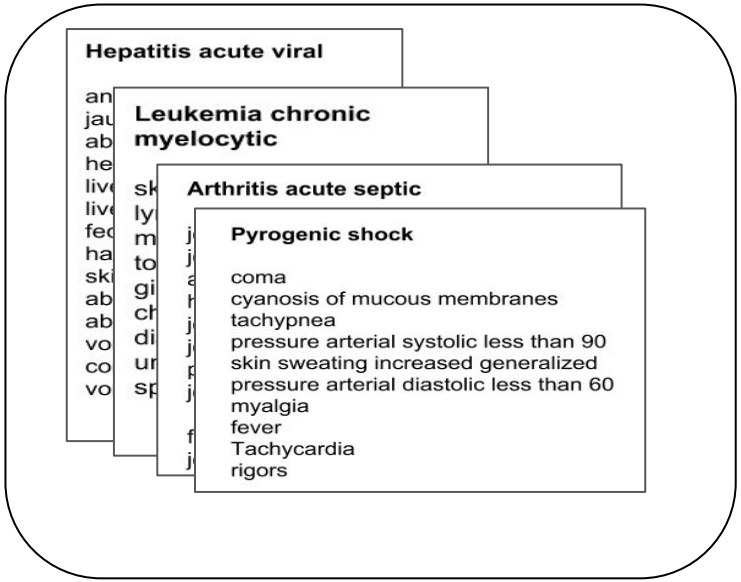
Key results

Setup: 250 diseases with ~500K simulated cases, uniformly sampled

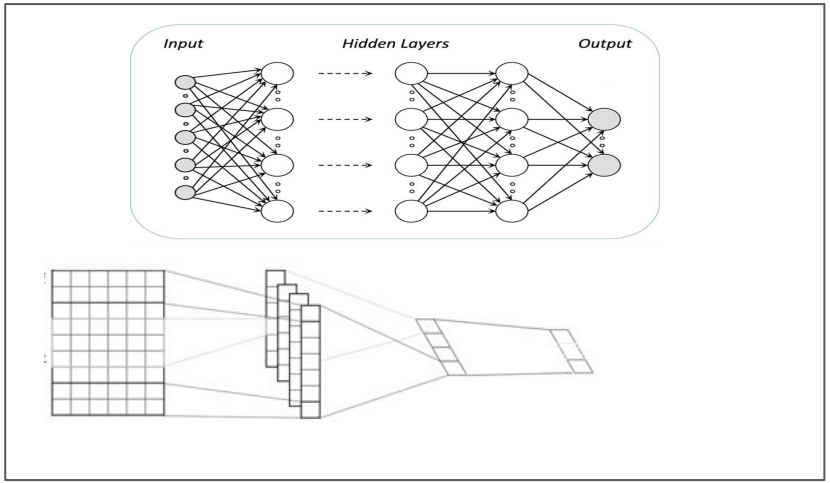


- Robustness of learned models
- Resilience to noise obtained through injecting noise during training

Incorporating data from EHR



clinical cases simulated from expert systems



ML classification models for differential diagnosis

clinical cases other sources eg. electronic health records

Part II.
Medical AI = data + **models**

AI for medical diagnosis (multimodal inputs)

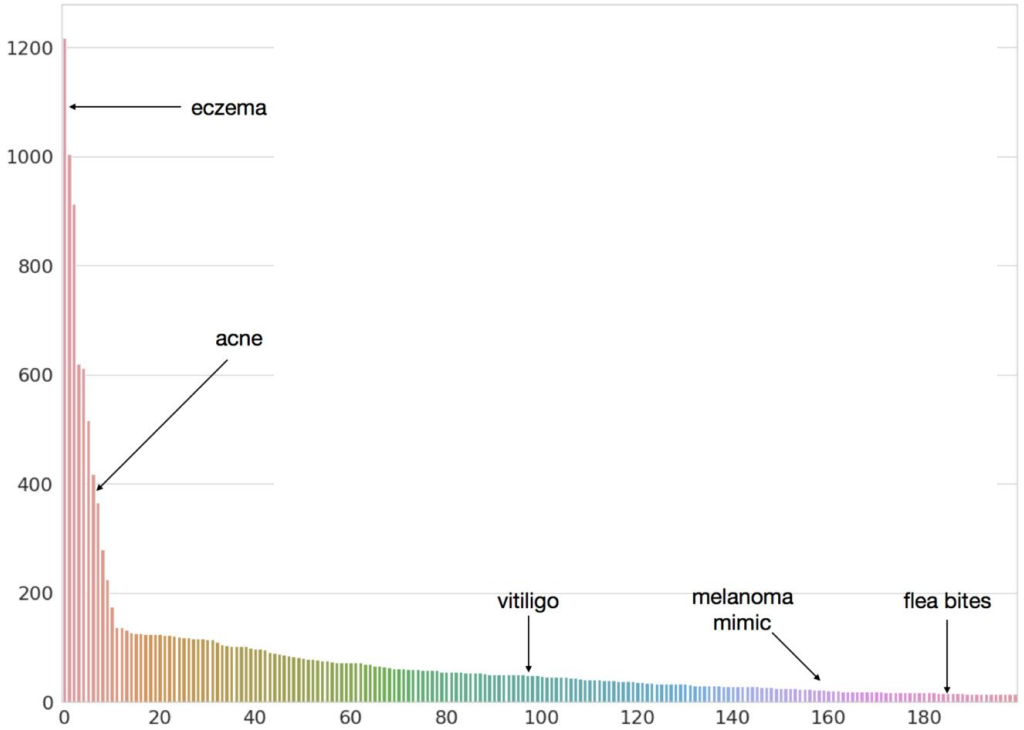
Modeling multi-modal inputs

User : This is not sore or anything its just red and the nail i sent ingrown either
Dr : Thanks for sharing the picture. Glad you reached out. Le t's discuss this further. Just a few questions if you don't mind.
User : Yes sure
Dr : When did you notice this change in the toe?
User : Its mostly notticable when im working since i work with rubber boots
Dr : I see. Is there any pain or itching over the toe?
User : No pain or itching but sometimes moderate soreness
Dr : Okay. Does the toe feel warm to touch?
User : No
Dr : Alright. Does it hurt to walk?

Dermatological disease diagnosis

- 30% of derm conditions seen by primary care physician

- Long-tailed data distribution
- Huge intra-class variability
  - Eg. Eczema on hand is different from that on legs!

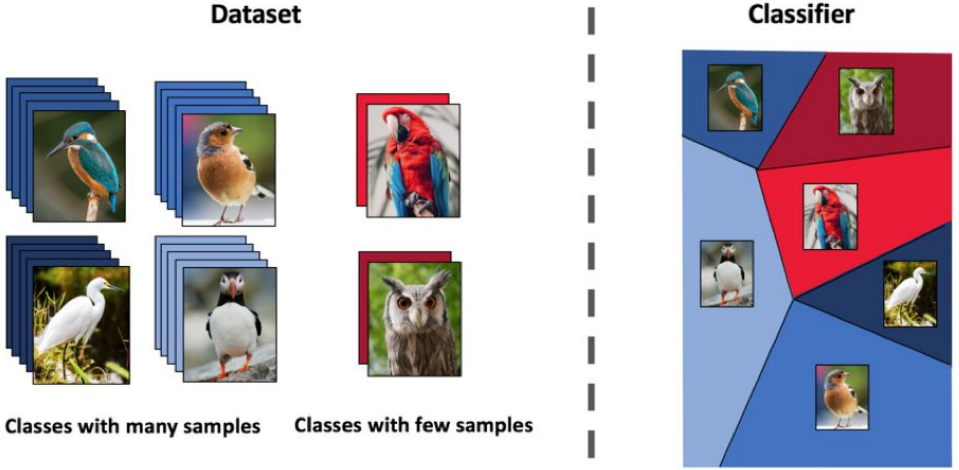


Prabhu et.al Prototypical Clustering Networks for Dermatological Disease Diagnosis, 2018
Estreva et.al ,Dermatologist-level classification of skin cancer, 2017

Few-Shot learning

Learn generalizable representations

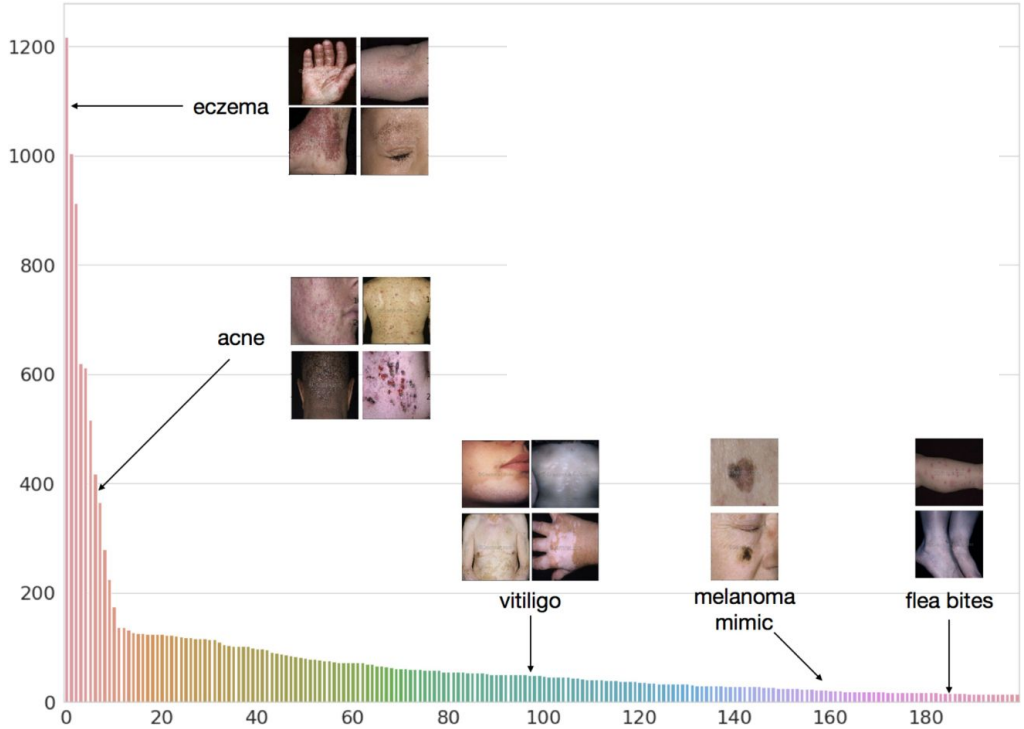
- Given few examples
- Resistant to overfitting



Finn et,al, Model Agnostic meta-learning for fast adaptation of deep networks, 2018
Wang et.al. Low-Shot Learning from Imaginary Data, 2018
Snell at.al. Prototypical networks, 2017
Vinayals et.al. Matching Networks for one-shot learning, 2017

Our Approach: Prototypical Clustering Networks

- Learn multiple representations for each class
- At inference time:
  - Find the best matching cluster and its associated class



Prabhu et.al Prototypical Clustering Networks for Dermatological Disease Diagnosis, 2018

Combining modalities for diagnosis

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Open Challenges

CURAI

- Cost of errors
- Medically-aware conversational models
  - Importance of eliciting information
  - Importance of communicating outcomes
- Diagnosis in the wild
  - Reducing agnostophobia: diseases that model doesn’t know
- Modeling causation
  - Causation from correlation

Looking Forward...

CURAI

- Mobile First World, **Mobile First Care**
- **AI + human practitioners** for Quality Care
- **Less than 20% of the cost** for **best** healthcare access

Part III. Curai

What are we doing?

CURAI

- **Mission**: Scaling the world's best healthcare for every human being
  - lower barrier-to-entry for quality healthcare by helping patients make optimal health decisions
- Building an awesome and diverse team
- Combining state-of-the-art AI/ML and best product/UX practices to build a service that revolutionizes healthcare