Neural Networks and Deep Learning

Dr. Jerome J. Braun

This Lecture:
Introduction — Part 1

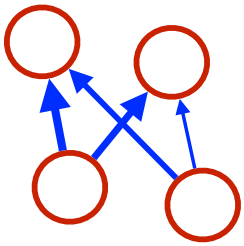
Course: Neural Networks and Deep Learning
IE 7615

This Lecture

- Neural networks and deep learning — field
- Applications

What is Artificial Neural Network (ANN)?

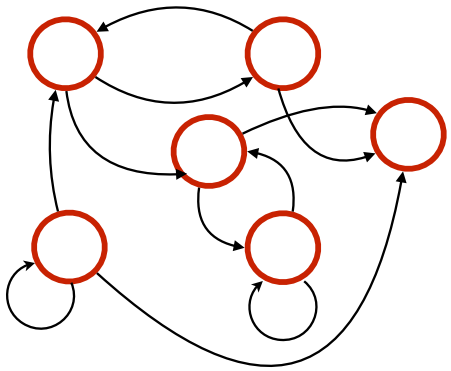
- Units with associated function
  - Also referred to in literature as nodes or "neurons"
- Connections — weighted links between units



- Learning algorithm
  - Typically — modify weights of connections
  - Sometimes — modify units, network topology
- Conventional artificial neural networks (ANNs) are NOT models of biological neural networks or brain !
  - We will see this later in this course

ANN Topologies

- **Most general — fully/arbitrarily connected**



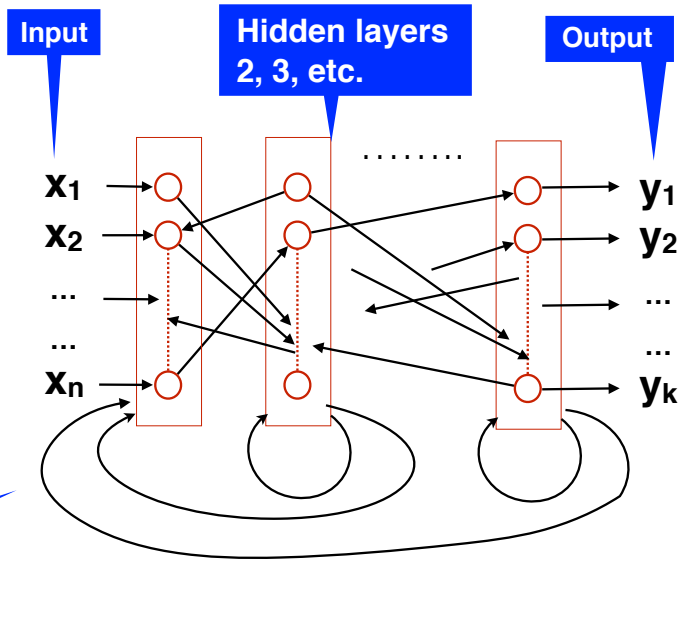
List of *Some* ANN Architecture Categories

- **"Shallow" multilayer perceptron (MLP) networks**
- **Deep MLP networks**
- **Convolutional networks**
- **Recurrent networks, LSTMs, GRUs, …**
- **Autoencoders**
- **Transformers, BERT, …**
- **Generative adversarial networks (GANs)**
- **… and other**

We will study them in this course

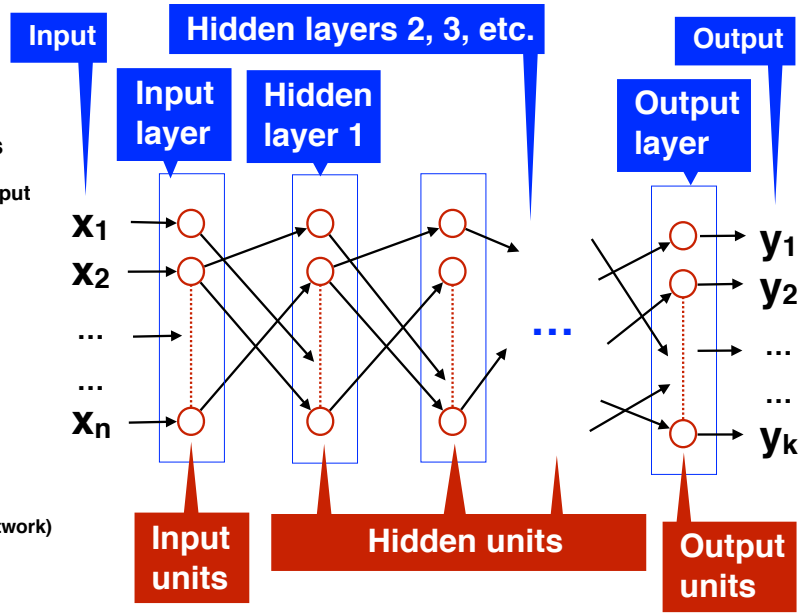
ANN Topologies — Layered

- Layered
- Any number of layers
- Retrograde connections
  - Within layers
  - To previous layers

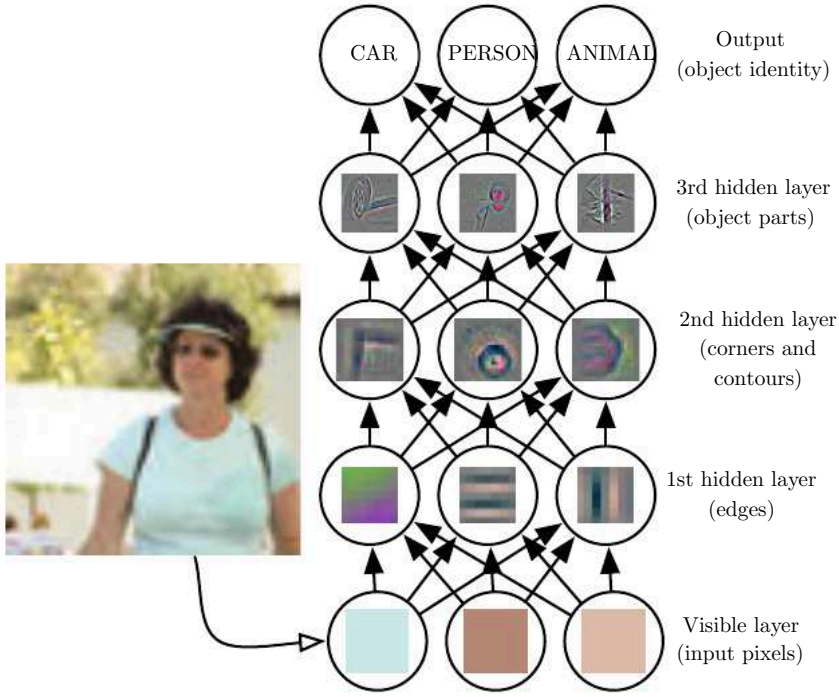


ANN Topologies — Feedforward

- Layered
- Only forward connections
  - Direction from input to output
  - From layer i to layer i + 1
- Any number of layers
- Layers
  - Input layer
  - Hidden layers
    - One (shallow network)
    - More than one (deep network)
  - Output layer



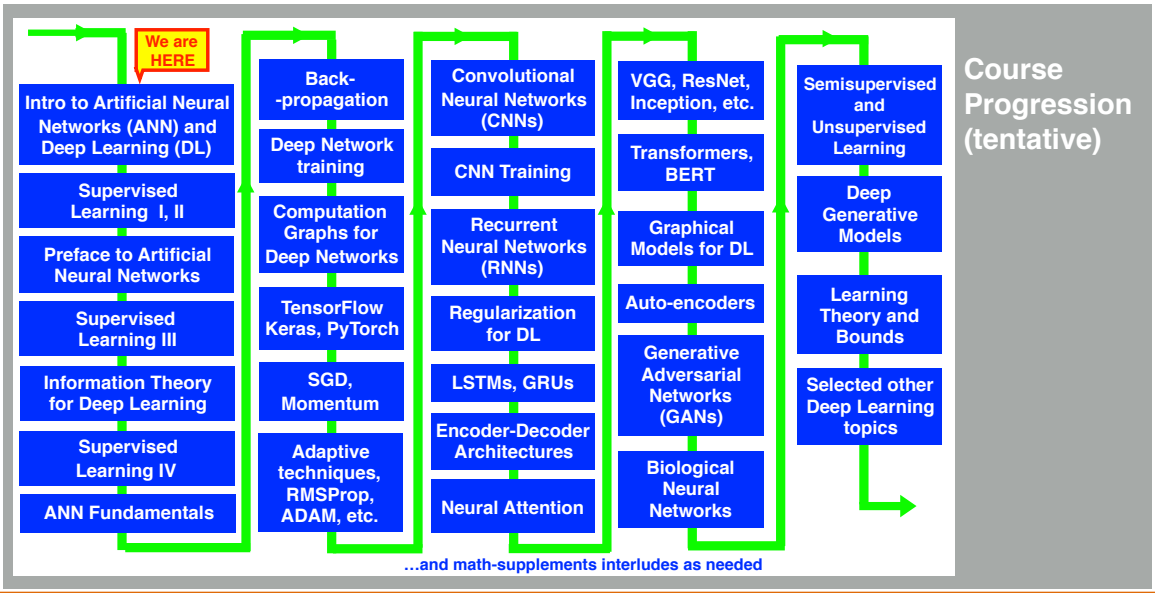
Deep Learning Model



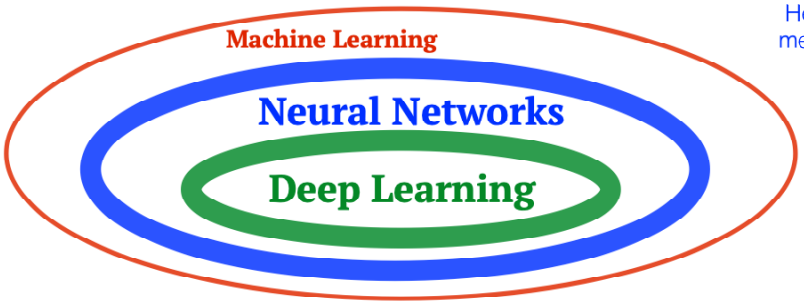
[Goodfellow, 2016]

Course Progression

- **Selected machine-learning fundamentals are necessary for understanding neural networks and deep learning — we will study these necessary fundamentals in the first part of the course**
- **Then we will focus on neural networks (ANN) and deep learning (DL) in detail**

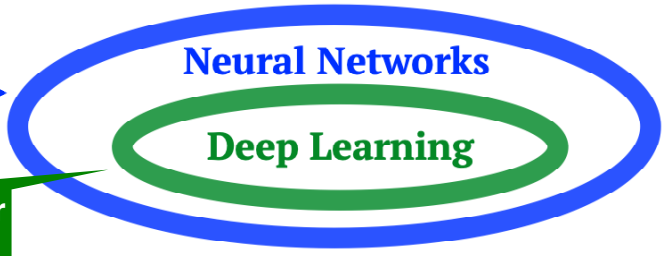


Neural Networks and Deep Learning



Here "Neural Networks" means "***Artificial*** Neural Networks"

Neural networks have evolved into dominant, large and uniqely powerful domain



Solve problems too difficult for any other known approaches

Deep Learning = deep neural networks !

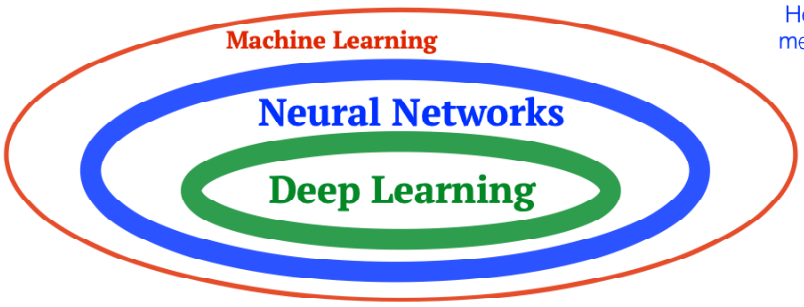
Machine Learning

- **Many tasks not feasible to "pre-program"**
  - **Not feasible to find "rules"**
  - **Too much variability**
  - **Examples: handwriting recognition (e.g., zipcode on envelopes), speech recognition**
- **Machine learning — algorithmic methods to learn**
  - **From data, from experience**
  - **Arthur Samuel (1959): *Machine Learning — field of study that gives computers ability to learn without being explicitly programmed***
- **Learning from data**
  - **Some data**
  - **Lots of data ("Big Data")**
  - **Little data**

Learning From Data — Algorithmic Paradigms

- Classical statistical (regression, decision-trees, etc.)
- Clustering (nearest-neighbor, etc.)
- Component analyses (PCA, ICA, DCA, etc.)
- Hidden Markov models (HMM)
- Support vector machines (SVM)
- … etc. …
- Artificial neural networks and deep learning
  - Feedforward neural networks
  - Recurrent neural networks
  - … etc. …

Neural Networks and Deep Learning (1)



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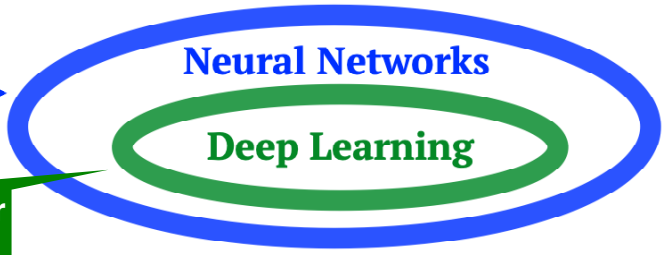
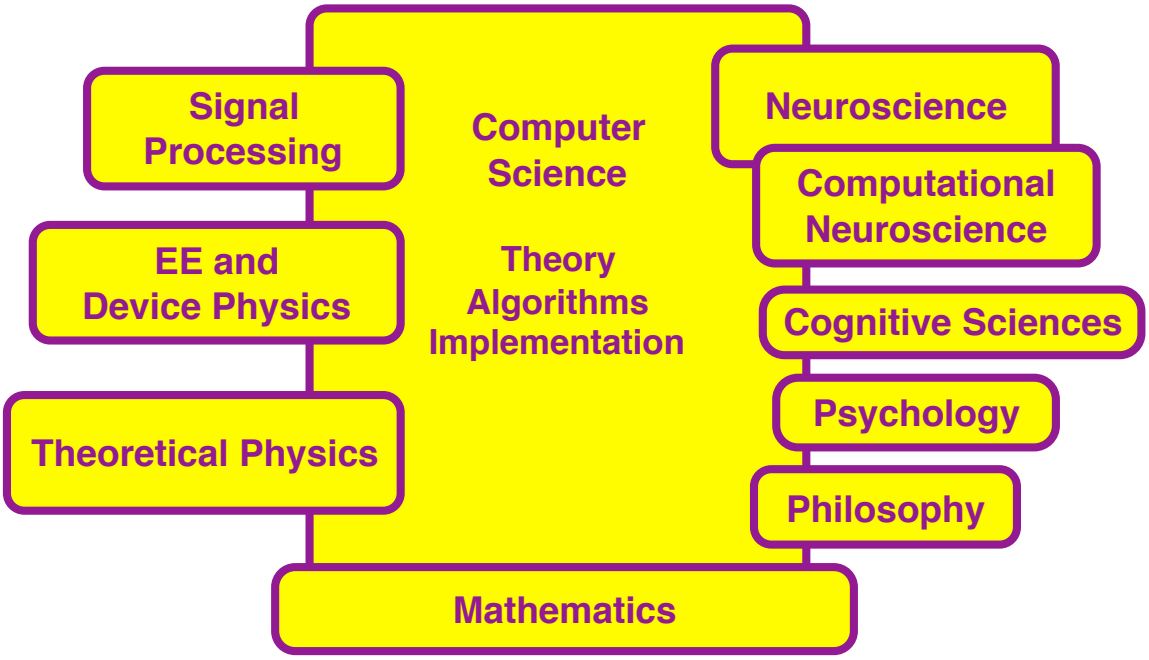


Solve problems too difficult for any other known approaches

Deep Learning = deep neural networks !

Neural Networks and Deep Learning (2)



Neural Networks and Deep Learning (3)

- Learning in biological species vs. machines
  - Learning vs. innate capabilities in biological species
- Reasoning vs. learning
  - Machine Reasoning
  - Learning to reason
- Deep Learning and Artificial Intelligence (AI)
  - At present neural networks and deep learning are necessary for AI

Neural Networks and Deep Learning (4)

- In biological systems, robust learning is key to intelligent behaviors
  - Same for artificial systems!
- Robust learning is key for developing intelligent machines
- Central core of contemporary Artificial Intelligence (AI)
  - Modern AI is dominated by deep neural networks (deep learning)
- AI is currently "street name" for deep neural networks and deep learning
  - In media (TV, etc.), advertising, popular press

Neural Networks and Deep Learning (5)

- Who cares? Everybody!
  - Deep learning — currently "hottest" area!
- Companies racing to make/use systems based on neural networks and deep-learning
    - Amazon, Google, Facebook, Apple, Microsoft, and other high-tech giants
    - Scores/hundreds of other companies in industry and commerce
      - From healthcare, through manufacturing, to entertainment — and many more!
        - Wide range of areas and applications

This Lecture

- Neural networks and deep learning — field
- Applications

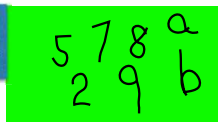
Neural Network and Deep Learning — Applications

A few examples (out of many)	
Machine Vision	Speech & Language Processing (NLP)
Face Recognition, Object Recognition	Autonomous Vehicles
Self-driving cars	Robotics
Forecasting	Assistive Robotics
Wheather, climate, etc.	Bioinformatics
Computational biology, neuroscience	"X-"informatics
Analytics (text, video, etc.)	Economics, Financial forecasting
Medical diagnostics	Insurance
Biomed data analysis; healthcare	Fraud detection
Drug development	Image/photo tagging
Personalized medicine	
… many others…	

- Span of potential applications enormous
- But beware of misapplication and overkills!

Application Examples

Handwriting Recognition



Face Recognition

In 2011, IBM Watson system won "Jeopardy!" TV game against human champions

Movie suggestions, e.g., "Other Movies You Might Enjoy"

Self-Driving Cars

- **Google:**

From Wikimedia Commons, the free media repository

Description	**English:** A Google self-driving car at the intersection of Junction Ave and North Rengstorff Ave in Mountain View. This picture was taken from the bike lane of North Rengstorff Ave.
Date	9 March 2016, 12:50:57
Source	Own work
Author	Grendelkhan

- **Others**

Speech Processing

- Speech Recognition
- Language Identification
- Speaker Recognition / Verification
- Accent Recognition
- Speech Synthesis
- …more

Siri

"Big Data" and Deep Learning

Huge and growing data collected, stored and available

Amazon

Facebook

Twitter

Insurance companies

Healthcare

Credit companies

Banking industry

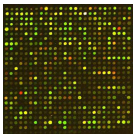
… etc., etc., from engineering to basic sciences

Deep neural networks — deep-learning systems

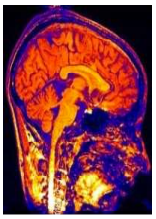
Uniquely suitable for exploiting very large amounts of data ("big data")

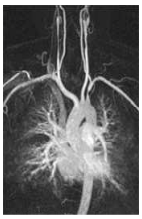
Biomedical Applications

- Large and growing range of applications in medicine, healthcare, and other life-sciences areas
  - High potential for revolutionizing disease diagnostics and treatment
- Examples
  - Bioinformatics and biomedical data analysis
    - E.g., gene expression analyses

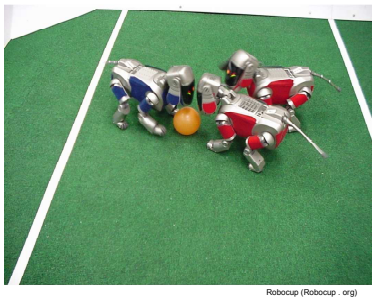


  - Medical imagery analysis for disease diagnostics
    - E.g.,abnormality detection, lesion classification (diagnosis)

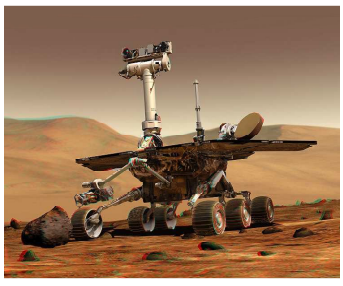




Robotics Applications



Robocup (Robocup . org)



NASA Mars Spirit Rover (Wikipedia . org)

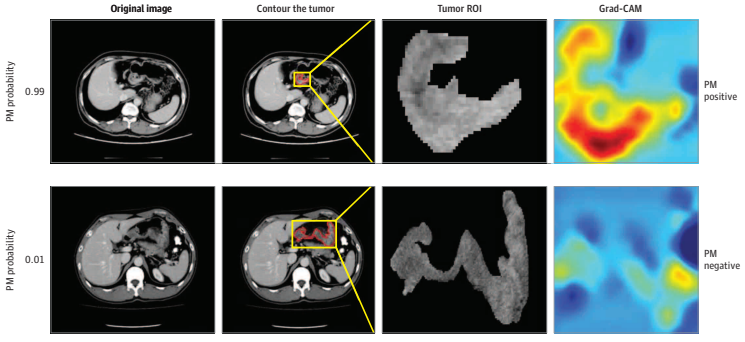
- Wide range of applications
- Examples: assistive robotics, medical robotics, disaster robotics, manufacturing

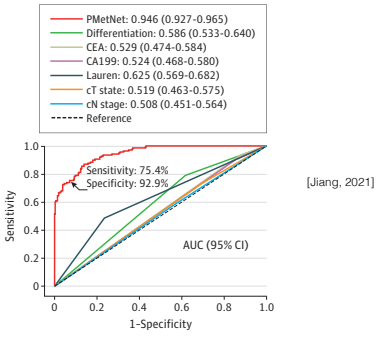
Deep Learning for Medical Diagnostics

- In popular press referred to as AI
- In reality — deep artificial neural networks (deep learning)
  - Convolutional networks, etc.
- Wide range of diagnostic applications and successful results
  - Lung disease, including malignancies
  - Skin lesions and malignancies
  - Breast cancer
  - and other…
- Arguably revolution of medicine
  - Current results indicate performance superior to human experts

Deep Neural Networks for Noninvasive Prediction of Occult Peritoneal Metastasis in Gastric Cancer

- Jiang *et al.*, JAMA Network Open, January 5, 2021
- Noninvasive preoperative (pre-surgery) assessment of occult peritoneal metastasis of gastric cancer
- Potentially useful to aoid unnecessary surgery and risk of associated complications
- CT imagery
- 1978 patients
- Densely connected convolutional neural network (CNN)
- Discrimination performance of network substantially higher than conventional clinicopathological factors

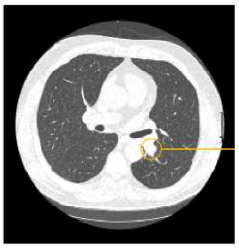


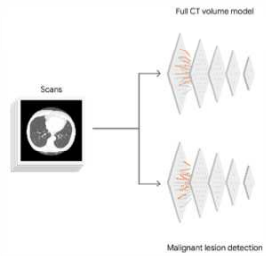


[Jiang, 2021]

Deep Neural Networks for Lung Cancer Screening

- Ardila *et al.*, Nature Medicine, May 2019
- Predict lung cancer risk by comparing patient's current and prior CT imaging
- Deep convolutional neural networks (CNN)
- 6,716 National Lung Cancer Screening Trial (NLST) cases
- 94.4% AUC performance
- Performance better or comparable with human readers (radiologists)

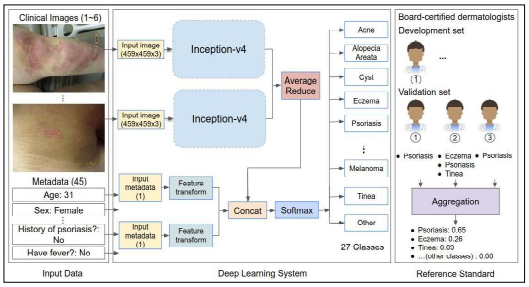




[Ardila, 2019]

Deep Neural Networks for Skin Lesion Classification

- Liu *et al.*, 2019
- Differential diagnosis of 26 skin conditions from photographs and medical histories
- 14,021 development cases, 3,756 evaluation cases
- Variable number of deep convolutional neural network modules to process images
  - Inception-v4
- Shallow module for patient demographic information and medical history (metadata)



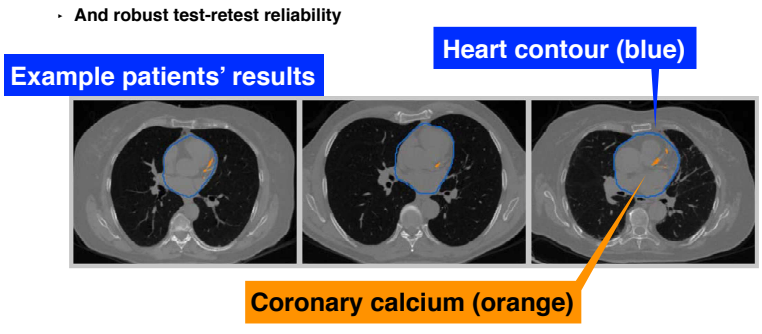
[Liu, 2019]

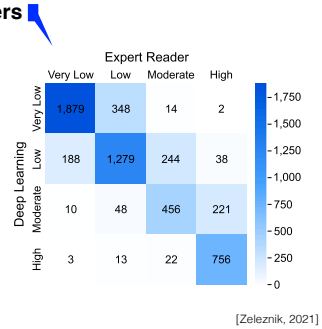
Deep Neural Networks for Breast Cancer Screening

- McKinney *et al.*, Nature, January 1, 2020
- Breast cancer prediction from mammograms
- Ensemble of three deep-learning models
- Exploit ImageNet, RetinaNet, ResNet
- All models implemented in TensorFlow
- Platform includes Google TPU hardware
- System performance — potential to perform better than trained radiologists
  - False positives reduction: 5.7% and 1.2% (US and UK)
  - False negative reduction: 9.4% and 2.7%
  - Able to generalize from UK data to US data
  - Able to outperform human experts
    - Six readers (radiologists)
    - AUC-ROC performance higher than that of human readers by 11.5% margin

Deep Neural Networks for Cardiovascular Risk Prediction

- Zeleznik *et al.*, Nature Communications, Jan. 2021
- Coronary artery calcium — predictor of cardiovascular events
- Visible on all CT chest scans computed tomography (CT) scans
  - But quantification requires expertise, time, and specialized equipment
- Robust automatic quantification by deep-learning system
  - Convolutional neural networks
- 20,084 individuals from asymptomatic, and stable and acute chest pain cohorts
- High correlation of deep-learning system with quantification by expert readers
  - And robust test-retest reliability

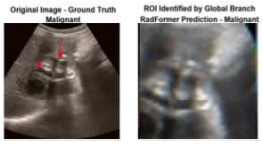


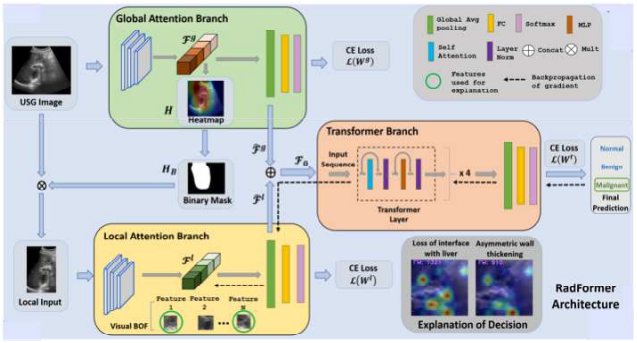


[Zeleznik, 2021]

Deep Neural Networks for Gallbladder Cancer Diagnostics

- Basu *et al.*, 2022
- Diagnostics of gallbladder malignancies
- Input: ultrasound sonography images
- Transformer network architecture
- Basu *et al.* compared system results with conclusions of two expert radiologists
  - Found system performance was better

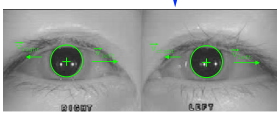




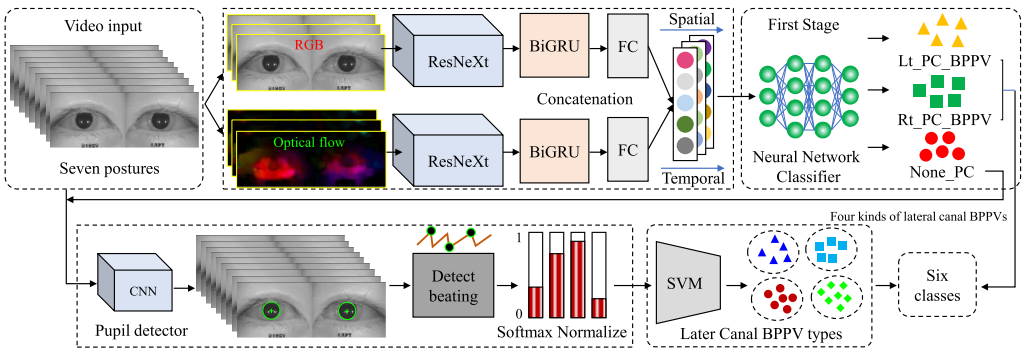
[Basu, 2022]

Deep Neural Networks for BPPV Diagnosis

- Pham *et al.*, Oct. 2022
- Diagnostics of benign paroxysmal positional vertigo (BPPV) types
  - Posterior canal types (Left, righT), Lateral canal types: geotropic BPPV (left, right), apogeotropic (left, right)
- Input: video stream of patient eye-motion during diagnostic medical exam (Dix-Hallpike test)
- Hybrid deep artificial neural network architecture
  - Exploit deep convolutional networks and recurrent networks

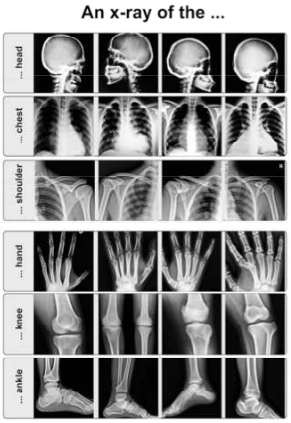


[Pham, 2022]



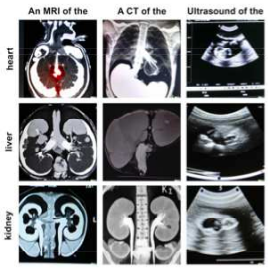
Deep Generative Models for Medical Imagery

- Adams *et al.*, 2022
- AI in radiology
  - Using DALL-E 2 generative model for text-to-image generation, image augmentation, and manipulation
  - DALL-E 2 learns relevant representations of X-ray images
    - Zero-shot text-to-image generation of new images, continuation of image beyond original boundaries

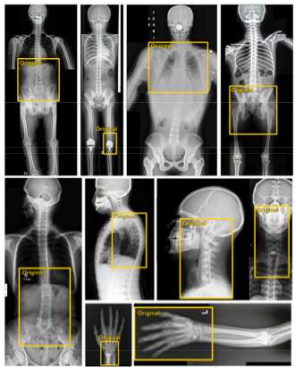


X-ray images from short texts

MRI, CT, and ultrasound images from short texts



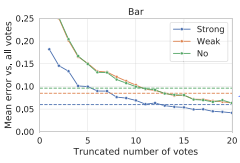
Extending images (input areas marked in yellow)



[Adams, 2022]

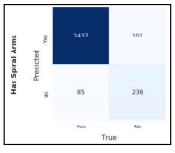
Deep Neural Networks for Understanding Universe

- Walmsley *et al.*, MNRAS 509, 2022
  - Deep neural networks for astronomy and astrophysics research
  - Visual morphological classification of galaxies from images
    - Morphology of galaxies— key to understanding galactic evolution
- Data — *Dark Energy Camera Legacy Survey* images of galaxies
- Ensemble of convolutional neural networks
  - Exploit EfficientNet-B0 architecture with modifications
- Predict morphology features of galaxies
  - E.g., spiral arms, bars, etc.
  - Measured against confident volunteer classifications
    - Galaxy Zoo volunteers
  - Trained networks reach up to 99% accuracy
    - Measured against ~10 volunteers, could be viewed as achieving superhuman performance



[Walmsley, 2022]

Network (dashed)



Questions?