Beth Israel Deaconess Medical Center

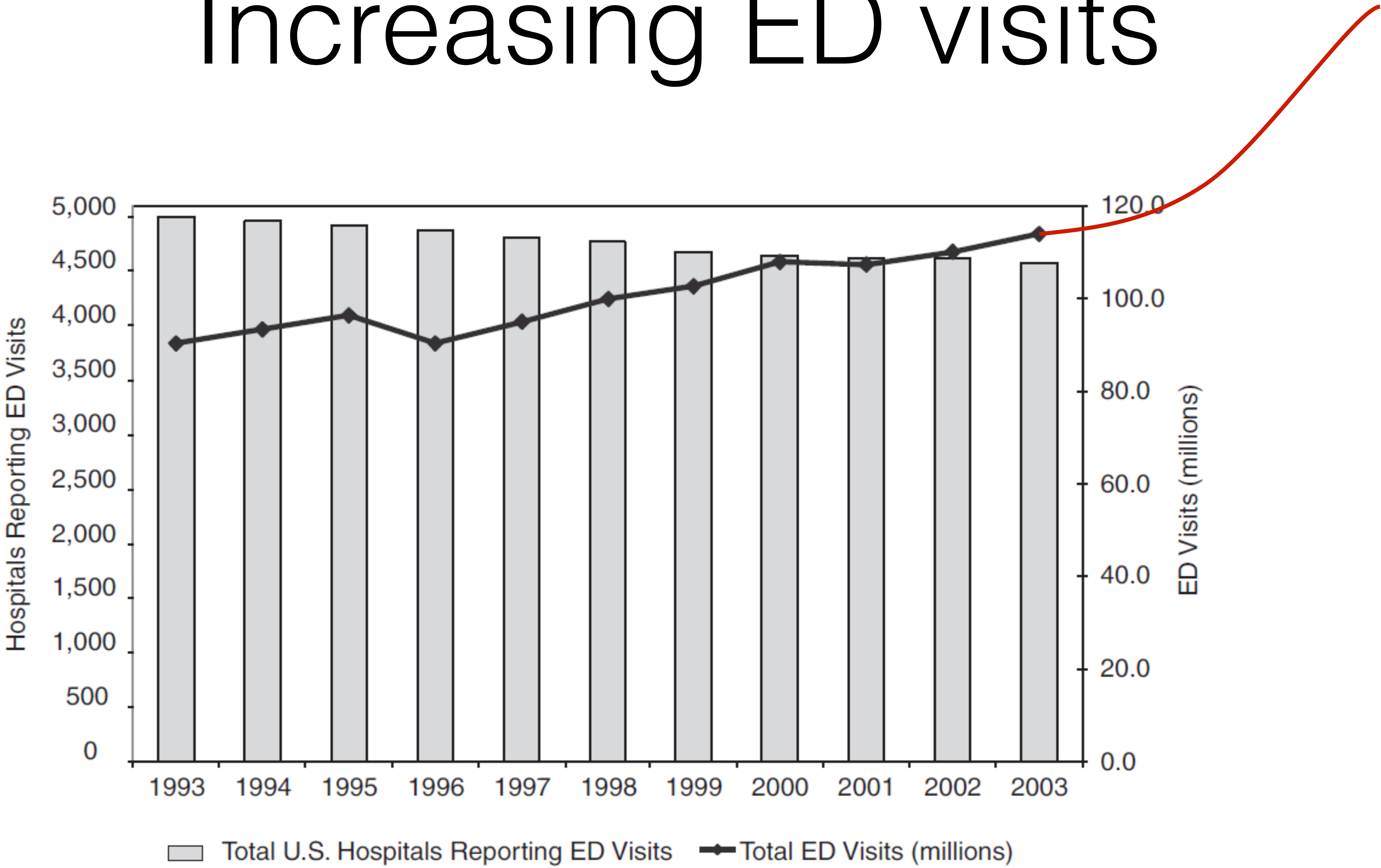
A teaching hospital of Harvard Medical School

Machine Learning at BIDMC:

augmenting clinical workflows

Steven Horng, MD MMSc FACEP
Clinical Lead for Machine Learning
June 25, 2019

Increasing ED visits

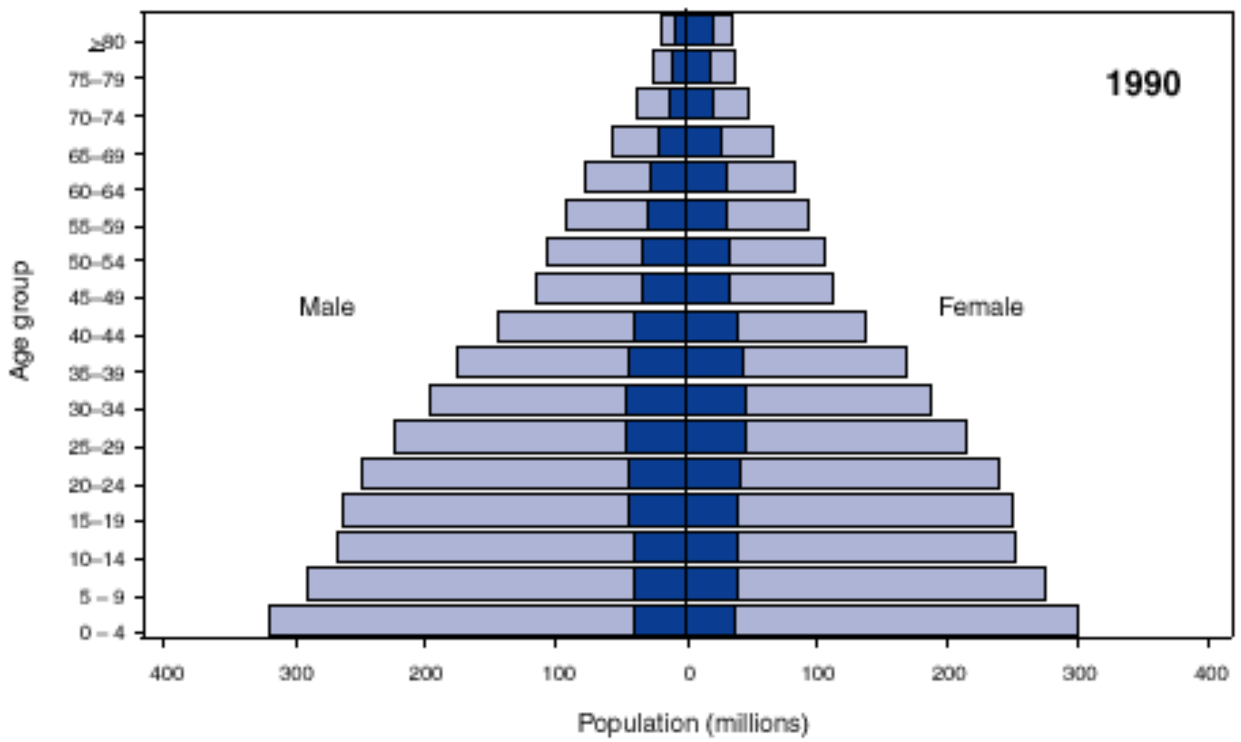


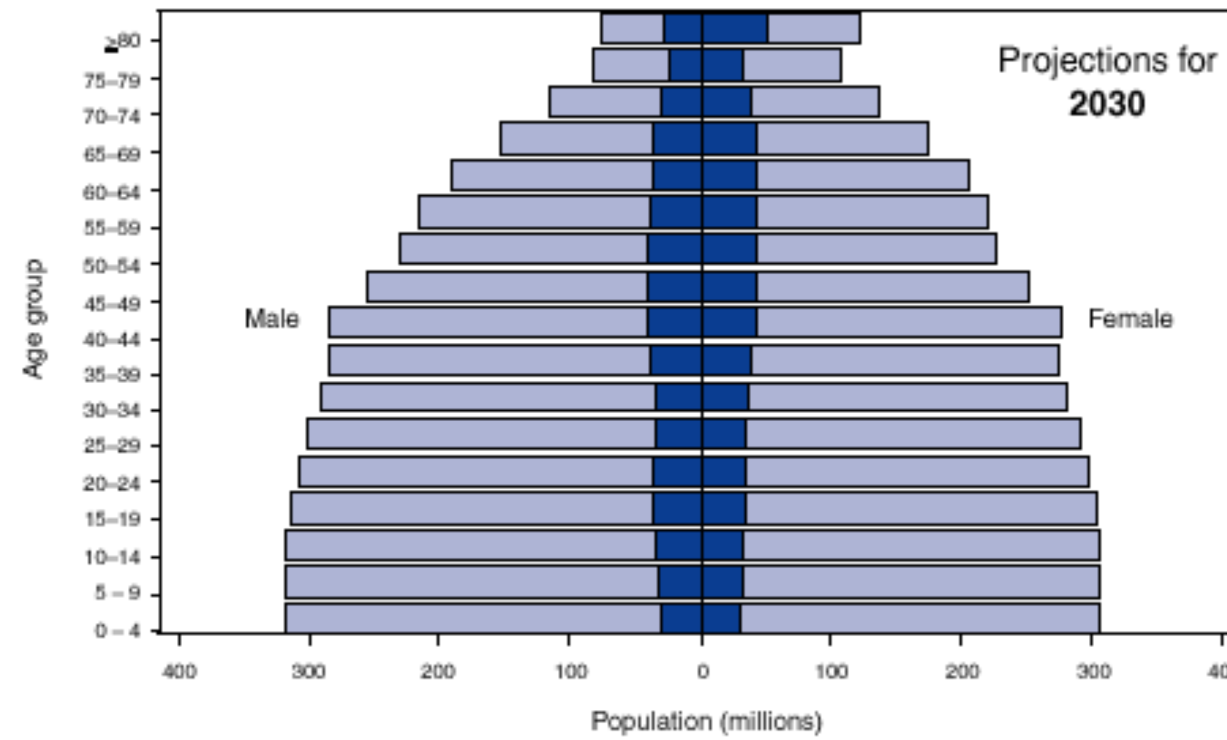
↑ Life Expectancy

↓ Fertility Rate

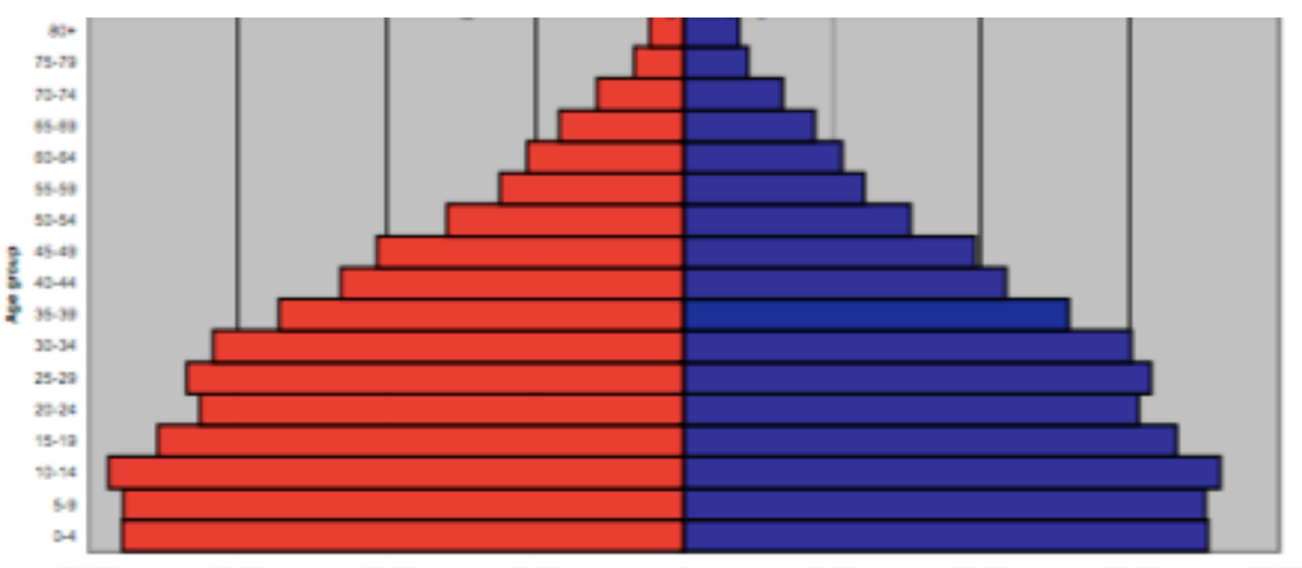
Shifting Age Demographic

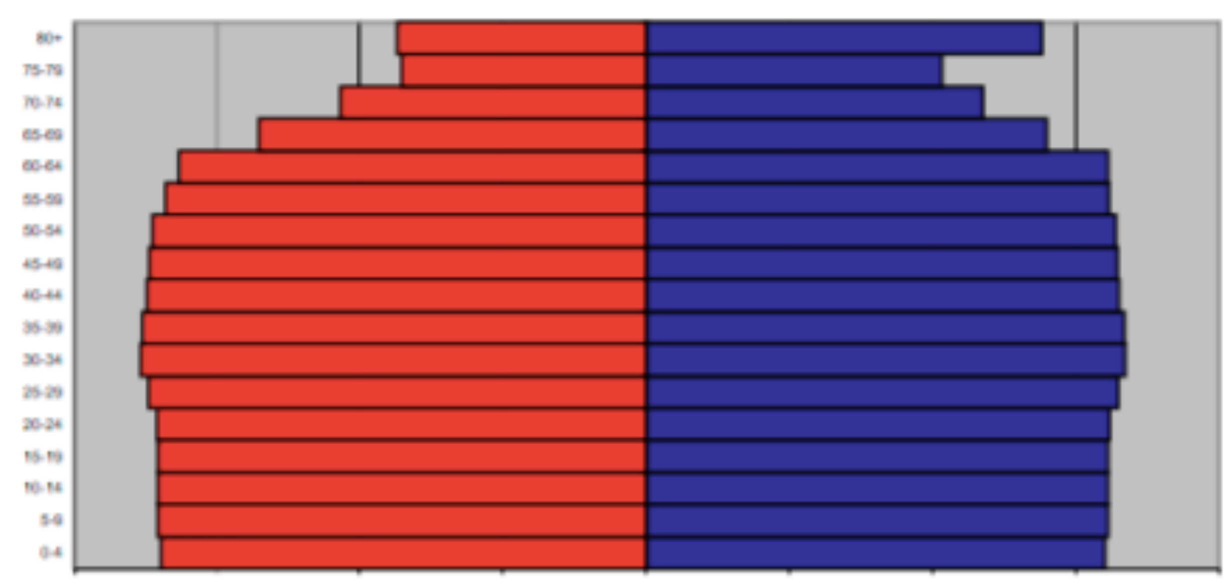
USA



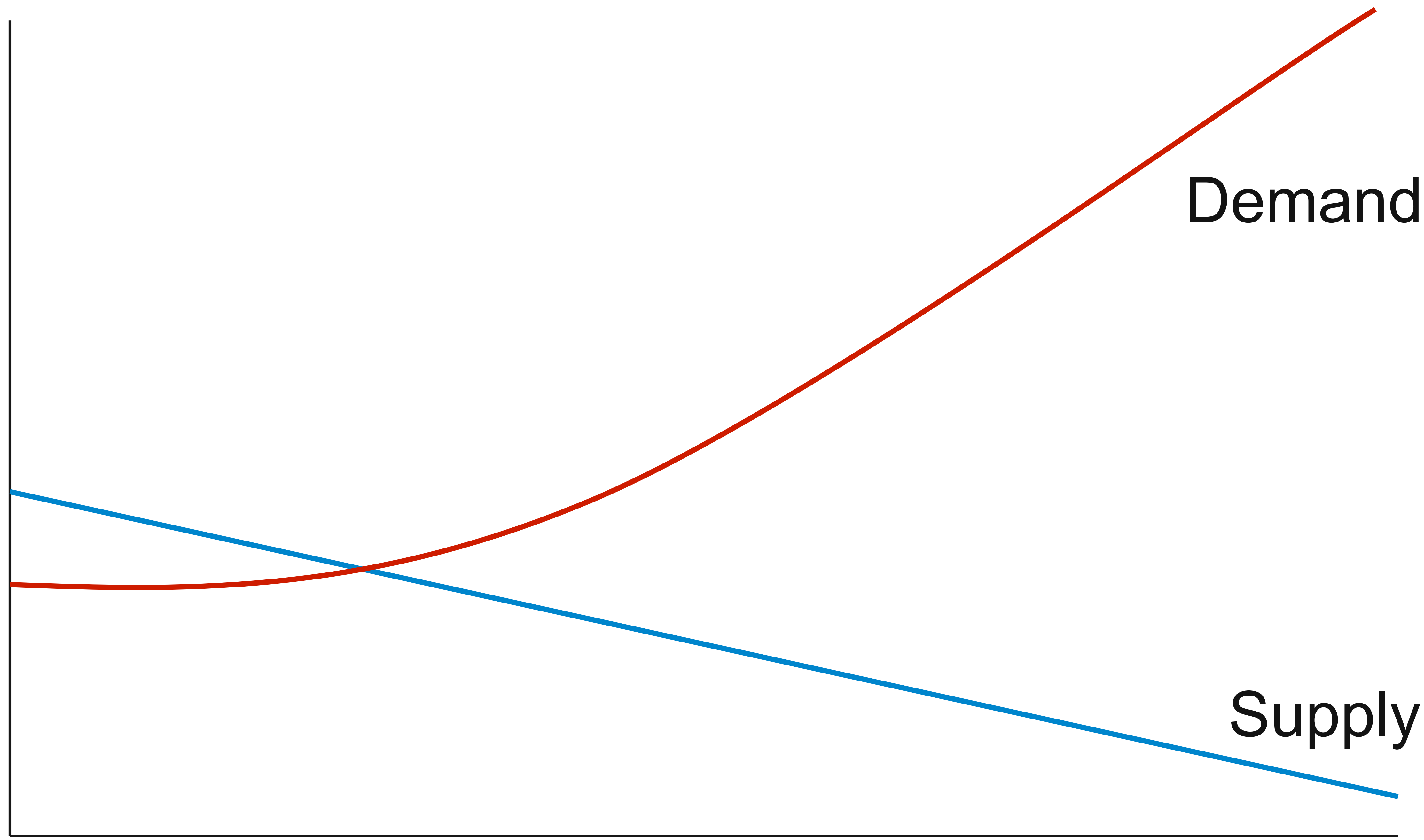


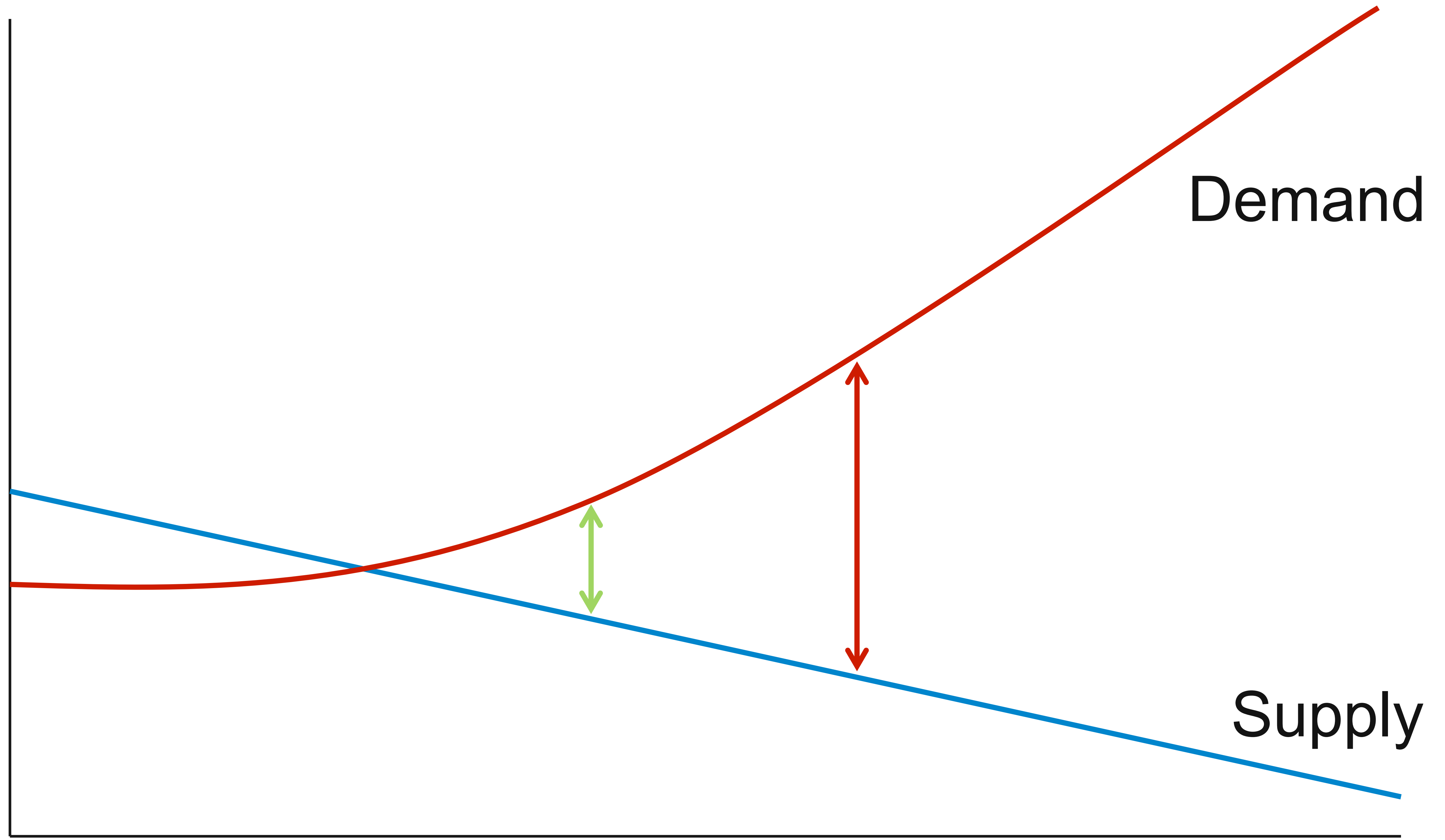
Asia





Supply - demand mismatch




Demand
Supply

Need to fundamentally change our care processes

Recent Advances in Machine Learning

Speech Recognition

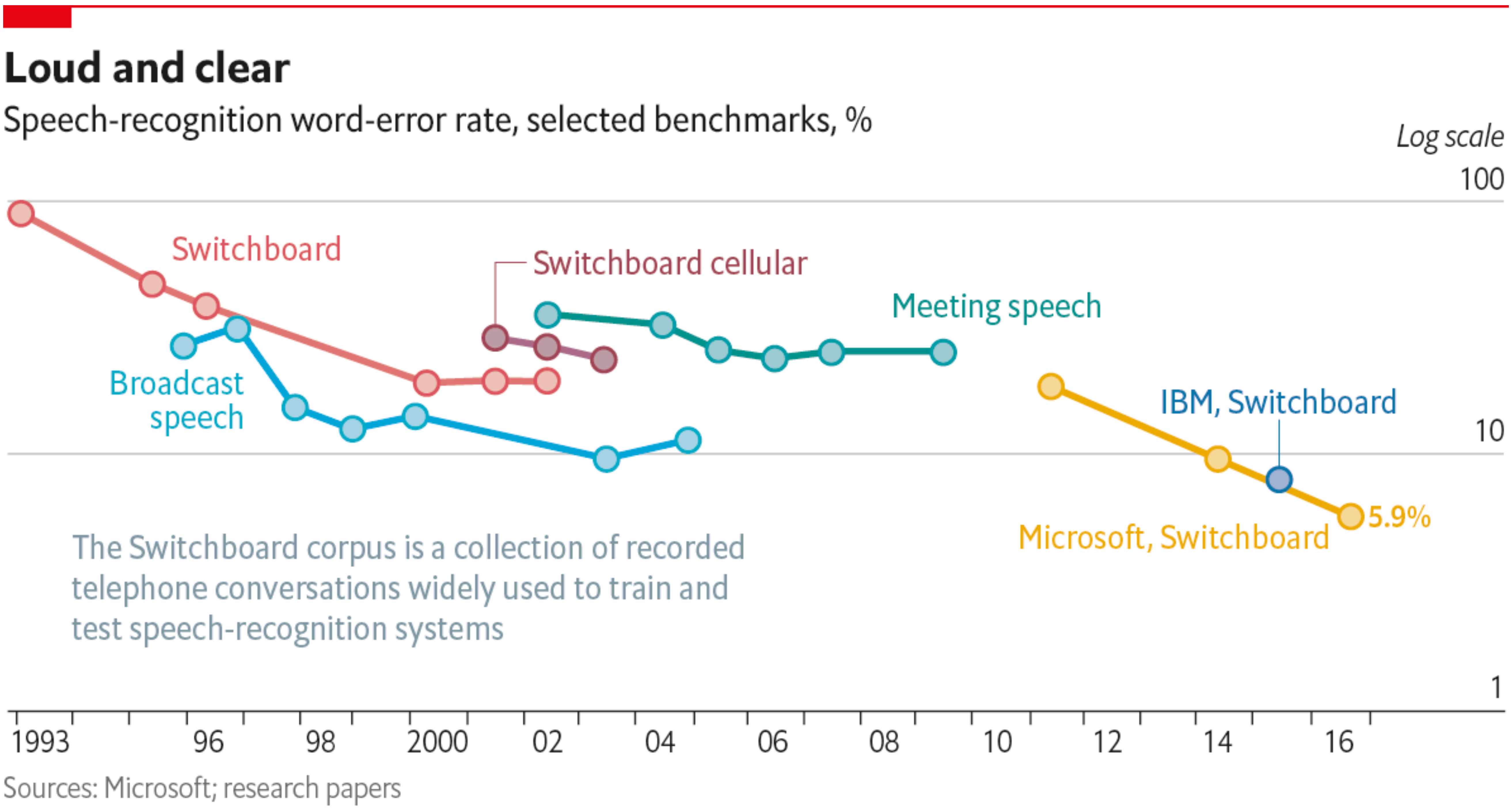
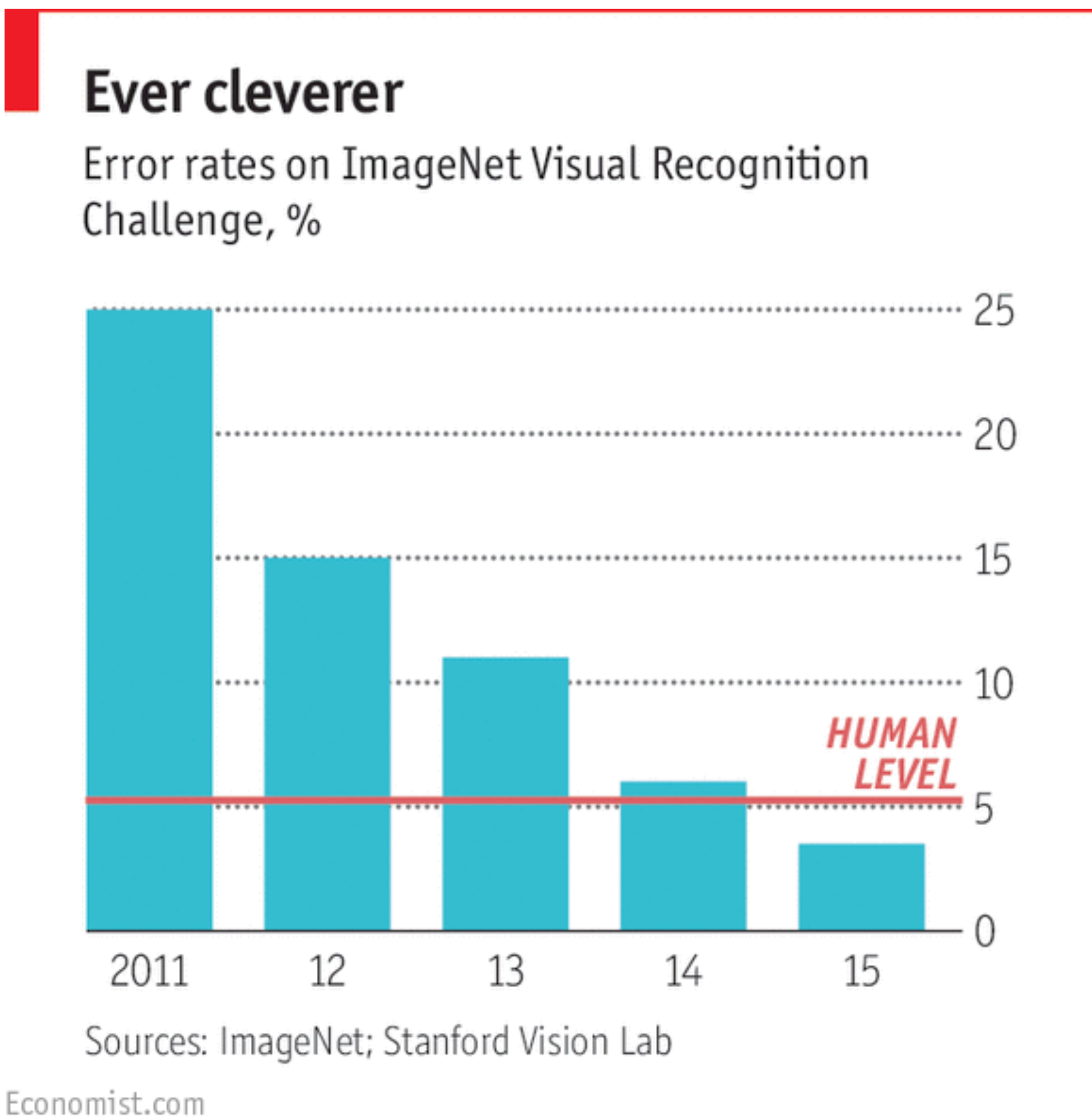
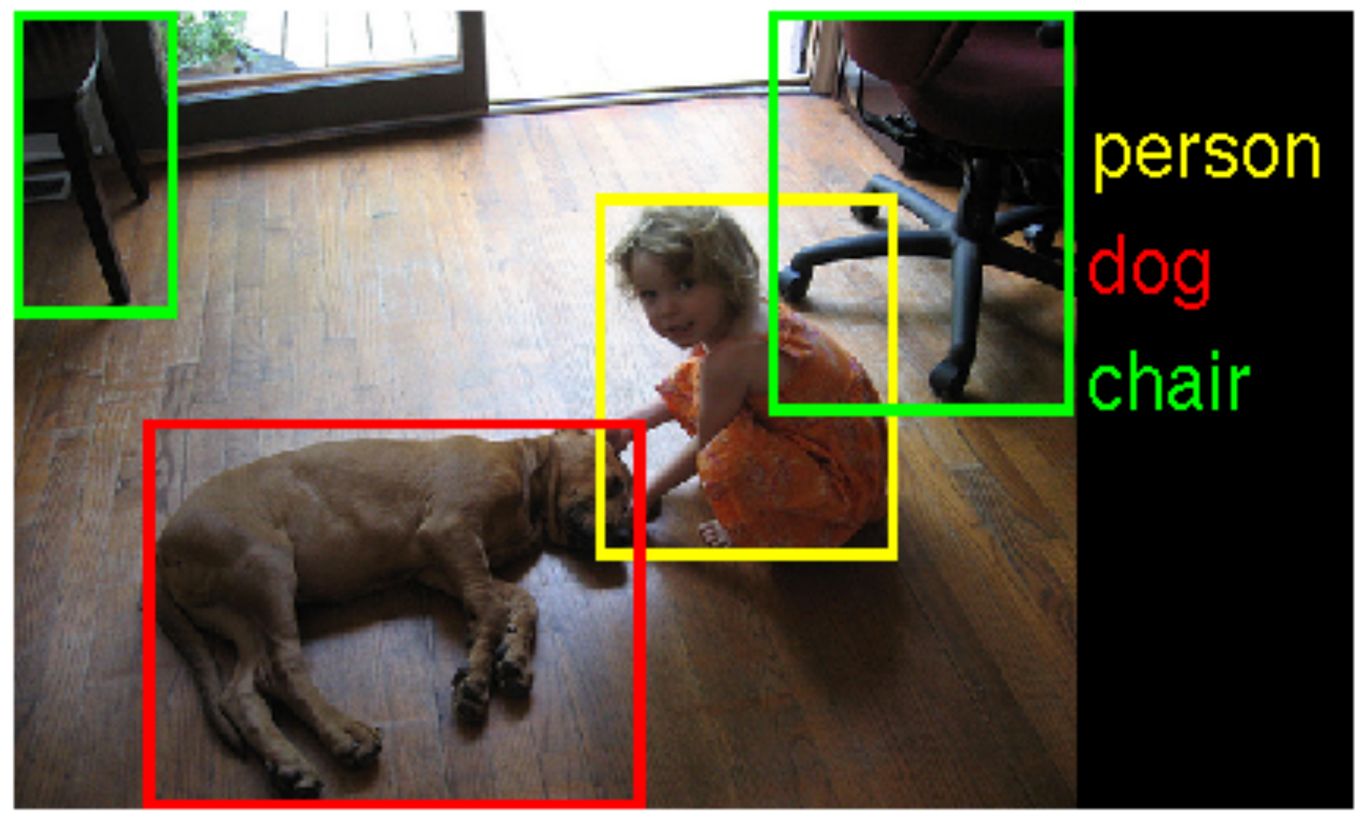


Image Recognition



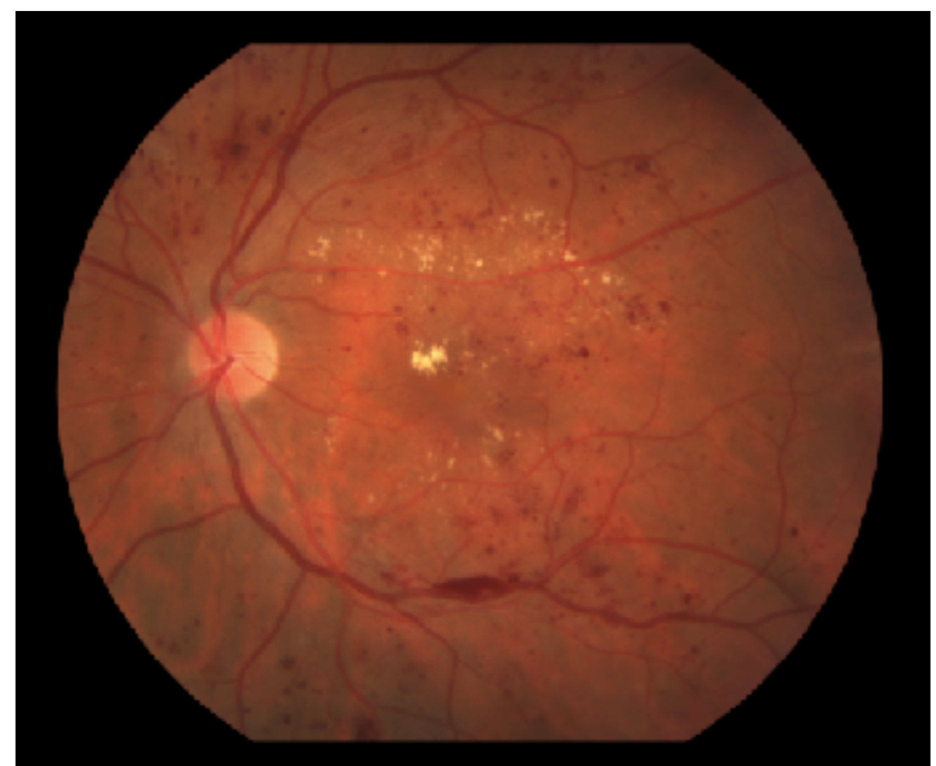


JAMA | Original Investigation | INNOVATIONS IN HEALTH CARE DELIVERY

Development and Validation of a Deep Learning Algorithm for Detection of Diabetic Retinopathy in Retinal Fundus Photographs

Varun Gulshan, PhD; Lily Peng, MD, PhD; Marc Coram, PhD; Martin C. Stumpe, PhD; Derek Wu, BS; Arunachalam Narayanaswamy, PhD; Subhashini Venugopalan, MS; Kasumi Widner, MS; Tom Madams, MEng; Jorge Cuadros, OD, PhD; Ramasamy Kim, OD, DNB; Rajiv Raman, MS, DNB; Philip C. Nelson, BS; Jessica L. Mega, MD, MPH; Dale R. Webster, PhD

Normal



Diabetic Retinopathy

MENU
nature
International journal of science

Altmetric: 2555 Citations: 85 More detail »

Letter

Dermatologist-level classification of skin cancer with deep neural networks

Andre Esteva, Brett Kuprel, Roberto A. Novoa, Justin Ko, Susan M. Swetter, Helen M. Blau & Sebastian Thrun

Nature **542**, 115–118 (02 February 2017)
doi:10.1038/nature21056
Download Citation

Diagnosis | Machine learning | Skin cancer

Received: 28 June 2016
Accepted: 14 December 2016
Published online: 25 January 2017

Corrigendum: 28 June 2017

Cardiologist-Level Arrhythmia Detection with Convolutional Neural Networks

Pranav Rajpurkar* PRANAVSR@CS.STANFORD.EDU
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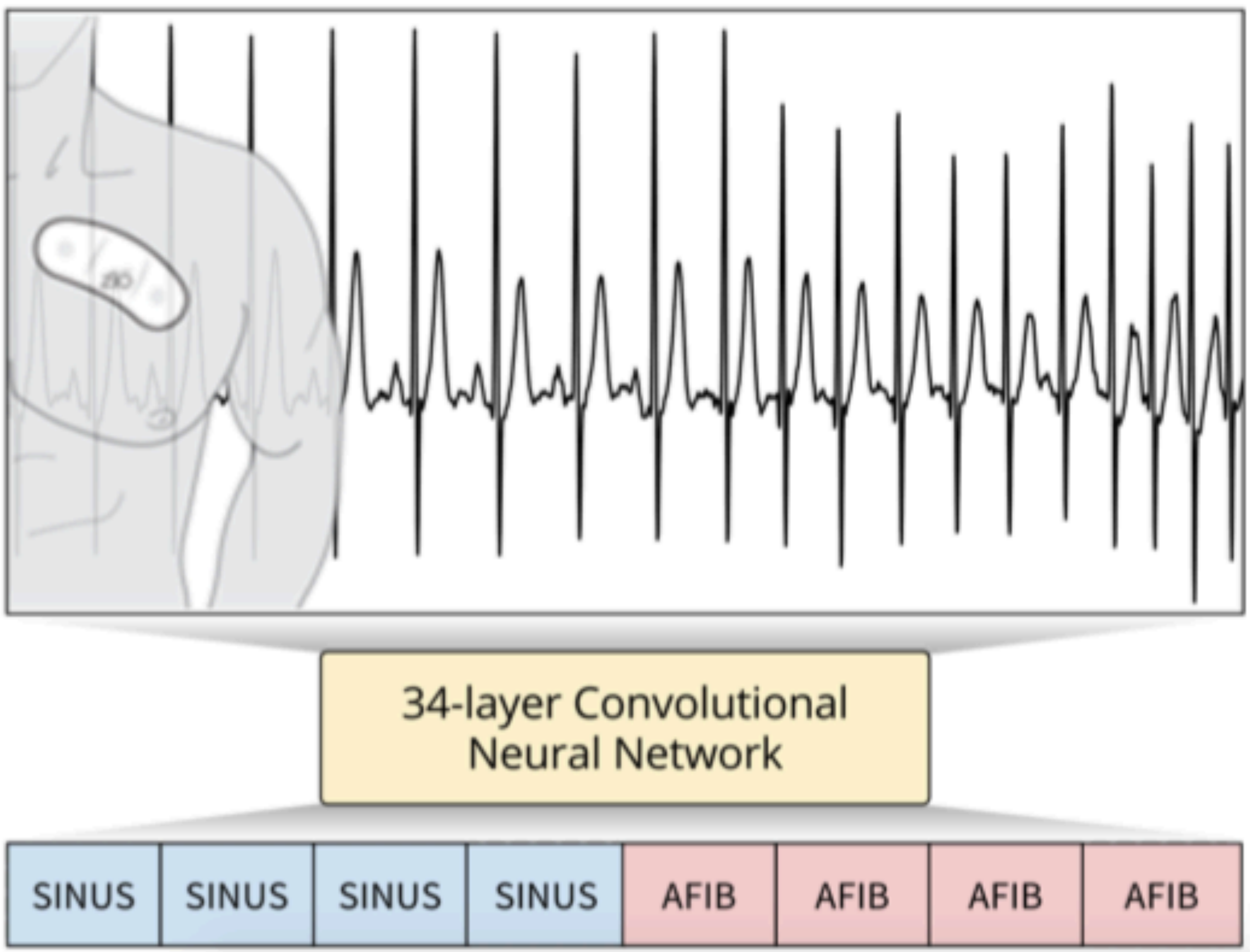
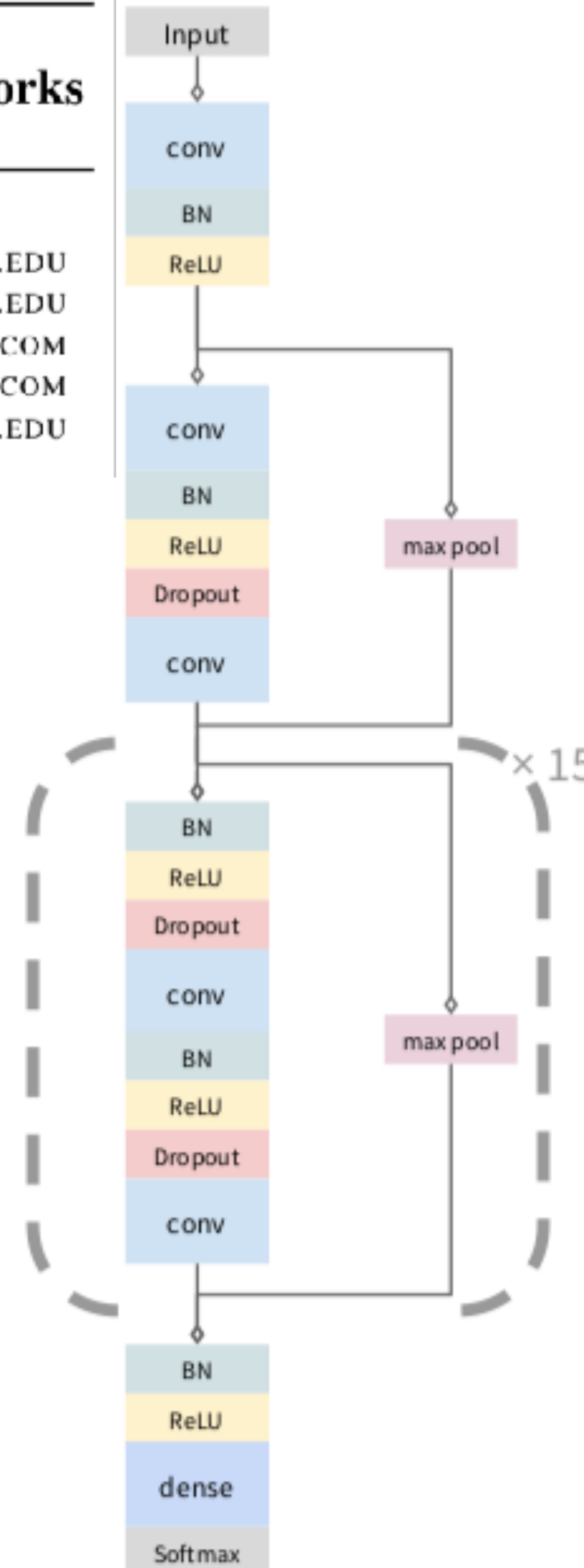
Masoumeh Haghpanahi MHAGHPANAHI@IRHYTHMTECH.COM
Codie Bourn CBOURN@IRHYTHMTECH.COM
Andrew Y. Ng ANG@CS.STANFORD.EDU

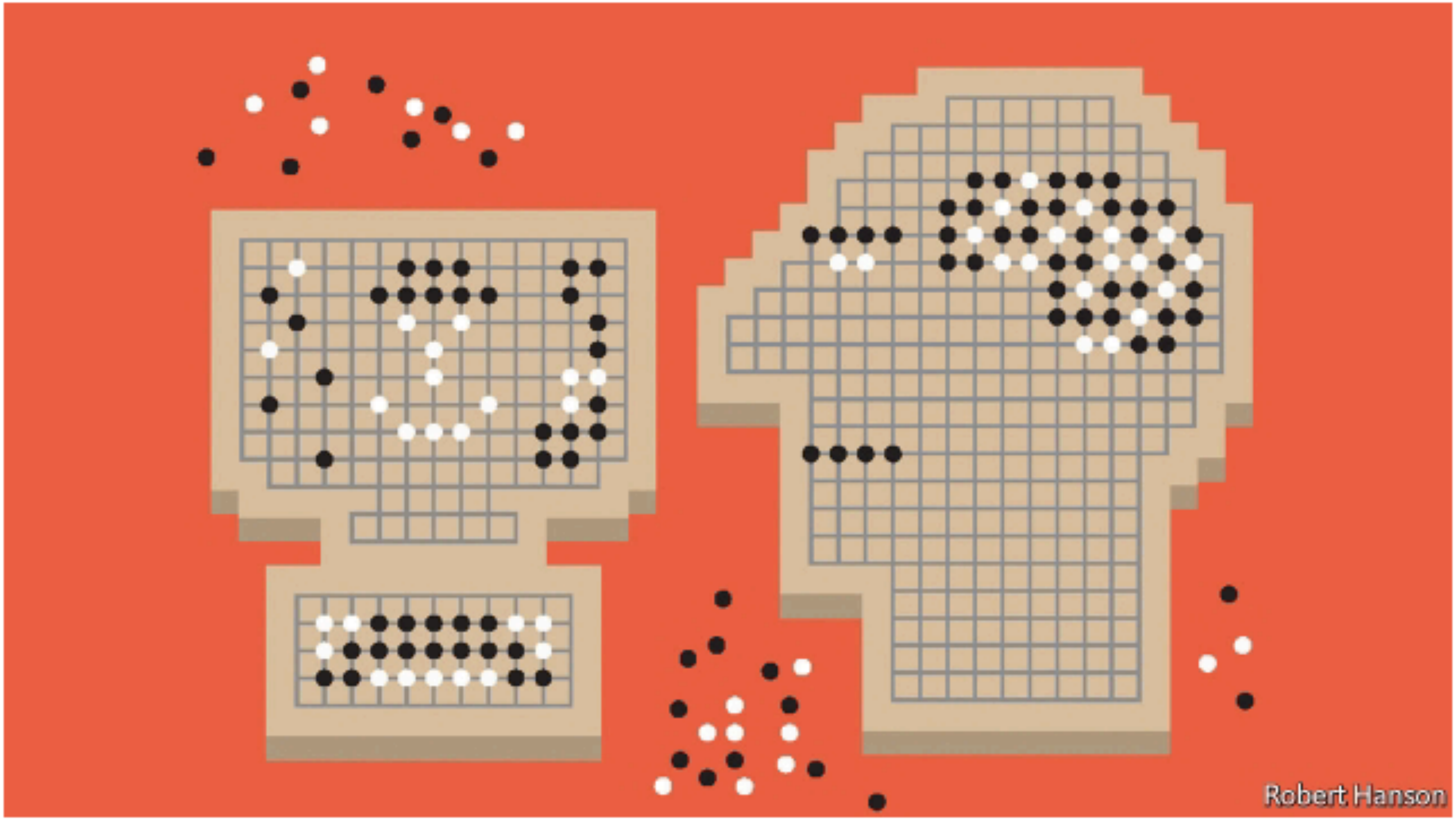




Artificial intelligence

The latest AI can work things out without being taught

Learning to play Go is only the start



Why the sudden jump?

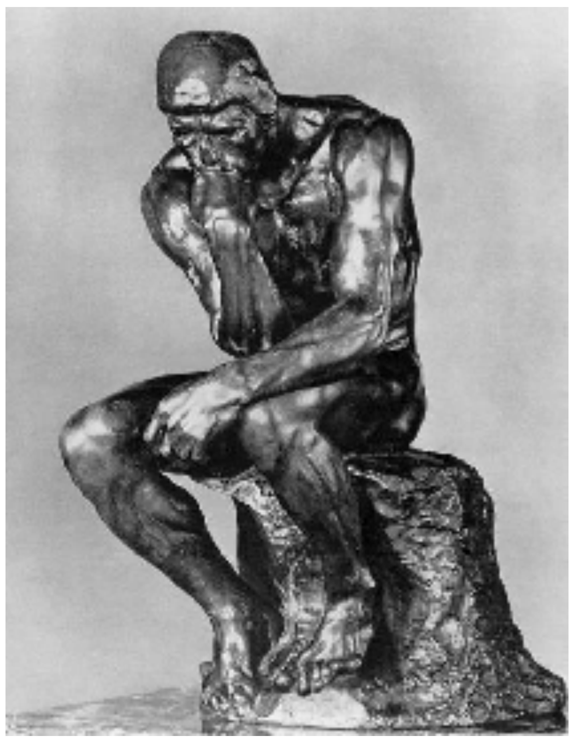
- Better at math?
- Large amounts of Data
- Increased Computational Capacity

Do we really need doctors?

Do doctors really need computers?

How do we get computers
to **help us** and **not hurt us**?

What are **humans** really good at?



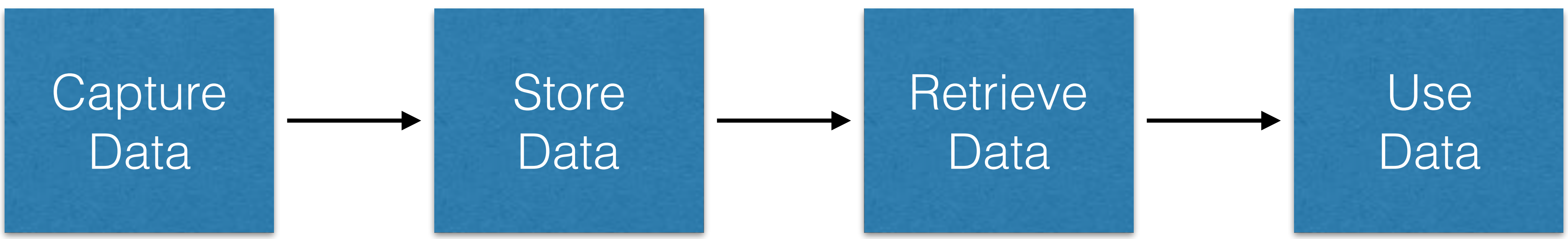
What are **computers** really good at?

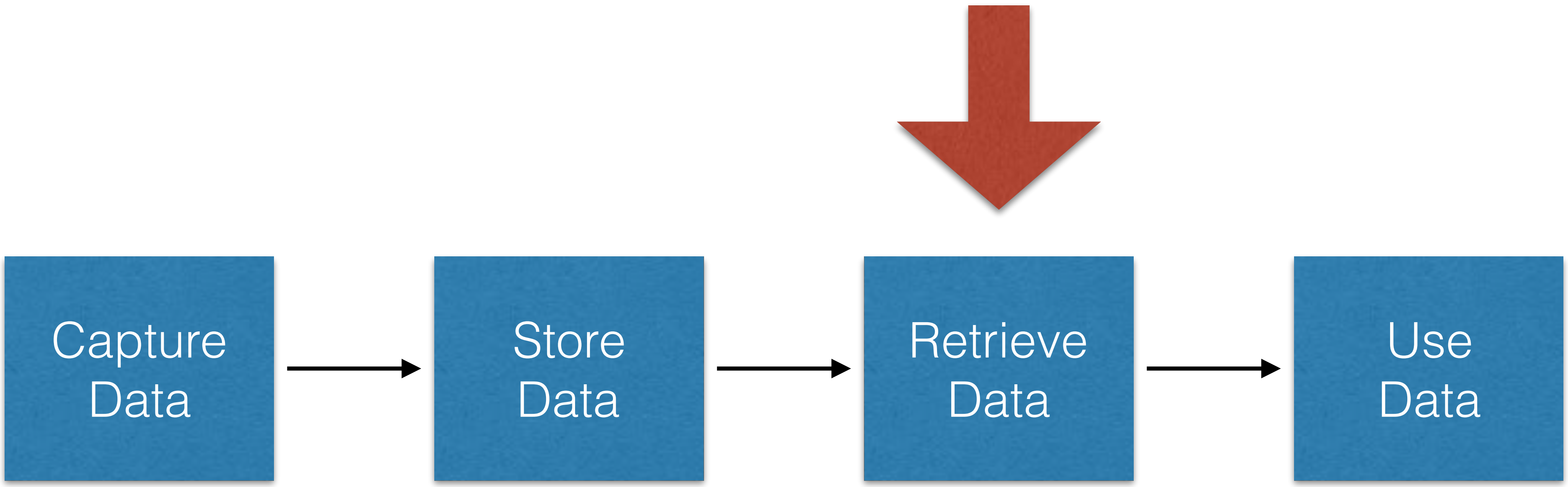
$$P(\boldsymbol{Z}, \boldsymbol{W}; \alpha, \beta) = \int_{\boldsymbol{\theta}} \int_{\boldsymbol{\varphi}} P(\boldsymbol{W}, \boldsymbol{Z}, \boldsymbol{\theta}, \boldsymbol{\varphi}; \alpha, \beta)\, d\boldsymbol{\varphi}\, d\boldsymbol{\theta}$$

$$= \int_{\boldsymbol{\varphi}} \prod_{i=1}^{K} P(\varphi_i; \beta) \prod_{j=1}^{M} \prod_{t=1}^{N} P(W_{j,t} | \varphi_{Z_{j,t}})\, d\boldsymbol{\varphi} \int_{\boldsymbol{\theta}} \prod_{j=1}^{M} P(\theta_j; \alpha) \prod_{t=1}^{N} P(Z_{j,t} | \theta_j)\, d\boldsymbol{\theta}.$$

Old Paradigm	New Paradigm
Capture Once, Use Once	Capture Once, Use Many Times
Know exactly how data will be used	Can not anticipate future secondary use of data
Schema on Write (highly structured data)	Schema on Read (less structured data)

Can’t just be about storage
Needs to **provide value**


Capture Data
Store Data
Retrieve Data
Use Data


Capture Data
Store Data
Retrieve Data
Use Data

murmur [Search]

All 761 ☑ omr 740 ☑ ops 21

TESTING

94 search results. (0.0106 seconds)

1. Followup (Progress note) omr

06/10/2015 Ayad Hamdan (Hematology/Oncology)

or thrush. Heart: Regular rate and rhythm. Normal S1, S2. No **murmurs**, rubs, or gallops. Lungs: Clear to auscultation bilaterally without rhonchi, rales

2. CHRONIC OBSTRUCTIVE PULMONARY DISEASE (Initial note) omr

06/02/2015 Douglas Beach (Pulmonary)

lymphadenopathy. Chest: Wheezing on exam Cardiac: Normal s1 and s2. No **murmurs** appreciated. No accentuated second heart sound or RV heave. Extremities: No edema

3. Discharge Summary (Disch Sum) ops

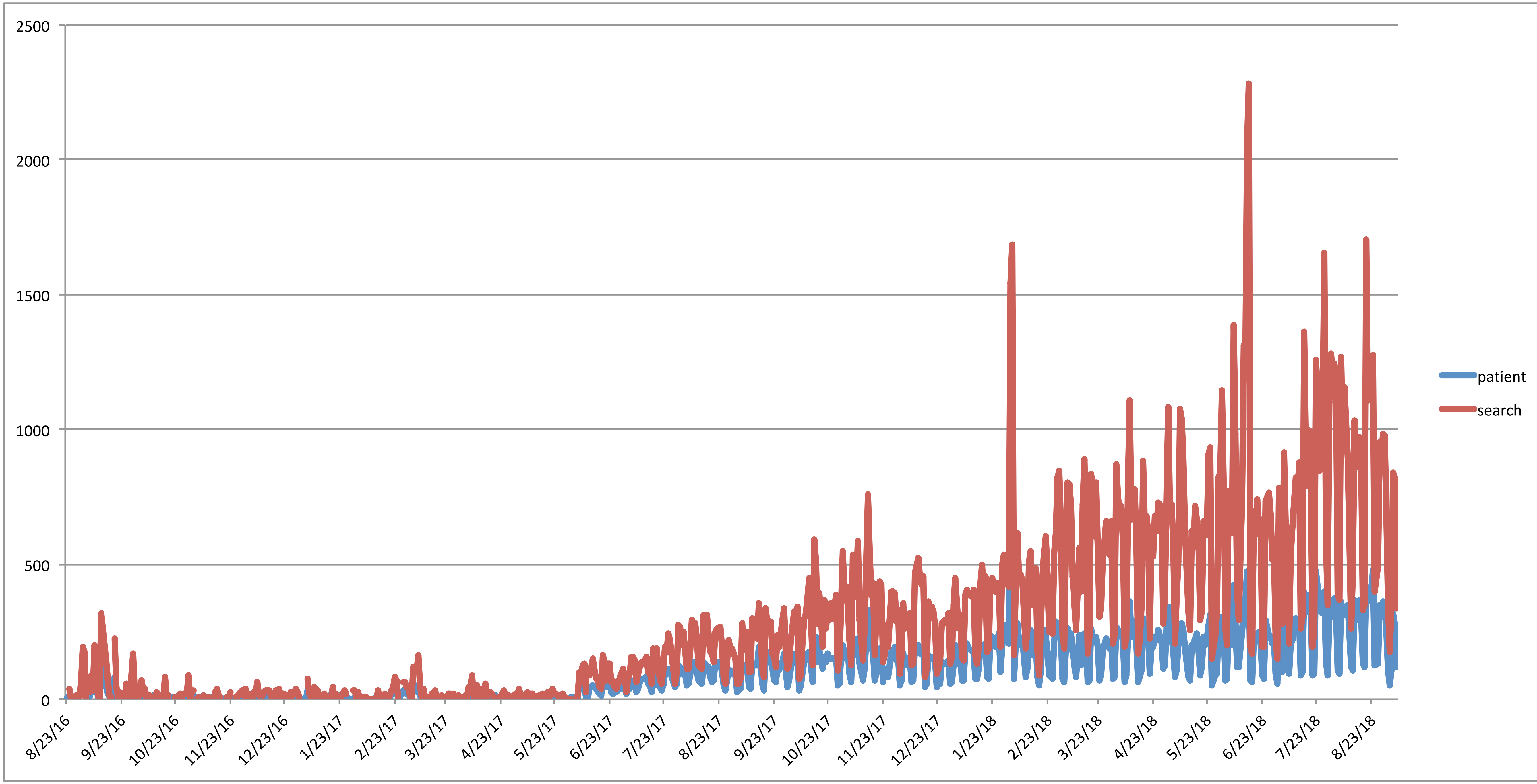
04/21/2015 Meghan J Campo (unknown)

to assess due to body habitus CARDIAC: tachycardic, S1/S2, no **murmurs**, gallops, or rubs LUNG: Diffusely wheezing ABDOMEN: nondistended, +BS, nontender...cough compred to prior CV: Regular rate and rhythm, normal S1 + S2, no **murmurs**, rubs, gallops Abdomen: soft, non-tender, non-distended, no pain on deep palpation

4. Follow-up (Progress note) omr

09/10/2014 Ayad Hamdan (Hematology/Oncology)

or adenopathy. Heart: Regular rate and rhythm. Normal S1, S2. No **murmurs**, rubs, or gallops. Lungs: Clear to auscultation bilaterally without rhonchi, rales



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patient
search

Contextual Information Retrieval

- Cardiac Info (10)

DM: metformin
HTN: metoprolol tartrate
Tobacco: None
FH: Father w/ hx of etoh abuse, passed away from MI @ 70s, first one in 50s. Paternal grandmother with CVA and paternal grandfather with MI in the 70s. mother with OCD. [12/19/2014 17:13]

10/20/2015	Echo	
09/30/2013	Echo	Normal left ventricular cavity size with mild global hypokinesis c/w diffuse process (toxin, metabolic, etc., CAD cannot be fully excluded, but less likely). Mild mitral regurgitation with normal valve morphology. Compared with the report of the prior study (images unavailable for review) of 8/19/2004, global left ventricular ejection fraction is more reduced. CLINICAL IMPLICATIONS: Based on 2007 AHA endocarditis prophylaxis recommendations, the echo findings indicate prophylaxis is NOT recommended. Clinical decisions regarding the need for prophylaxis should be based on clinical and echocardiographic data. Electronically signed by Warren J. Manning, MD on 10/1/2013 17:43.
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02/09/2006	NUCLEAR	No anginal symptoms or ischemic EKG changes noted. Nuclear report sent separately.
07/28/2005	NUCLEAR	Non-anginal chest discomfort and no ischemic ST changes at limited/fair exercise capacity. Nuclear imaging under separate report.
10/11/2004	NUCLEAR	No anginal type symptoms or ischemic EKG changes. Nuclear report sent separately.
08/19/2004	Echo	
05/25/2004	Cath	1. Coronary angiography of this right dominant circulation revealed singe vessel CAD. The LMCA had no signifcant stenoses. The LAD had minor luminal irregularities. The LCX had a 90% hazy lesion of a large OM1 with TIMI 2 flow. The RCA had no obstructive disease. 2. Resting hemodynamics showed elevated LV filling pressures. 3. Left ventriculography showed no wall motion abnormalities and an EF of 56%. 4. Successful stenting of the OM1 with 2.5 x 20 mm Taxus DES at 14 atms and successful PTCA of the mid OM1 with 2.0 x 15 mm open sail balloon at 6 atms with no residual stenosis in the stented segment, 25% residual stenosis in the mid OM1, no dissection and timi 3 flow. See PTCA comments.
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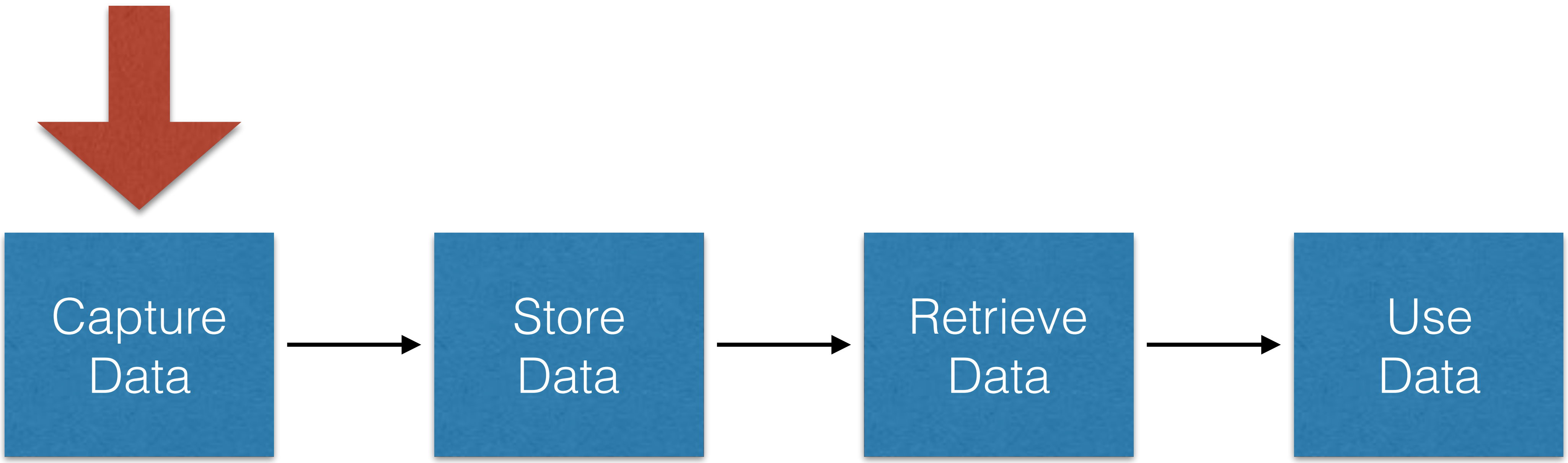


Capture Data
Store Data
Retrieve Data
Use Data

Structured Chief Complaints

- Almost always entered as free text
- Structured chief complaints have great utility
  - Clinical Decision support
  - Research
  - QA
  - Epidemiology

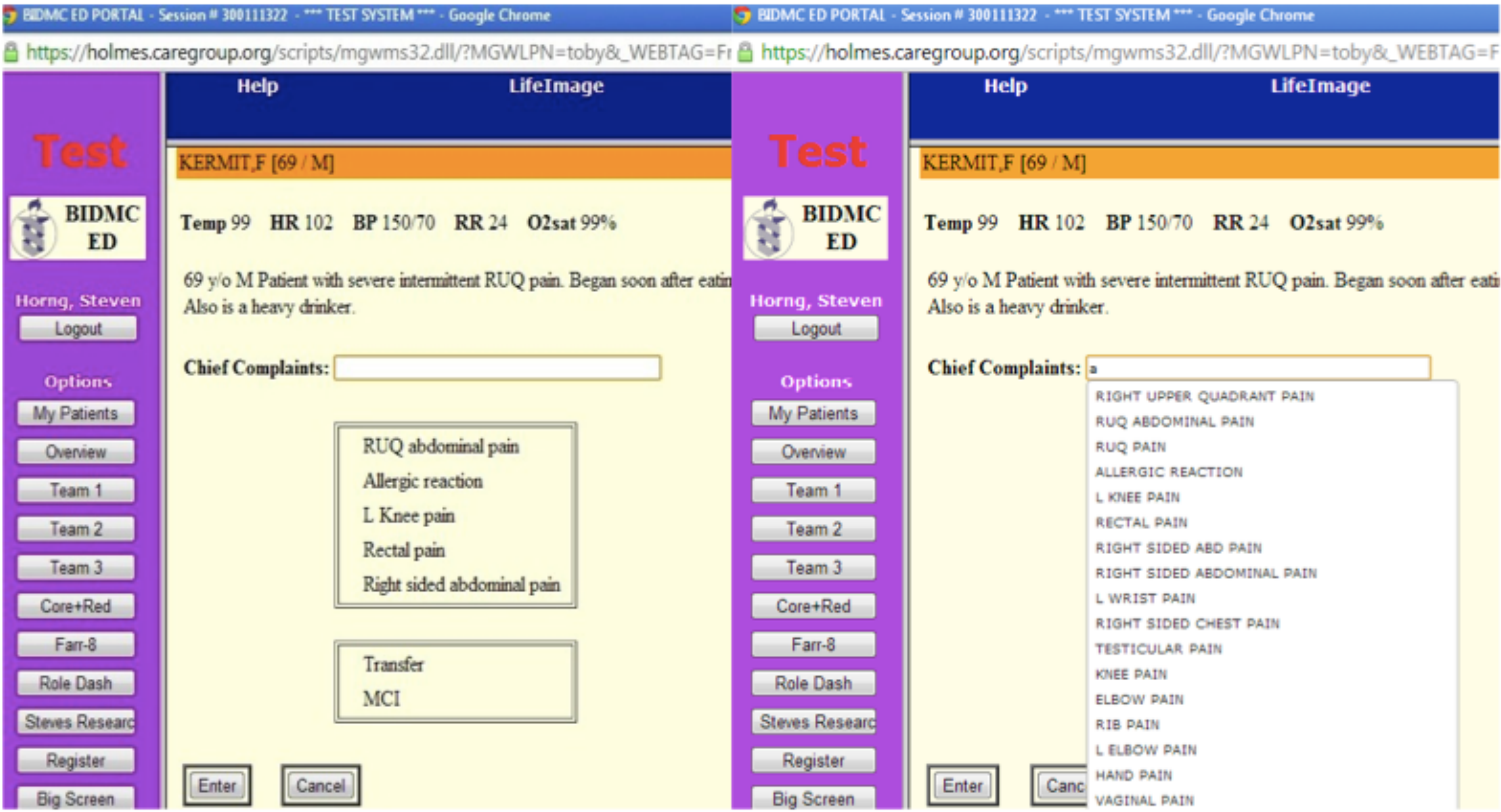
Standard vocabulary / ontology

Small vocabulary	Large vocabulary
Easy to learn and use	Difficult to learn and use
Reproducible	Quality dependent on user training and motivation
Too general, often times not accurately representing the chief complaint	Very specific, well representing the chief complaint if used properly

Probabilistic Inference for Chief Complaint UI

- **Essentially a Diagnosis Problem**
- Probabilistic Inference based on all available data(Age, Sex, Vital signs,Emergency Severity Index, Medical Problems, labs, etc.)
- Implemented as Contextual Auto-complete

Chief Complaint UI

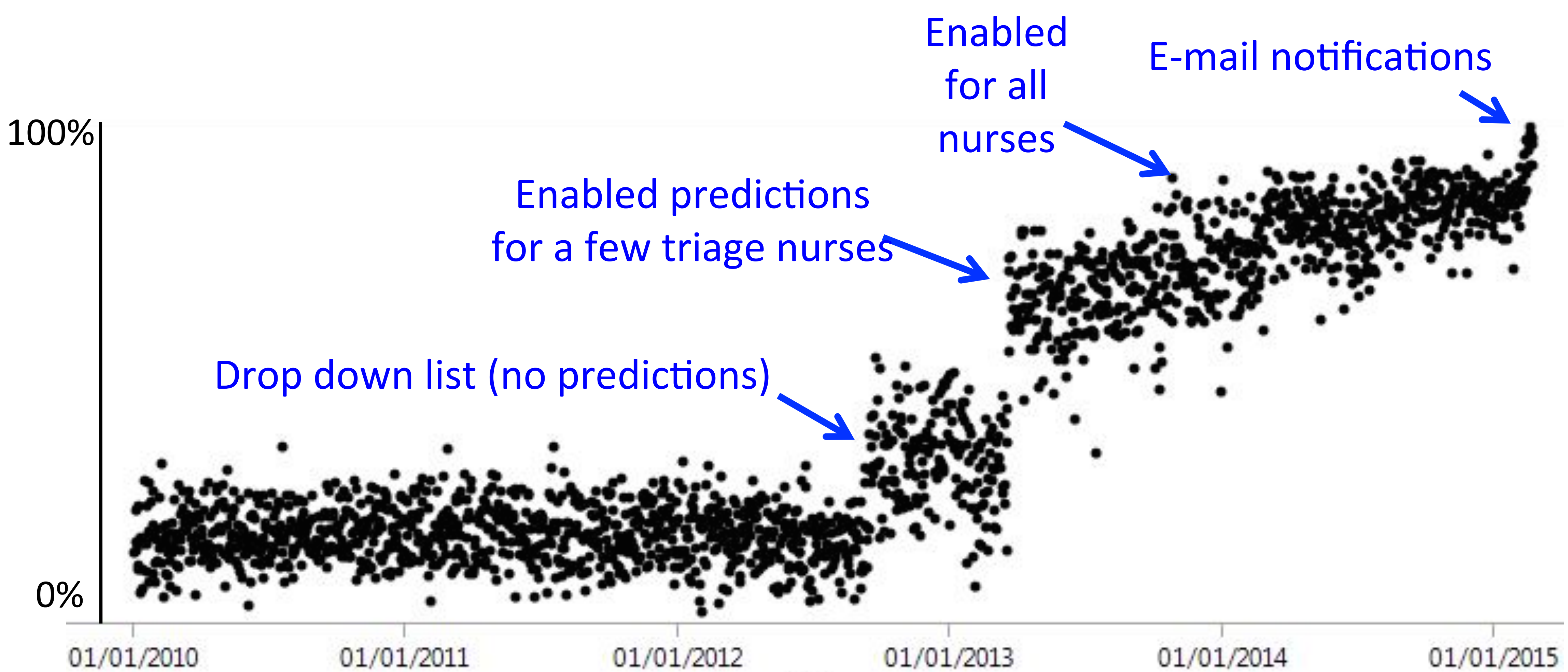


Chief Complaint UI Performance Characteristics

	Multiclass SVM
Best-5	0.757
Best-10	0.825
Discounted Cumulative Gain	0.613

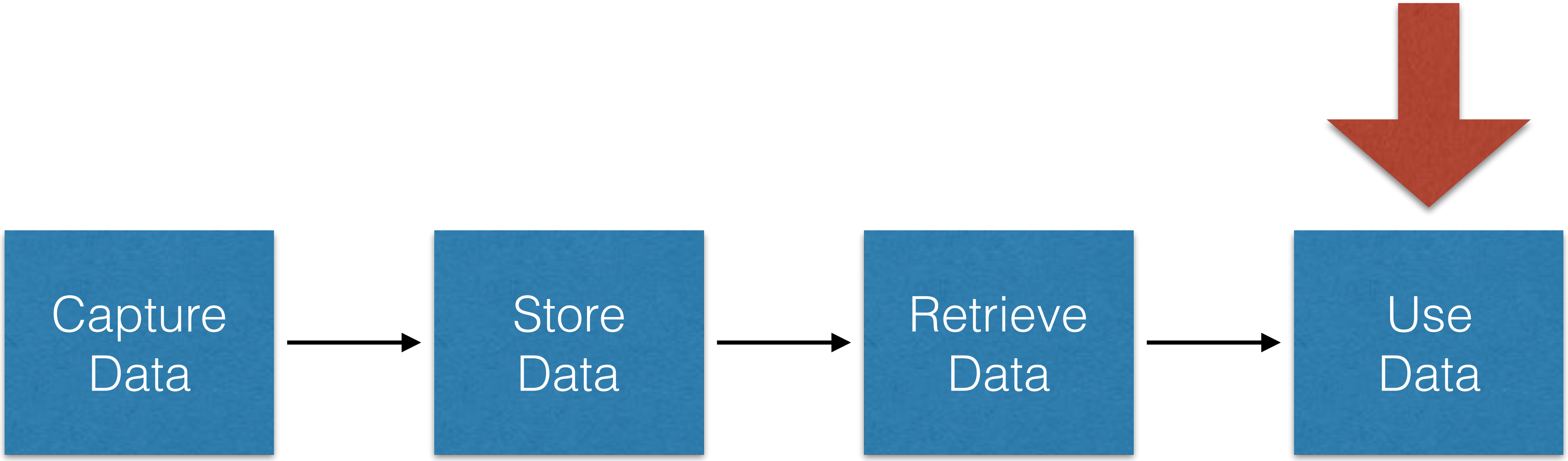
Compliance

- Structured chief complaint went from ~35% to ~95% ($p<0.001$)
- Nurses don’t realize it’s there



Can be applied to usage for any standard ontology

- Snomed CT
- ICD10
- CPT


Capture Data
Store Data
Retrieve Data
Use Data

Automated Triggering

- Clinical pathways
- Decision Support
- Order Sets
- Research eligibility screening

Benefits of Automated Triggers

- Doesn’t rely on user knowing that a function exists (important given our large number of transient users)
- Independent of user’s knowledge and motivation

Clinical State	Description	Value	Anchors	State	Reasoning
chestpain_acute	cardiac chest pain	.81			# chest pain
cardiac_acute		.07			also in ddx is angina or mi
cancer_history		.04			collins is a simnum year old female with a history of htn , mdd , and asthma who presents to the ed for chest pain and shortness of breath
abdominalpain_acute	acute abdominal pain	.03			chest pain
infection_acute		.03			cxr
asthma-copd_acute	active asthma/copd	.02			acute onset chest pressure with dyspnea possibly related to history of asthma and could be an exacerbation however she is not wheezy on exam
diabetes_history	diabetes	.02			age_63
syncope_acute		.02			she was also so uncomfortable that she had to get out of bed and lay on the floor
uti_acute		.01			ms
backpain_acute	acute back pain	.01			# chest pain
allergicreaction_acute	acute allergic reaction	.01			acute onset chest pressure with dyspnea possibly related to history of asthma and could be an exacerbation however she is not wheezy on exam
chf_acute		.01			# dyspnea :
psych_acute	acute psychiatric condition	0			she was also so uncomfortable that she had to get out of bed and lay on the floor
headache_acute	active headache	0			a / p :

SCIENTIFIC REPORTS

OPEN

Learning a Health Knowledge Graph from Electronic Medical Records

Received: 3 March 2017
Accepted: 1 June 2017
Published online: 20 July 2017

Maya Rotmensch[1], Yoni Halpern[2], Abdulhakim Tlimat[3], Steven Horng[3,4] & David Sontag[5,6]

Demand for clinical decision support systems in medicine and self-diagnostic symptom checkers has substantially increased in recent years. Existing platforms rely on knowledge bases manually compiled through a labor-intensive process or automatically derived using simple pairwise statistics. This study explored an automated process to learn high quality knowledge bases linking diseases and symptoms directly from electronic medical records. Medical concepts were extracted from 273,174 de-identified patient records and maximum likelihood estimation of three probabilistic models was used to automatically construct knowledge graphs: logistic regression, naive Bayes classifier and a Bayesian network using noisy OR gates. A graph of disease-symptom relationships was elicited from the learned parameters and the constructed knowledge graphs were evaluated and validated, with permission, against Google's manually-constructed knowledge graph and against expert physician opinions. Our study shows that direct and automated construction of high quality health knowledge graphs from medical records using rudimentary concept extraction is feasible. The noisy OR model produces a high quality knowledge graph reaching precision of 0.85 for a recall of 0.6 in the clinical evaluation. Noisy OR significantly outperforms all tested models across evaluation frameworks ($p < 0.01$).

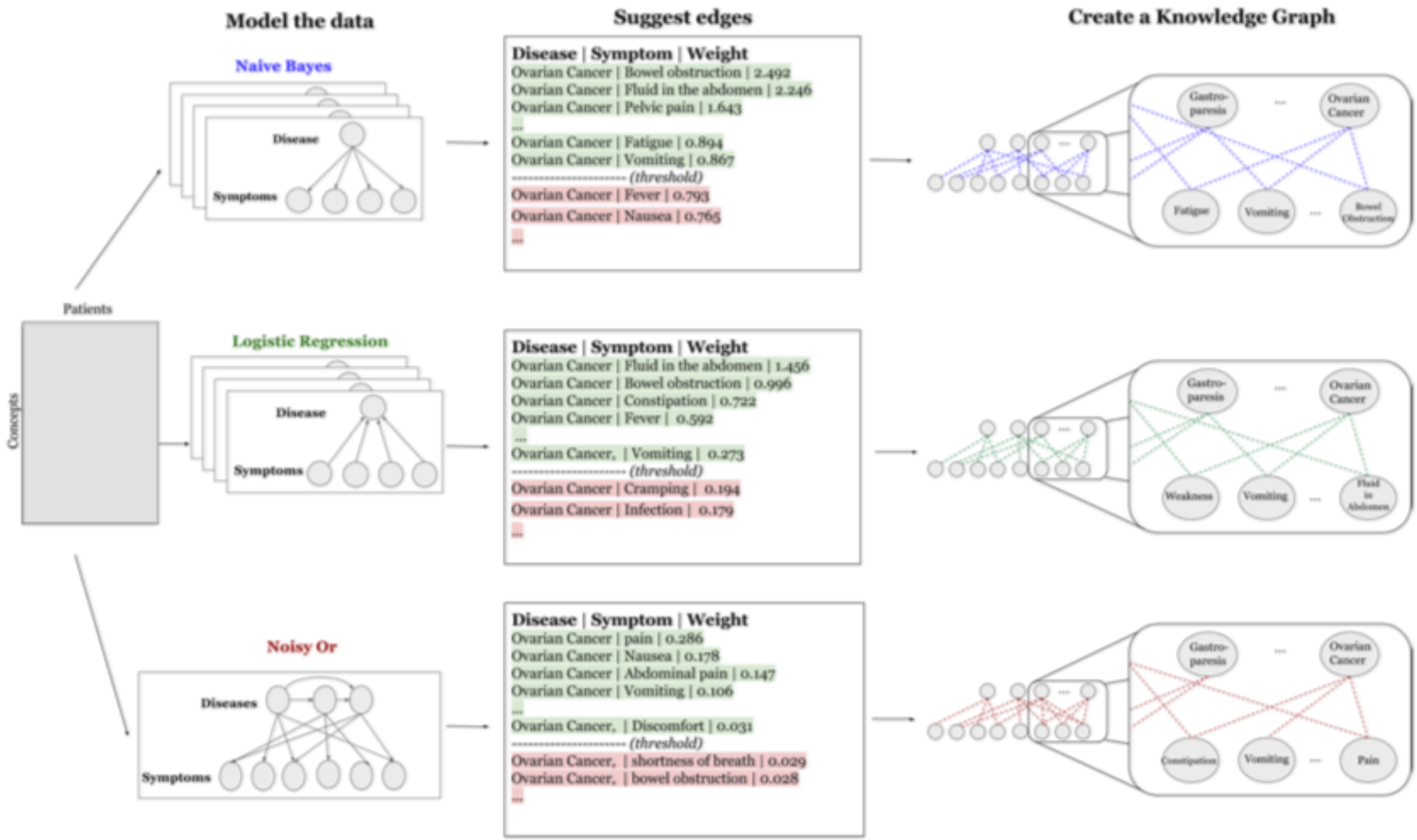


Figure 2. Workflow of modeling the relationship between diseases and symptoms and knowledge graph construction, for each of our 3 models (naive Bayes, logistic regression and noisy OR).

- Cardiac CP Order Set

- (•) To be drawn immediately ( ) Add-on

Initial

- [ ] IVs: Place IV (saline lock);
  flush per protocol
- [ ] Noninvasive Patient Monitoring: Continuous Cardiac monitoring
- [ ] Noninvasive Patient Monitoring: Continuous Pulse oximetry

EKG (pick 1)

- [ ] EKG (to be performed): Indication: Chest Pain
- [ ] EKG (to be performed): Indication: Dyspnea

Laboratory

- [ ] CBC + Diff
- + [ ] Chem-7
- [ ] Troponin

Aspirin (pick 1)

- [ ] Aspirin 243 mg PO *Allergy
- [ ] Aspirin 324 mg PO *Allergy
- [ ] Aspirin taken before arrival

Imaging

- [ ] XR Chest PA & Lateral
- [ ] XR Chest AP Portable

Stress

- [ ] Exercise Stress Test (ETT) *i*
- [ ] Stress Echo *i*
- [ ] Myocardial Perf with Exercise *i*
- [ ] Myocardial Perf with Pharm Stress *i*

+ Other

Order More **Order+Sign**

Contextual Information Retrieval

- Cardiac Info (10)

DM: metformin
HTN: metoprolol tartrate
Tobacco: None
FH: Father w/ hx of etoh abuse, passed away from MI @ 70s, first one in 50s. Paternal grandmother with CVA and paternal grandfather with MI in the 70s. mother with OCD. [12/19/2014 17:13]

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05/25/2004	Echo	
03/30/2004	NUCLEAR	

Checklists

- Unstructured Data
- Scanned Images (consent forms, DNR/DNI, etc.)

Risk Stratification

Triage waiting room sorting

- Triage is most necessary when demand > supply
- Same time when very difficult to allocate additional resources to re-prioritize / monitor patients
- Automated methods using already collected data would be helpful

Probabilistic Inference for Triage Rack Sorter

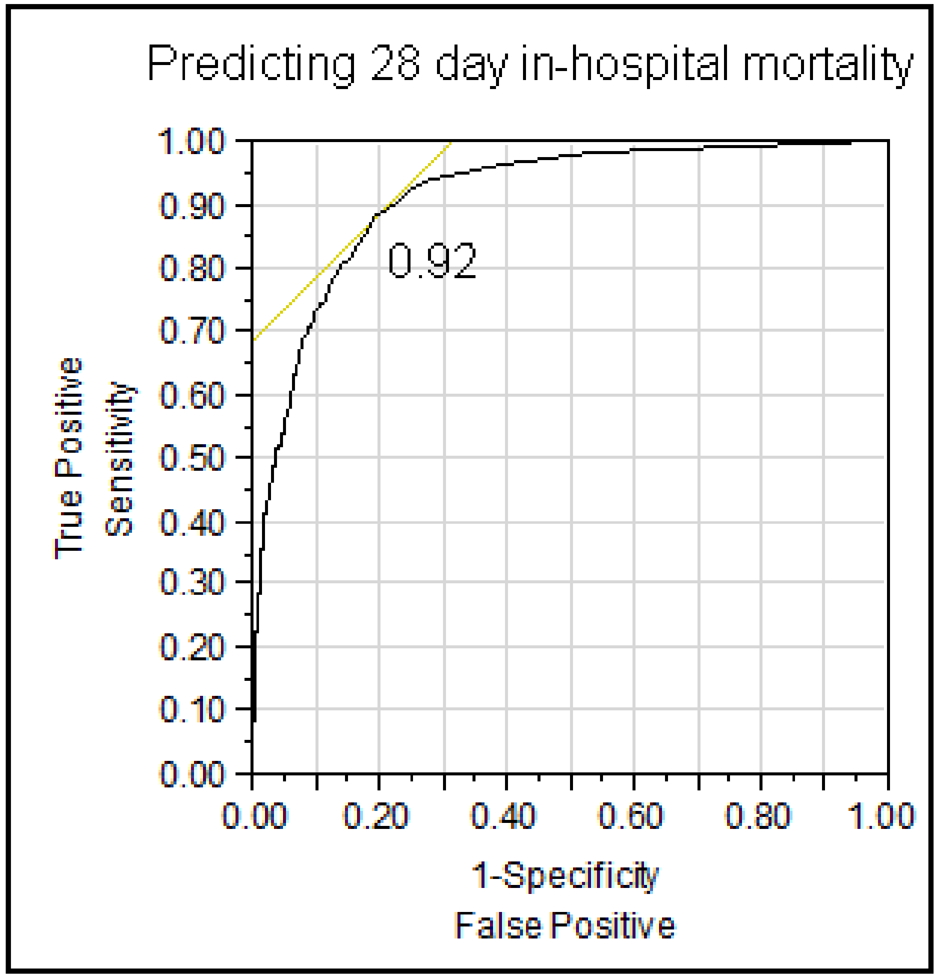
- **Essentially a Risk Stratification Problem**

- Probabilistic Inference based on all available data(Age, Sex, Vital signs,Emergency Severity Index, Medical Problems, labs, etc.)

- Implemented as graphical risk stratification meter

Risk Stratification

Outcome	Algorithm AUC	
All ED Patients	derivation	Validation
	(n=75,992)	*(n=18,981)*
Infection	0.88	0.88
28 day mortality	0.94	0.92
ICU admission	0.91	0.90



Triage

eRack (7)

TIR	TID	Age	Rm	Name	Chief Complaint	Att	Res	Nur	Mortality
1439d	10:34	77	7	Corporan-Can...	Sob, Cough, Vom	LarryN		Beth	
1430d	10:11	23	5	Lin, B	Sob, Throat Closing	Alden		n/o rob	
917d	8:15	84	2	Bissell, P	Black Stools	LarryN			
1176d	-261d5h	56	21	Mills, M	Test Ewd2 Hisel2 R C				
1439d	11:35	64	23b	Post Franken...	Melena	Horng		n/o rob	
1439d	9:15	60	22a	Pullano, H	↑ Inr, Fever,			M.A.	
1430d	10:20	73	32	Uyeno, J	Fever, c/p Sinus Sur			Yolo	

[redacted]

Temp 97.3 **HR** 96 **BP** 104/69 **RR** 24 **O2sat** 100%

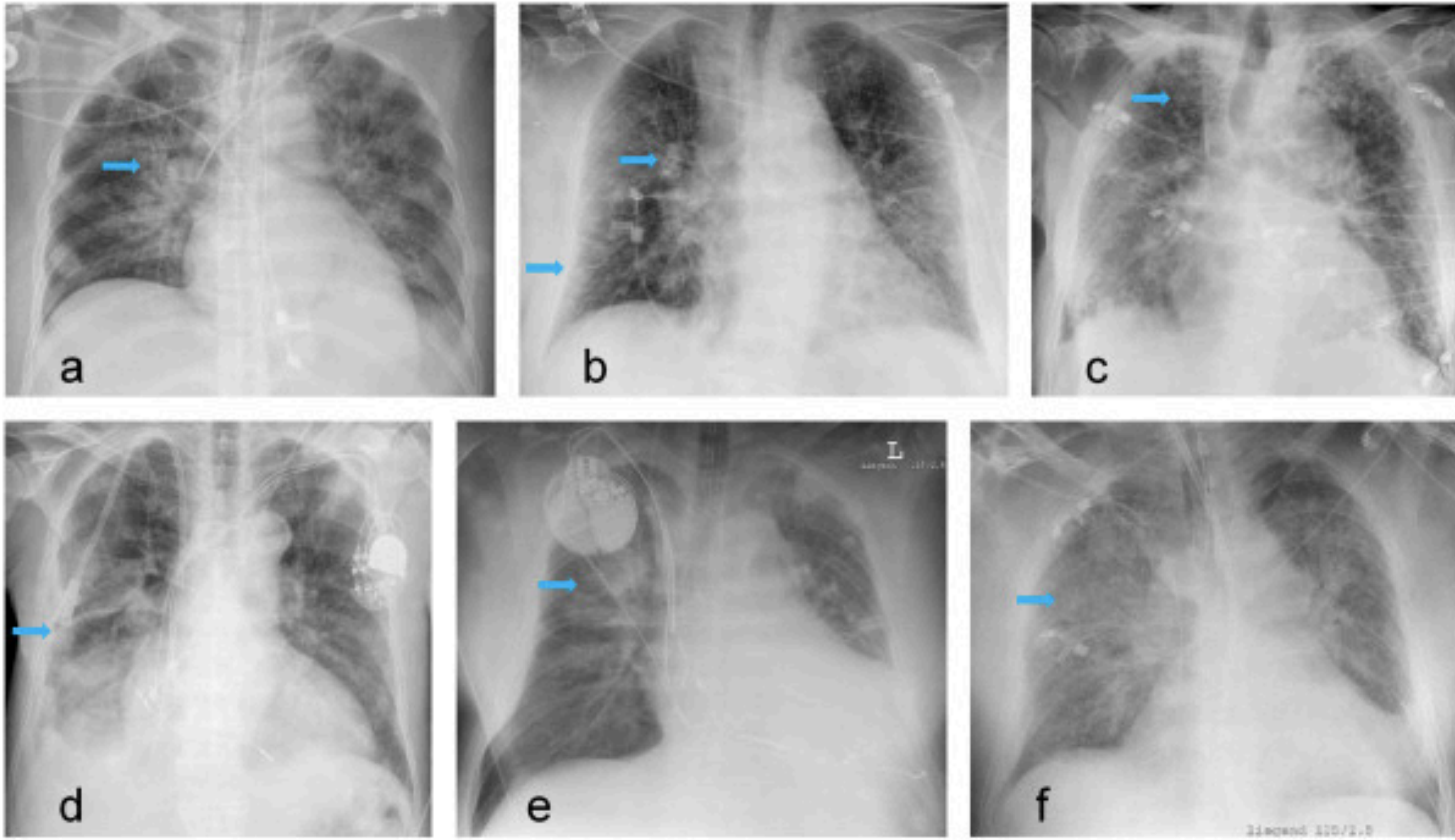
88 y/o M pt from coolidge house with past few days of altered mental status, lethargic, fevers. o2sat today 88% ra. also with INR>10, Na=161. triggered to room 20

Time	Pain	Temp	HR	BP	RR	Pox	Glucose
+ Triage 13:12	u/a	97.3	96	104/69	24	100% NRB	

30 day mortality: 71%

Go to Patient View -->

Quantification of pulmonary edema as a surrogate for **fluid status**


a
b
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L
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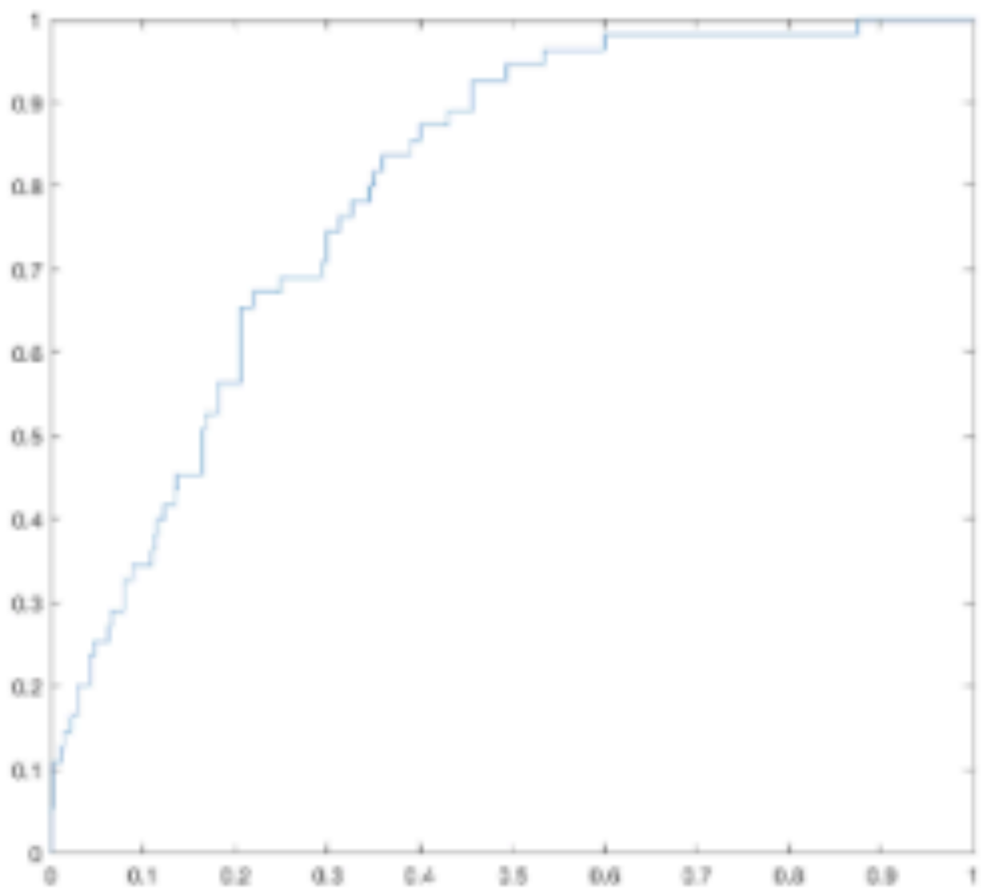
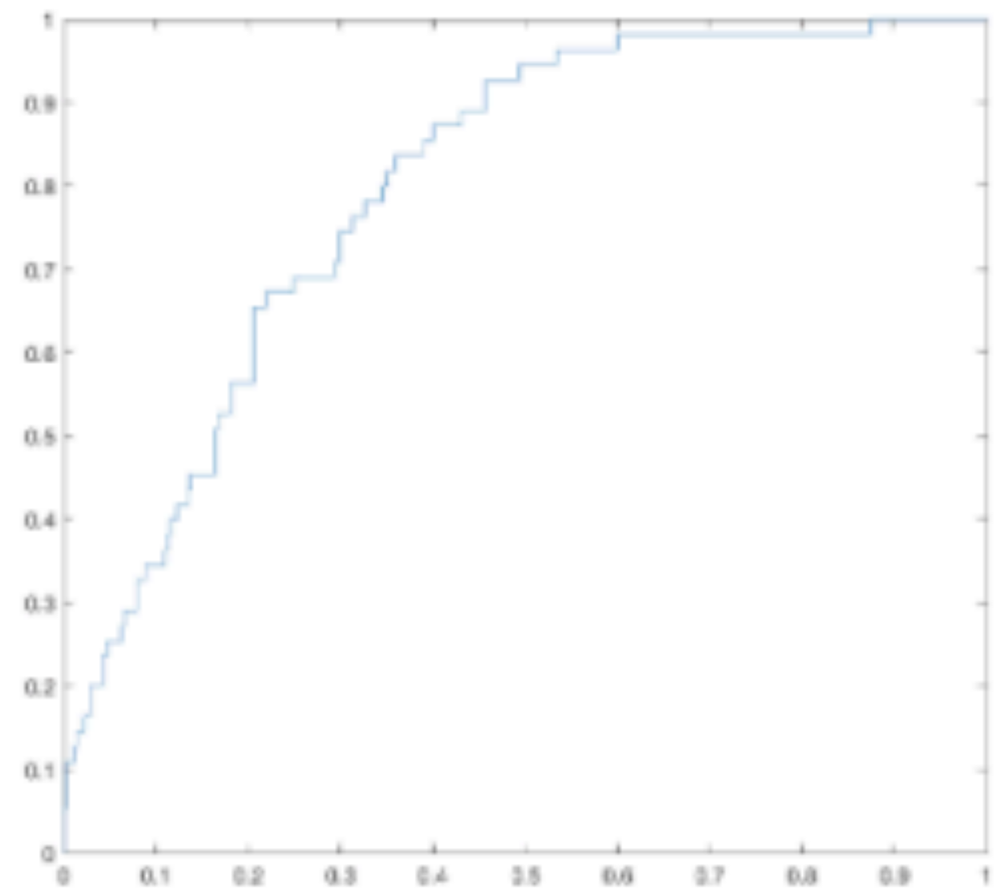
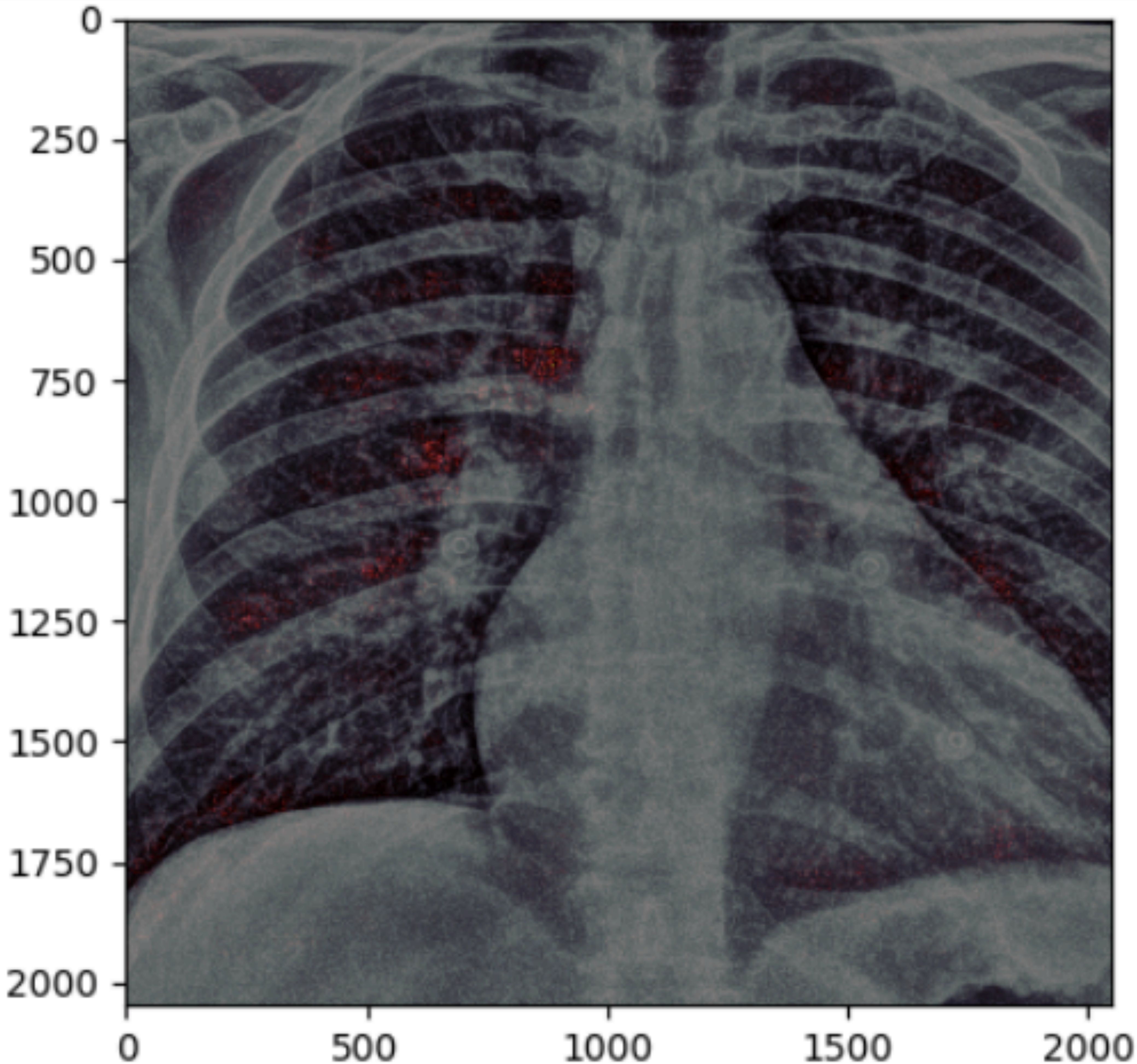
Table 1

Radiologic scoring of pulmonary edema on bedside chest radiographs

Variables		Score		
		Mild	Moderate	Severe
Hilar vessels	Enlarged	1	2	3
	Increased in density	2	4	6
	Blurred	3	6	9
Kerley B lines		4	-	8
Micronoduli		4	-	8
Widening of interlobular fissure		4	8	12
Peribronchial and perivascular cuffs		4	8	12
Extensive perihilar haze		5	10	15
Diffuse increase in density		5	10	15

kappa 0.68

 AUC=0.75	 AUC=0.80
No Edema vs. Mild/Moderate/Severe edema	No/Mild Edema vs Moderate/Severe Edema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1000
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2000

Summary

- Big data / Machine Learning will help us leverage the data already being generated
- Right information at the right time
- Design for the user (save time, facilitate workflow)
- Build decision support directly into the user interfaces