Topics in Deep Learning: Healthcare

Instructor: Erik Drysdale
TA: Jenny Du

Course outline

- The practice of healthcare, medicine, and life sciences (**today**)
- Implementing AI in healthcare #1 (week 1)
- Implementing AI in healthcare #2 (week 1)
- Survival modeling (week 2)
- Protein folding, drug discovery, and medical imaging, and ‘Omics (week 2)
- Commercial applications (week 2)
- "White box" model explainability (week 2)
- "Black box" model explainability (week 3)
- Prediction intervals and quantifying uncertainty (week 3)
- Business thinking and organization structure (week 3)

Lecture 1: The practice of healthcare, medicine, and life sciences

`Topics in Deep Learning`

Lecture 1 Outline

- Course outline
- Intros
- Terminology
- Why healthcare
- Brief history of AI in healthcare
- Why *now*
- Challenges and Opportunities in applying AI in healthcare
- Examples of successful applications in healthcare
- Examples of failed applications in healthcare

Intros

- Instructor: Erik Drysdale (that's me!)
    - Started career in economics
    - Transitioned to healthcare data science
    - Have seen first hard how hard it is to implement models in HC
    - Bringing 9 years of professional experience to this course

Institutions where I've worked

- TA: Jenny Du
  - Master of Science in Applied Computing Program at UofT (current)
  - BA in CS and Bioinformatics
  - Research focus: Applications of ML & DS to health and biology

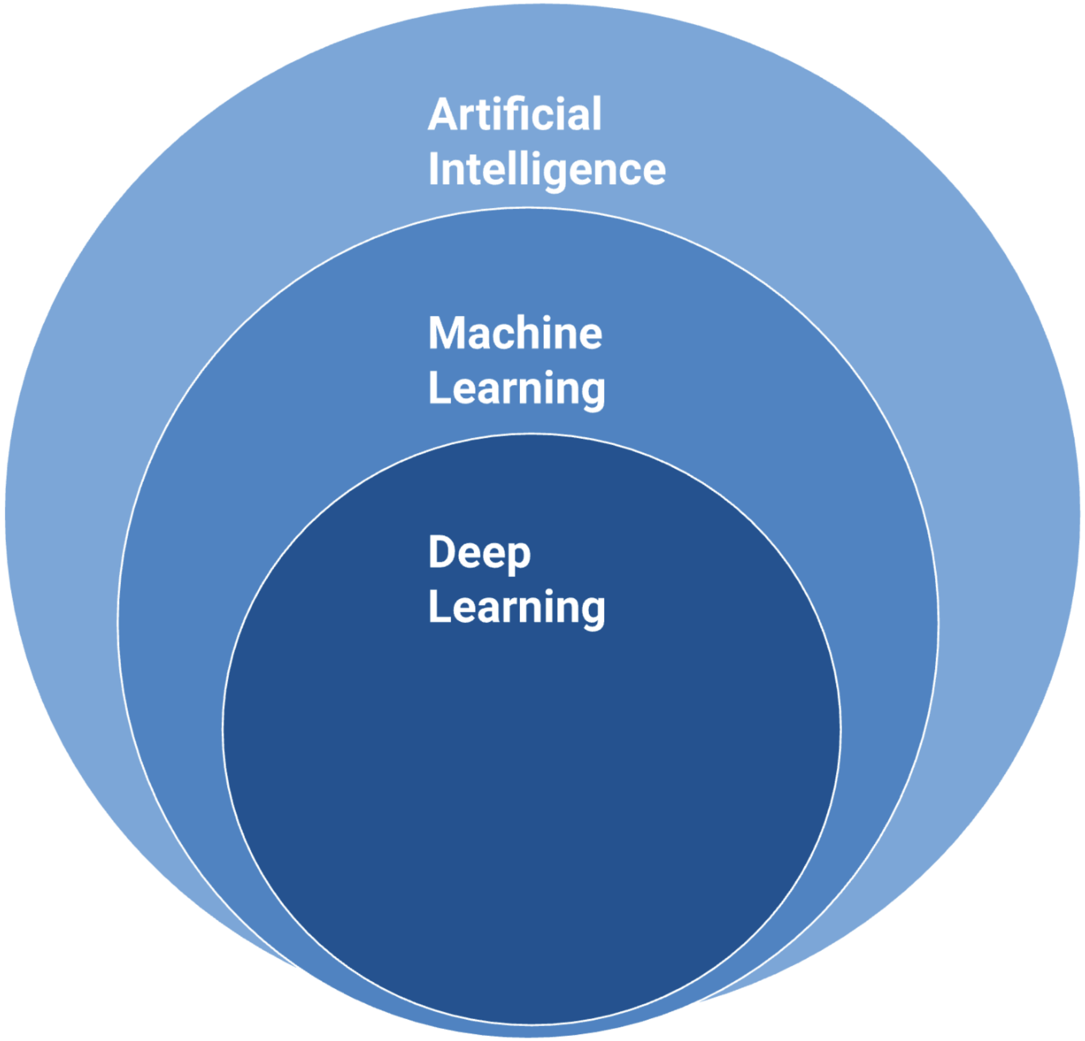

Jenny with trusty coffee

- Yourselves!
  - Name and background
  - What are you doing currently (work/school)
  - In your last interaction with the healthcare system, do you think AI/ML was involved?
- This course will be very interactive
  - Any concerns?

Terminology

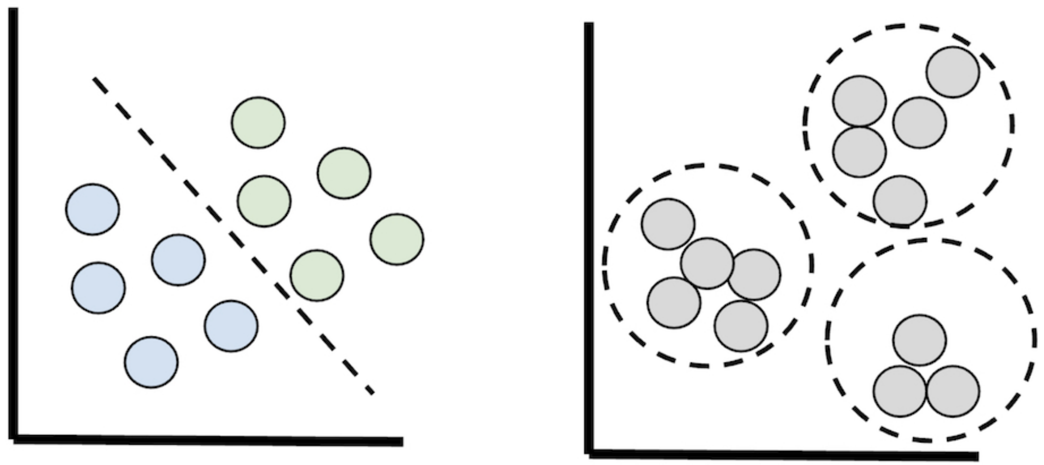
Terms

- **Artificial Intelligence (AI)** → any technique that enables computers to mimic human behaviour
- **Machine Learning (ML)** → a form of AI which involves computational techniques that learn from examples rather than explicitly being programmed.
    - *Example:* programming a computer to detect cancer from a brain scan.
- **Deep learning (DL)** → ML based on neural networks


Artificial Intelligence
Machine Learning
Deep Learning

Types of ML

- **Supervised learning** → Use labeled data to train the ML model (task-driven)
- **Unsupervised learning** → Uncover insights about the data and validate with domain experts (data-driven)



Supervised Learning
Classification → Known Label

Unsupervised Learning
Clustering → Unknown Label

Why Healthcare?

Potential applications of AI in healthcare

Several aspects of the health care involve prediction, including diagnosis, treatment, administration, and operations. Potential application for AI:

- **Improved diagnosis and treatment** → early detection more accurately
- **Personalized medicine** → tailored treatment to individual patients, based on specific medical profiles
- **Increase efficiciency** → automate routine tasks, free up health care professionals to focus on more complex tasks

Some specific domain applications[1]

1. **Clinical operations** → enhance the efficiency and effectiveness of clinical processes within healthcare organizations (this includes things like workflow, freeing up staff time and improving resource utilization)
    - *Examples:* Optimization in areas like emergency departments and operating rooms, capacity management, and supply chain.
2. **Clinical analytics** → analysis of clinical data to support decision-making and improve patient care.
    - *Examples:* Providing clinical decision support (CDSS), treatment recommendations and care pathway designs

Some specific domain applications[1]

3. **Quality & Safety** → ensure the highest quality of care and patient safety.
    - *Examples:* Prediction of adverse events, deterioration of patients condition and readmissions
4. **Corporate Functions** → improving efficiency and steamlining administrative processes within healthcare.
    - *Examples:* automating various administrative tasks

Current healthcare costs[1,2]

- Healthcare costs globally are on the rise & clinical expertice is $$$.
- In the United States adoption of AI could save their healthcare system ~**$200 to $360 billion** (cost 2023: $4.7 trillion, 18% GDP).
    - Administration, medical knowledge, clinical operations, diagnostics
    - Three "big players": hospitals, payers, physicians/nurses

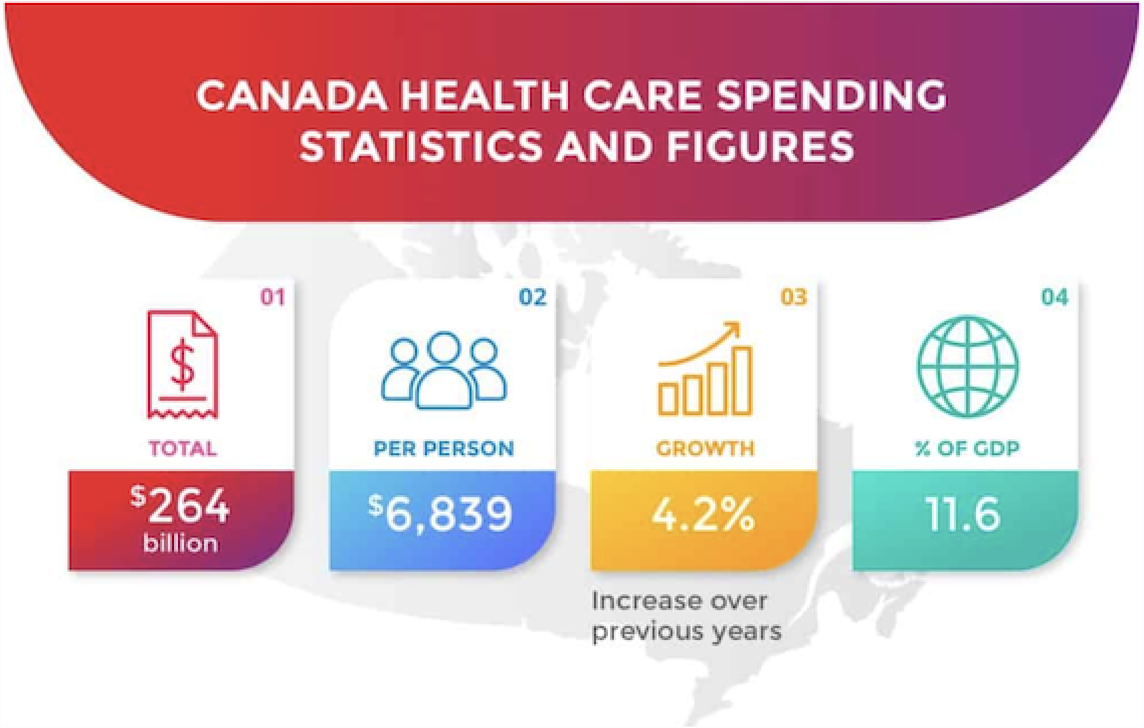


Figure 2. Hospital AI domains and example use cases

Domain	Description	Examples of AI-enabled use cases	Potential impact on total mission value[1] (Low – Med – High)	Position on technology adoption curve[2]	Cost category affected[3] (Admin – Medical)	Process type affected (Existing – New)
Continuity of care	Optimizing point-of-service and referrals to improve patient care	• Referral management • Patient transfers		D		
Network and market insights	Tracking relationship strength among providers	• Provider segmentation • Benchmarking (e.g., quality, cost effectiveness)		P		
Clinical operations	Optimizing clinical workflow and capacity throughout care journey	• Operations optimization (e.g., ED, OR, units)[4] • Capacity / bed management • Supply chain optimization		P		
Clinical analytics	Improving patient care journey with data at all points of care delivery	• Clinical decision support • Treatment recommendations • Care pathway design		P		
Quality and safety	Reducing major adverse events with special attention to patient experience and legal compliance	• Condition deterioration • Readmissions • Regulatory compliance		D		
Value-based care	Improving patient outcomes with value-based care models	• Patient stratification and risk scoring • Utilization management		P		
Reimbursement	Automating and optimizing payment flows between providers and payers	• Coding • Denials management		S		
Corporate functions	Managing back-office, administrative functions	• Talent management • Call center enablement		S		
Consumer	Understanding how best to engage consumers using tools	• Segmentation and channel preference • Personalized engagement	*Not included in sizing given use cases often are a net-zero activity across organizations*			

1. We define "total mission value" as the combination of financial and non-financial factors, such as quality outcomes, patient safety, patient experience, clinician satisfaction, and access to care.
2. D = development of solutions; P = piloting; S = scaling and adapting; M = mature.
3. Positioning represents the direct cost category affected; second order effects may also reduce costs, but are not estimated.
4. ED = emergency department; OR = operating room.

Source: Authors' analysis

Source: The Potential Impact of Artificial Intelligence on Healthcare Spending.

General Recipe

1. *Identify a challenge* where the application of AI can decrease process costs or enhance the efficiency and accuracy of tasks performed by clinicians.
2. *Develop an AI* choosing appropriate algorithms or models, and training it on relevant data.
3. *Employ the developed AI* to automate or enhance the specified task or process.

Breakout #1

Why would implementing AI/ML in healthcare be harder than in other fields?

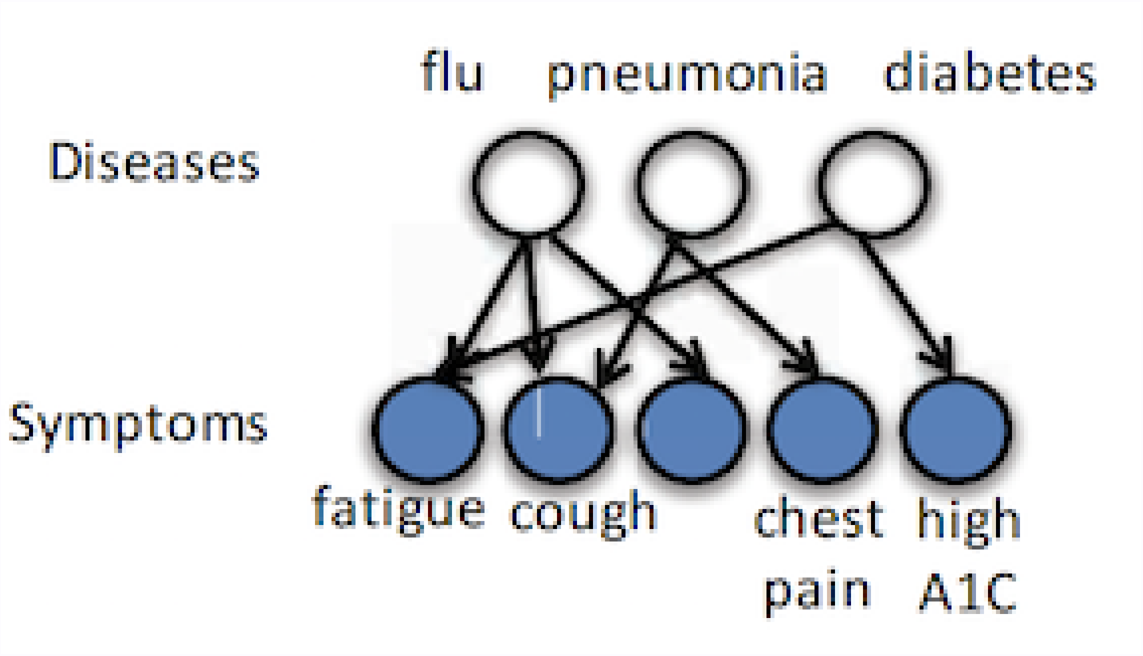
Brief history of AI in healthcare

1970s

- One of the earliest examples: **MYCIN system** developed at Stanford.[3]
- **Goal:** Assist physicians in the diagnosis and therapy selection for patients with bacterial infections based on symptoms and test results.
- **Performance of MYCIN**
  - *Algorithm Success:* Proposed a good therapy in 69% of cases.
  - *Comparison:* Comparable or better than the best infectious disease experts at the time.

1980s

- **INTERNIST-1** developed at University of Pennsylvania.[4]
- **Goal:** Automated diagnosis for general internal medicine.
- Utilized a probabilistic model to diagnose a patient's health based on thousands of symptom variables.



1990s

- **Neural networks** gained popularity in clinical medicine **research**.[5]
  - These networks were simpler than contemporary deep neural networks.
  - Utilized only a few features to make predictions.
  - Predictions were based on data collected through chart review.
- **Paving the Way for Modern Healthcare**
  - Despite their simplicity, and lack of adoption, these early applications paved the way for the hope that AI would one day be integrated into modern healthcare.

Why now

Evolution of AI in Medicine

- Traditional AI in medicine was not data-driven → mainly focused on leveraging domain knowledge.
- Adoption of *Electronic Medical Records* (EMRs) in the early 2010's increased dramatically, fueled by digital health funding.[6]
- Diversity of digital health → lab tests, vital signs, proteomics, imaging, social media etc...

Significance of *Big Data*

- The abundance of data presents a significant opportunity for ML applications in healthcare.
- Enables more comprehensive and data-driven approaches in diagnosis, treatment, and research.
- Some examples of high-performance AI in medicine (Aidoc, iCAD, IDx etc.)[7]

Table 2 | FDA AI approvals are accelerating

Company	FDA Approval	Indication
Apple	September 2018	Atrial fibrillation detection
Aidoc	August 2018	CT brain bleed diagnosis
iCAD	August 2018	Breast density via mammography
Zebra Medical	July 2018	Coronary calcium scoring
Bay Labs	June 2018	Echocardiogram EF determination
Neural Analytics	May 2018	Device for paramedic stroke diagnosis
IDx	April 2018	Diabetic retinopathy diagnosis
Icometrix	April 2018	MRI brain interpretation
Imagen	March 2018	X-ray wrist fracture diagnosis
Viz.ai	February 2018	CT stroke diagnosis
Arterys	February 2018	Liver and lung cancer (MRI, CT) diagnosis
MaxQ-AI	January 2018	CT brain bleed diagnosis
Alivecor	November 2017	Atrial fibrillation detection via Apple Watch
Arterys	January 2017	MRI heart interpretation

Adoption of AI in healthcare

- **Hype and Potential:**
  - Significant hype and recognized potential for AI in healthcare, despite fairly little adoption.
- **Lagging Behind Other Industries:**
  - AI adoption in healthcare lags behind its adoption in other industries (e.g., finance, information, technical services).[8]
  - Various factors contribute to the slower pace, including:
    - Regulatory barriers
    - Challenges in data collection
    - Algorithmic limitations
    - Misalignment of incentives

Challenges and Opportunities in applying AI in healthcare

Some Considerations When Applying AI to Healthcare

Available data is often limited

- Challenges with missing data, limited longitudinal data, heterogeneous samples, and small sample sizes, especially for rare diseases.

Opportunity

- Innovation in handling sparse data, addressing challenges in data imputation and statistical methods.

Some Considerations When Applying AI to Healthcare

Poor data quality

- AI algorithm performance depends on the quality of available data.
- Challenges lie in heterogeneous sampling, diverse data types, and varying time scales.
- Sparse data with unmeasured and unreported values, lack of follow-up.

Opportunity

- Development of algorithms capable of making robust and generalizable predictions even when data is missing.

Some Considerations When Applying AI to Healthcare

Scarse Labelled data

- Limited labeled data in healthcare due to challenges in obtaining consensus among clinicians, and clinican time is expensive!

Opportunity

- Leveraging unsupervised or semi-supervised learning for discovery, including identifying disease subtypes and predicting disease progression.

Some Considerations When Applying AI to Healthcare

Human centric decisions

- In healthcare, there is often decision-making in critical scenarios, including life and death situations.
- Ethical responsibility of AI developers and healthcare professionals to prioritize patient well-being.

Opportunity

- Develop fair and accountable algorithms for risk stratification and prioritizing resources based on predictions.

Some Considerations When Applying AI to Healthcare

Regulatory and Privacy Barriers:

- Regulatory barriers make it challenging to collect and pool healthcare data.
- Sensitivity of healthcare data poses difficulties in de-identifying information.

Opportunity

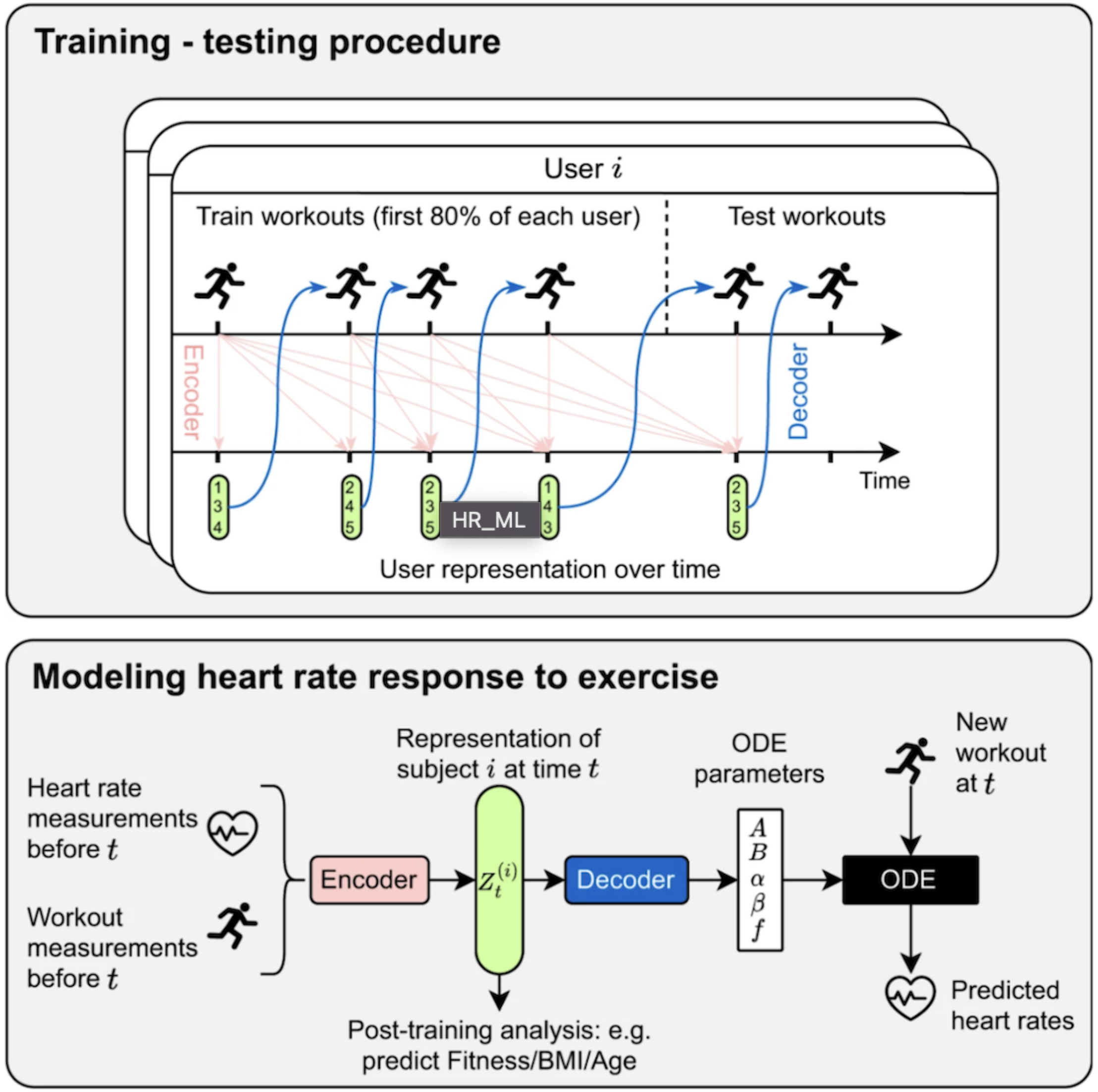
- Innovations in privacy-preserving technologies to navigate regulatory challenges, fostering data de-identification and secure data sharing.

Breakout #2

What are other challenges you think might limit the adoption of AI/ML tools in healthcare? What would it take to solve them?

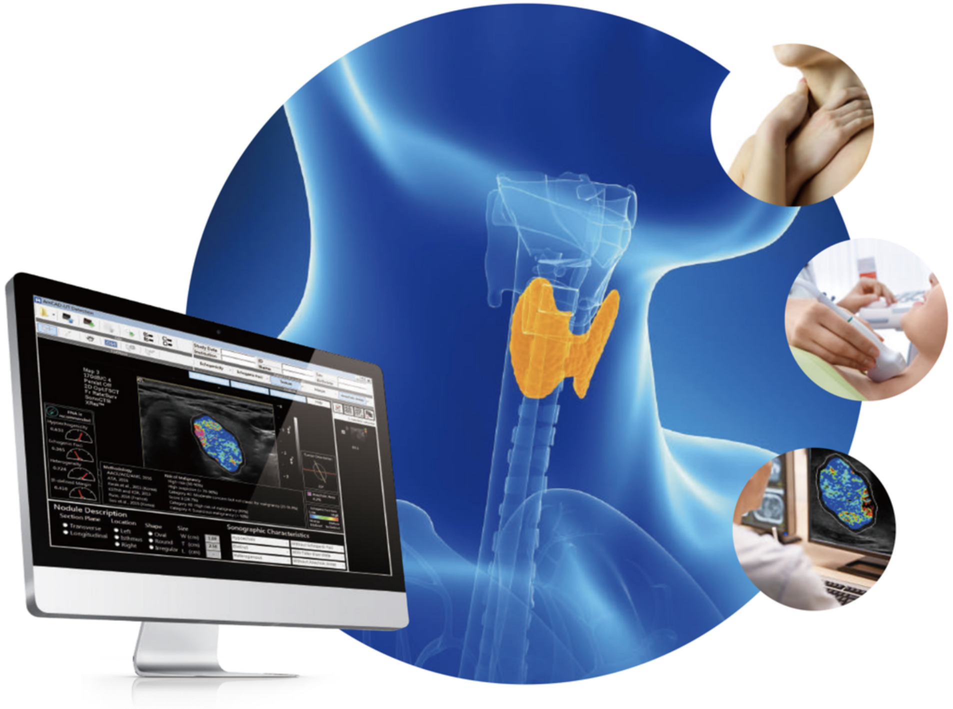
Examples successful applications in healthcare

Using ML to model heart rate response to exercise [9]



Using ML to guide decisions for cancer therapy [10]

AM-cad - Thyroid Cancer detection software



World's First Ultrasound CAD for Thyroid Cancer Detection.

And many more!

- Embryo selection for IVF
- Genome interpretation for sick newborns
- Paramedic diagnosis of heart attack, stroke
- Assist readings of imaging scans
- Classification of cancer, identify mutations
- etc.

> Examples adapted from Topol, E. J. (2019) [11]

Examples of failed applications in healthcare

Watson

- **Watson Health** was developed by IBM (International Business Machines Corporation). [12]
- It aimed to provide insights to oncologists about cancer treatment, assist pharmaceutical companies in drug development, and match patients with clinical trials, showcasing the potential of AI in healthcare.
- Despite significant investment and high expectations, Watson Health faced challenges in meeting its goals; company ultimately sold parts to a private equity firm.

Epic Sepsis Model

- **Epic Sepsis Model Issues → Lack of reproducibility:**
  - Peer-reviewed data questioned the effectiveness of Epic's sepsis prediction algorithm.[13]
  - University of Michigan Medical School study with over 27,000 patients found its performance "substantially worse" than reported.
- **Study Concerns:**
  - Lack of external validation for proprietary models and a call for transparency and validation before widespread clinical use.

Breakout #3

How would AI be used for "*Embryo selection for IVF*" and what problems (ethical, practical, etc) would this present?

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