Deep Features to Analyze Pulmonary Abnormalities in Chest X-rays Due to Covid-19

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Master's Thesis

Applied Artificial Intelligence Research Lab

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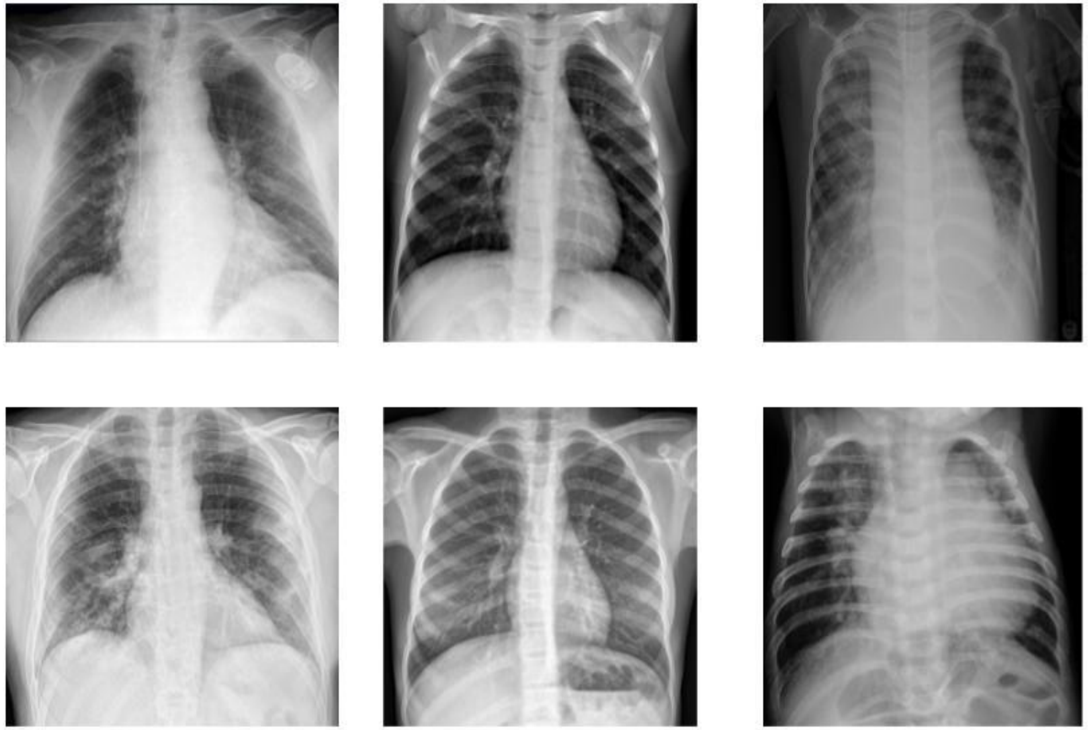
Overview

Chest X-ray images could facilitate greatly in mass Covid-19 screening.

In this study, we build deep learning models to detect Covid-19 positive cases using chest X-ray image.

We leverage DNN models such as CheXNet, DenseNet, ResNet, Vgg to build automated Covid-19 screening.

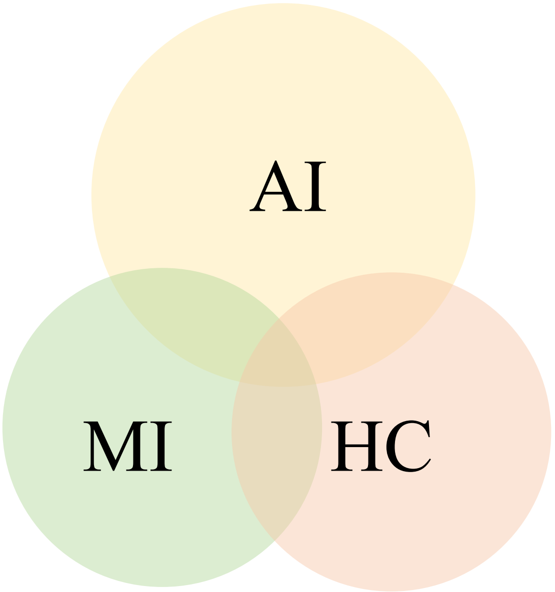
Results (based on deep features) show performance improvement and further possibilities.



COVID-19 Normal Pneumonia

Research Goal

Artificial Intelligence



Medical Imaging

Healthcare

MS Research

- CheXNet for the Evidence of Covid-19
- Systematic Review
- Features to Analyze Abnormalities

Publications

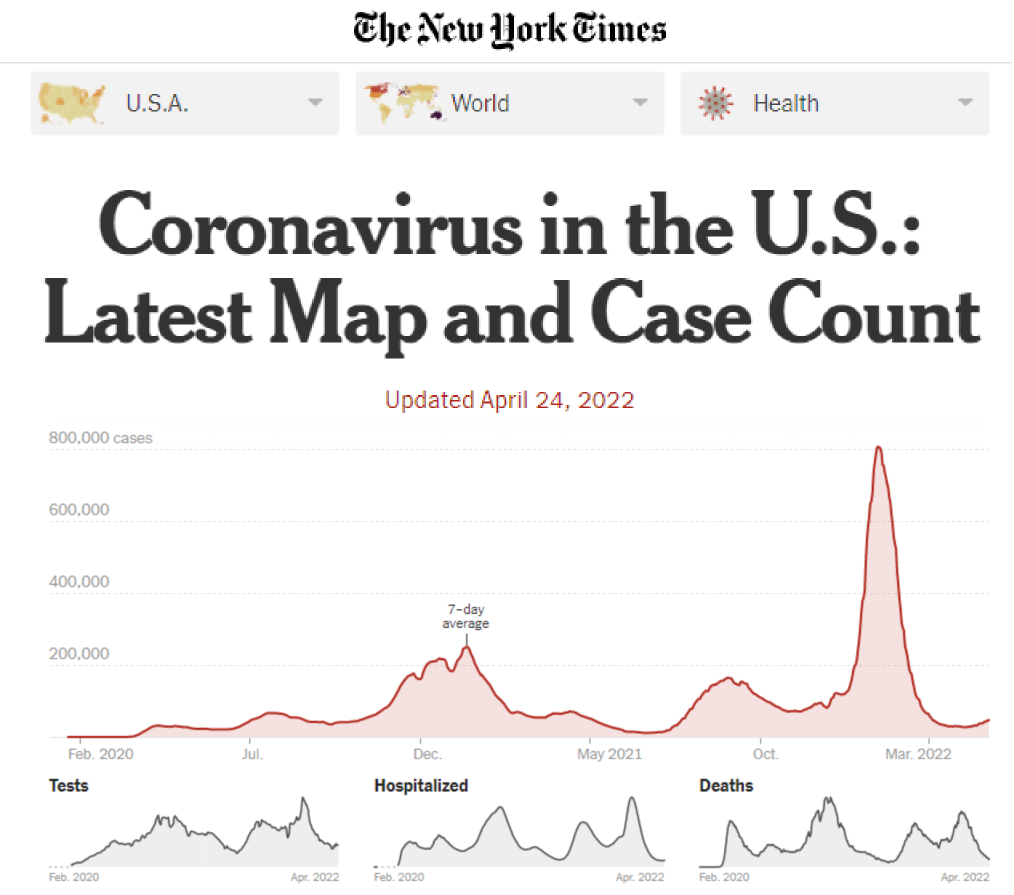
[1] KC Santosh, **Supriti Ghosh**, "**CheXNet for the Evidence of Covid-19 Screening using 2.3K Positive Chest X-rays**" The 4*th* International Conference on Recent Trends in Image Processing & Pattern Recognition (RTIP2R), December 2021.

[2] KC Santosh, **Supriti Ghosh**, Debasmita GhoshRoy, "**Deep Learning for Covid-19 Screening using Chest X-rays in 2020: A Systematic Review**" International Journal of Pattern Recognition & Artificial Intelligence (IJPRAI), https://doi.org/10.1142/S0218001422520103.

[3] KC Santosh, **Supriti Ghosh**, "**Deep Features to Analyze Pulmonary Abnormalities in Chest X-rays due to Covid-19**". [in process]

Motivation

- Since December 2019, the infection rate of Covid-19 cases has been very high.
- In such infectious disease, early detection tools would help largely to mitigate the spread and save lives.
- Current Covid-19 screening are expensive and time-consuming.
- Chest X-ray imaging is available and accessible in many clinical sites as it is considered standard equipment in most healthcare systems.



	DAILY AVG. ON APR. 23	14-DAY CHANGE	TOTAL REPORTED
Cases	46,582	+51%	80,855,787
Tests	813,142	+17%	—
Hospitalized	15,468	+3%	—
In I.C.U.s	1,900	−12%	—
Deaths	370	−34%	989,678

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Related Work

- A number of AI-driven tools have been used to help predict, screen, and diagnose Covid-19 positive cases.
  - Santosh, K.C. AI-Driven Tools for Coronavirus Outbreak: Need of Active Learning and Cross-Population Train/Test. Models on Multimudinal/Multimodal Data. J Med Syst 44, 94 (2020). https://doi.org/10.1007/s10916-020-01562-1

- A Convolutional Neural Network (CNN) –tailored Deep Neural Network (DNN) has been proposed that can collectively train/test both CT scans and Chest X-rays.
  - Mukherjee, H., Ghosh, S., Dhar, A., Santosh, K.C. et al. Deep neural network to detect Covid-19: one architecture for both CT Scans and Chest X-rays. Appl Intell (2020). https://doi.org/10.1007/s10489-020-01943-6

- However, the performance was not up to the mark because at that time there were not available data. Now we are using state-of-the art for better performance.

Workflow

- **Data Collection**
  - Total = 4,716 (Covid-19: 2,358 Non-Covid-19: 2,358)
- **Data Pre-processing**
  - Image size 224 × 224
- **Building and Training Model**
  - Pre-trained Model (CheXNet, DenseNet169, Resnet50, Vgg16) (Add Dense Layer, Dropout Layer, Activation Function)
- **Evaluating Model**
  - k(=5)-Fold Cross Validation
- **Predict Covid-19 or non-Covid-19**
  - If Covid-19, forward for the next step for visualization of evidence
- **XAI**
  - Find evidence in Chest X-ray from Heatmap

Data Collection

- We have collected 8,214 Chest X-Ray images from 4 different sources.

- Balanced Dataset for Experiment: 4,716 CXRs (2,358 Covid-19 positive & 2,358 non-Covid-19 (Healthy: 1,583 + Pneumonia: 775)

Chest X-Ray Image	**Collections**
Healthy Chest X-Ray	1,583
Pneumonia Chest X-Ray	4,273
Covid-19 Chest X-Ray	2,358
Total Chest X-Ray	**8,214**

Data Pre-processing

Data Pre-processing

- Shifting width and height
- Shear angle

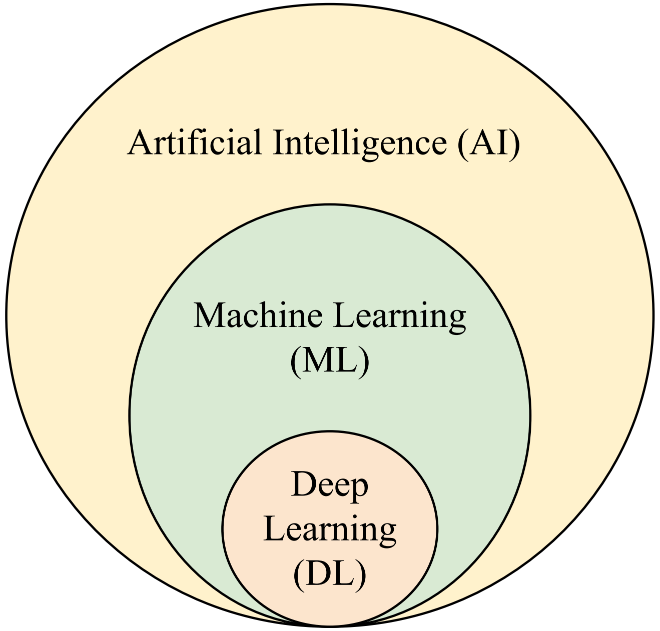
These allowed us to make the model more robust and work on different set of data.

Data Standardization

- Sample wise centering
- Sample wise standard normalization

These helped us to avoid overfitting and dependence on specific set of data or features.

Deep Learning



Deep Learning is an artificial intelligence function that imitates the working of the human brain in processing data and creating patterns for use in decision making.

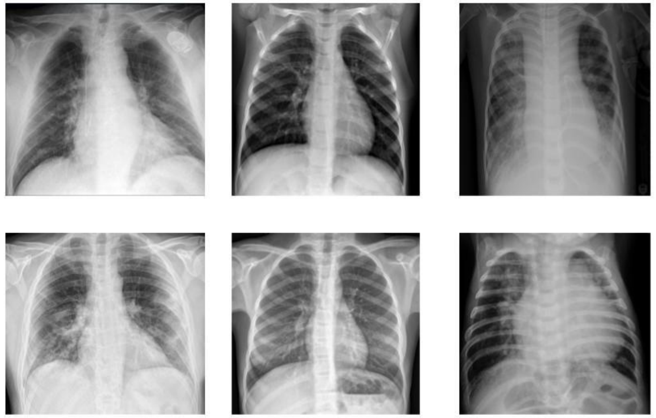
Deep Learning attempts similar conclusions as humans by analyzing data and finding patterns.

Deep Learning algorithms show powerful techniques to extract features from images.

Deep Learning

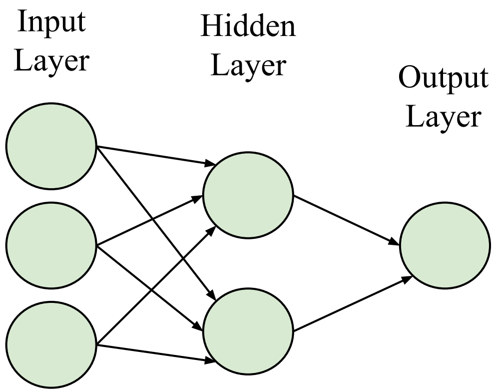
- Use of Deep Learning:

  Medical Imaging
  Self driving car
  Voice Assistant
  Agriculture
  Gesture Recognition
  And many more…



COVID-19 Normal Pneumonia

Neural Network



Deep learning refers to training neural networks sometimes very large neural networks.

Neural Network is a technology built to simulate the activity of the human brain.

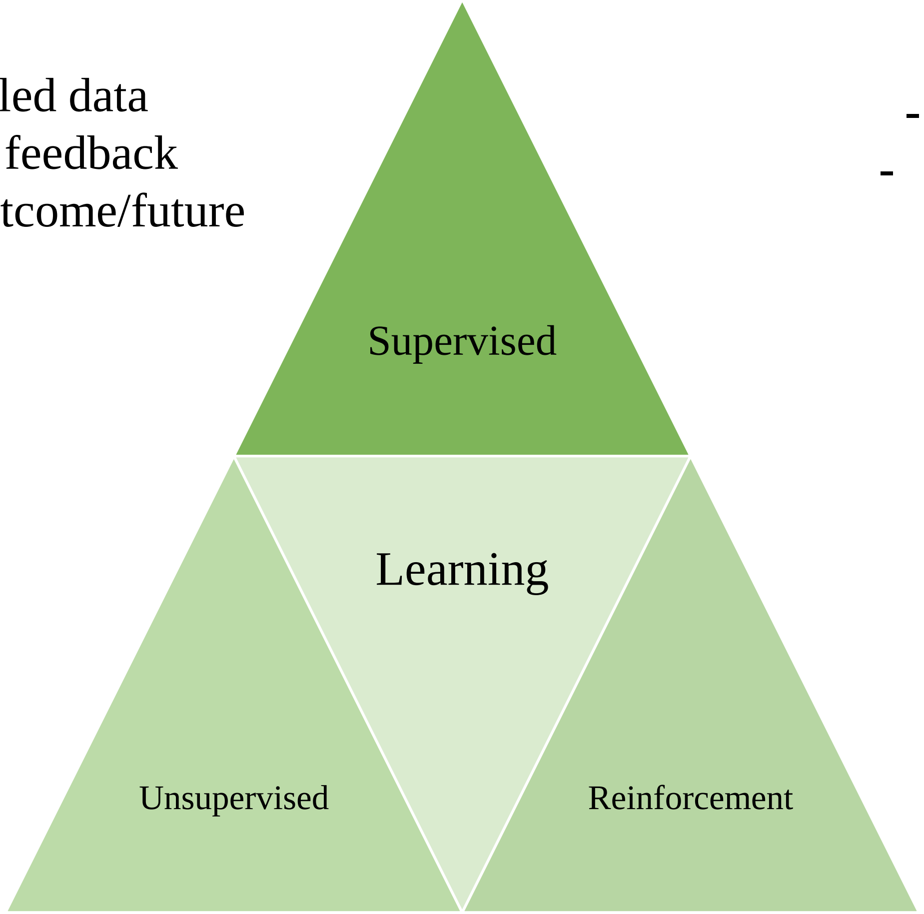
Massively used for problems of classification and regression

Inspired by human mind. Neurons are activated by some input

Learnings

- Labeled data
- Direct feedback
- Predict outcome/future

- Regression
- Classification

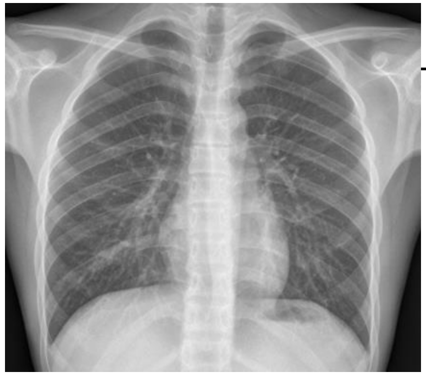


- No labels
- No feedback
- Find hidden structure

- Decision process
- Reward system
- Learn series of actions

Classifications

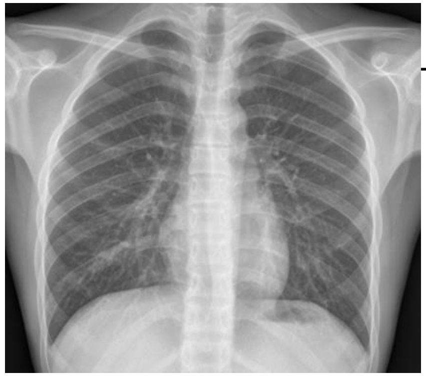
- In binary classification our goal is to learn a classifier that can input an image represented by its feature vector X and predict whether the corresponding label y is 1 or 0.



0 (Covid-19 Chest X-ray) vs 1 (Non Covid-19 Chest X-ray)

y

- In multi-class classification, machine can predict 0 or more non-exclusive class labels.



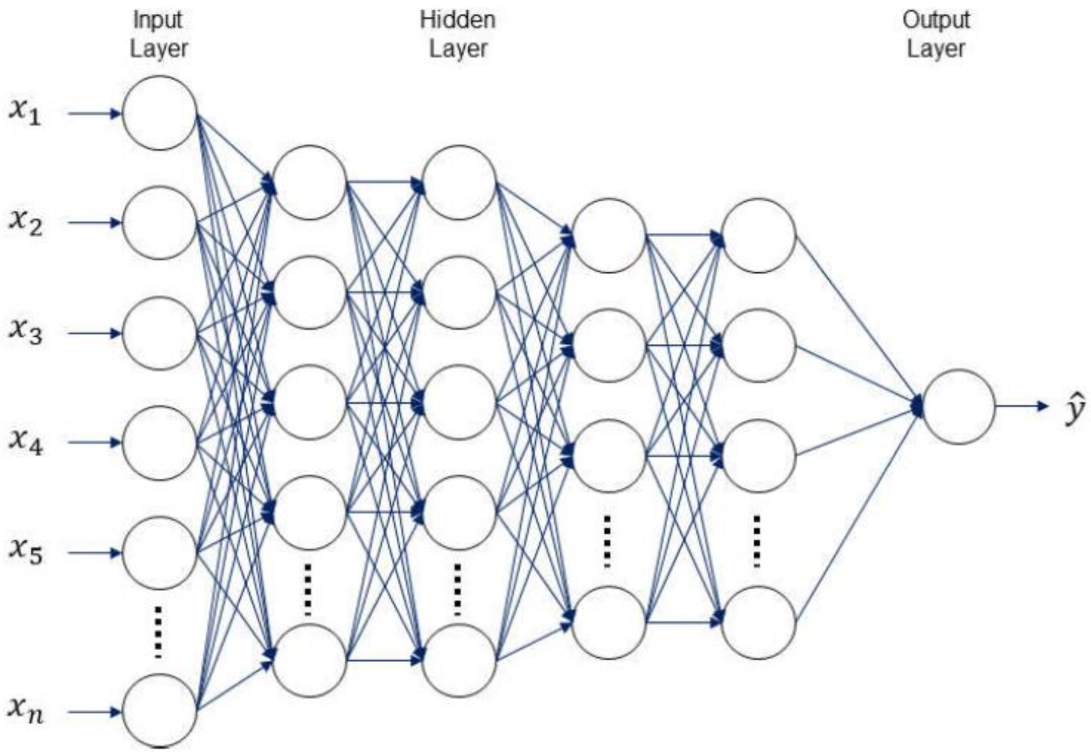
0 (Covid-19 Chest X-ray) vs 1 (Pneumonia Chest X-ray) vs 2 (Normal Chest X-ray)

y

Deep Neural Network

$x_1, x_2, ..., x_n$ represent the input data with n attributes

$\hat{y}$ represents the value predicted through the DNN.



Convolutional Layer

Consider that we have an image of size 3 x 3 and a filter of size 2 x 2

$$\begin{bmatrix} 1 & 7 & 2 \\ 11 & 1 & 23 \\ 2 & 2 & 2 \end{bmatrix} * \begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix} \quad \begin{bmatrix} 9 & \\ & \end{bmatrix}$$

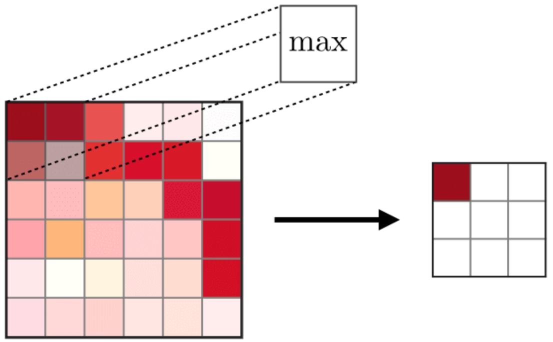
```
Z = X * f
```

```
(1x1 + 7x1 + 11x0 + 1x1) = 9
(7x1 + 2x1 + 1x0 + 23x1) = 32
(11x1 + 1x1 + 2x0 + 2x1) = 14
(1x1 + 23x1 + 2x0 + 2x1) = 26
```

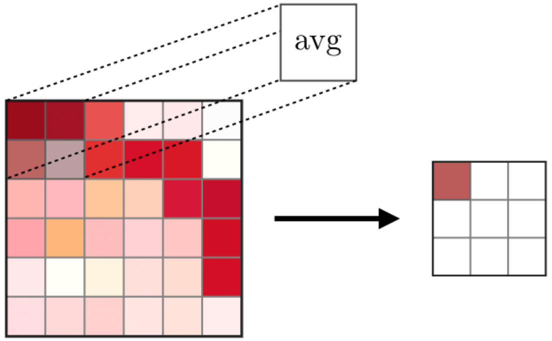
Pooling Layer

- Reduce dimensions of the feature maps.
- Reduce number of parameters to learn the network.
- makes the model robust
- Types of pooling layers-
  - Max pooling
  - Average pooling

• Preserves detected features
• Most commonly used

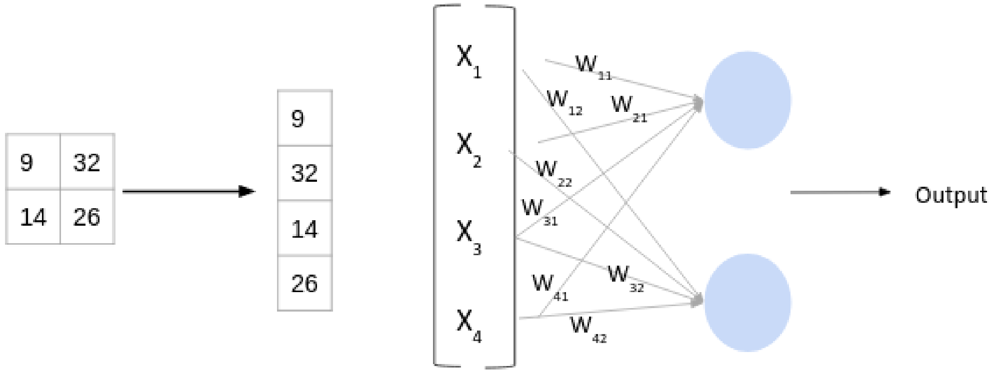


• Down samples feature map



Fully Connected Layer

- The features are sent to the fully connected layer that generates the final results.
- The fully connected layer in a CNN is nothing but the traditional neural network.



$$Z = W^T . X + b$$

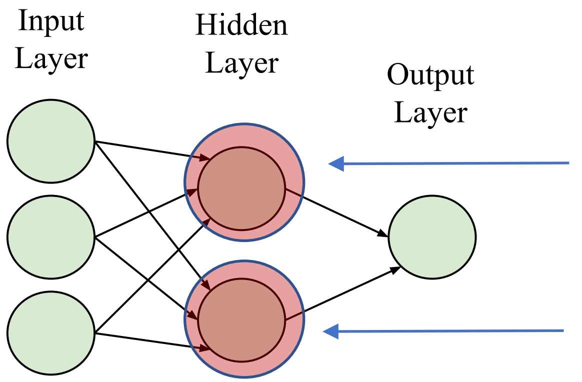
$$Z = \begin{bmatrix} W_{11} & W_{21} & W_{31} & W_{41} \\ W_{12} & W_{22} & W_{32} & W_{42} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \end{bmatrix} + \begin{bmatrix} b_1 \\ b_2 \end{bmatrix}$$

$$Z_{2x2} = \begin{bmatrix} W_{11}X_1 + W_{21}X_2 + W_{31}X_3 + W_{41}X_4 \\ W_{12}X_1 + W_{22}X_2 + W_{32}X_3 + W_{42}X_4 \end{bmatrix}$$

Activation Function

Some common activation functions are:

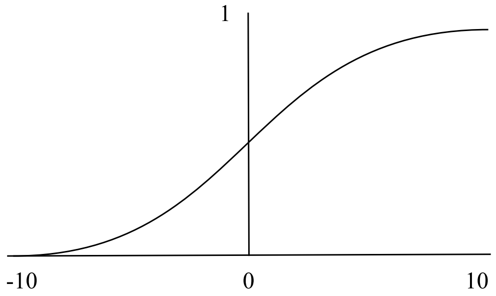
1. Sigmoid function
2. Hyperbolic tangent function (tanh)
3. Rectified linear unit (ReLU)
4. Softmax function



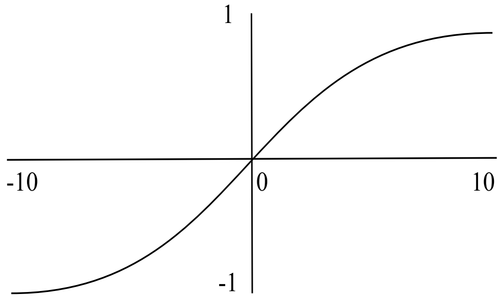
Apply activation

Apply activation

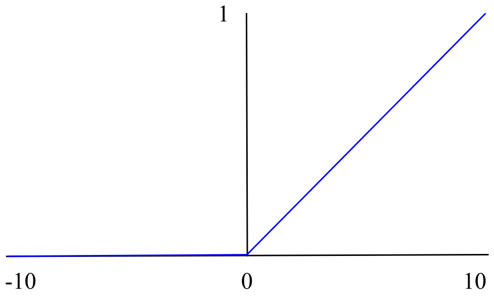
- Sigmoid function →



- Tanh function →



- ReLu function →



Pretrained Model

CheXNet

ChexNet is a 121-layer convolutional neural network that inputs a chest X-ray image and outputs the probability of disease.

DenseNet169

DenseNet169 is a network architecture where each layer is directly connected to every other layer in a feed-forward fashion

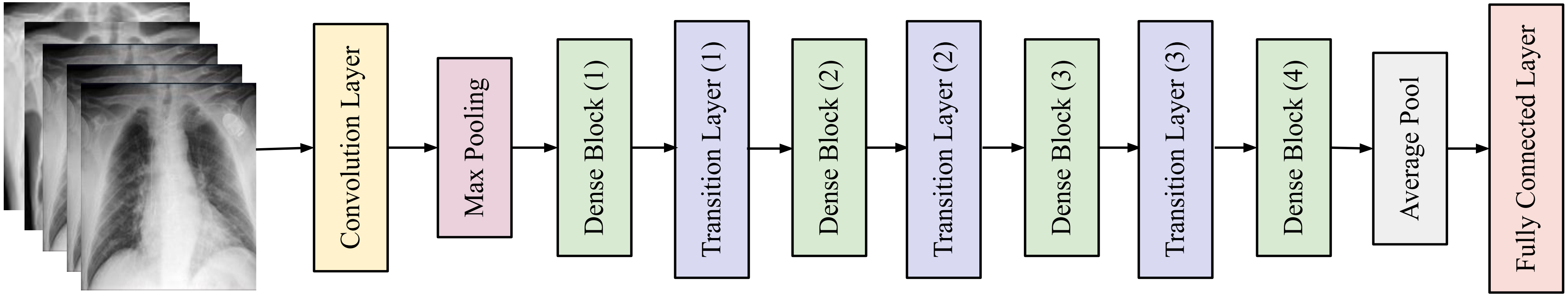
ResNet50

A residual neural network or ResNet is an artificial neural network (ANN) that is 50 layers deep.

VggNet16

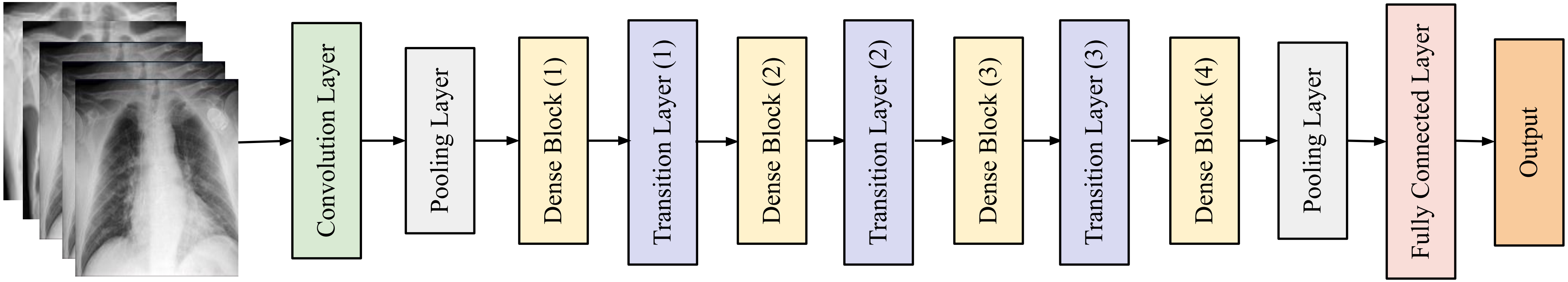
Visual Geometry Group or VGG refers to the fact that it is 16 layers deep neural network.

CheXNet Architecture



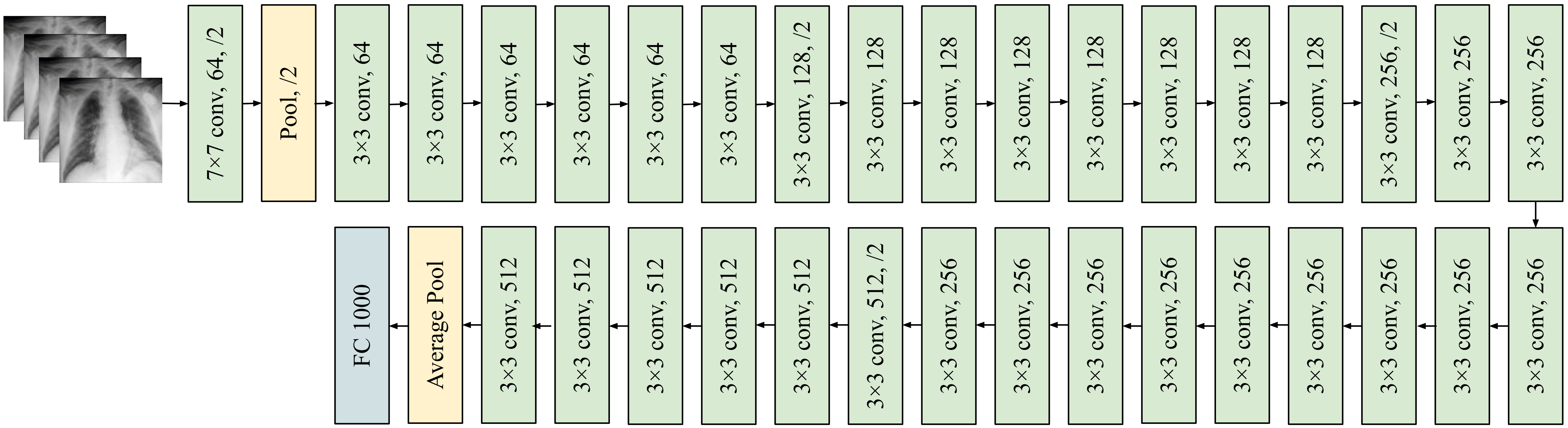
- Schematic representation of CheXNet Architecture

DenseNet Architecture



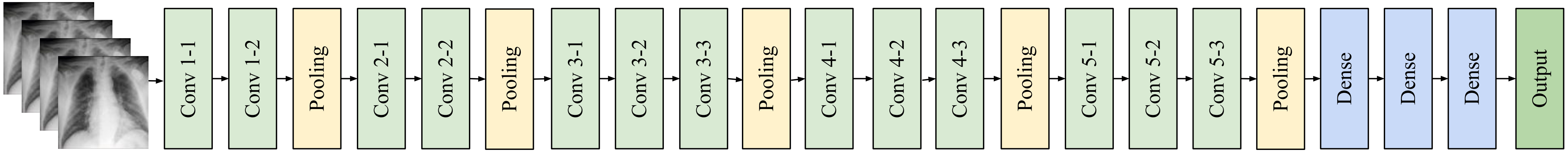
- Schematic representation of DenseNet Architecture

ResNet Architecture



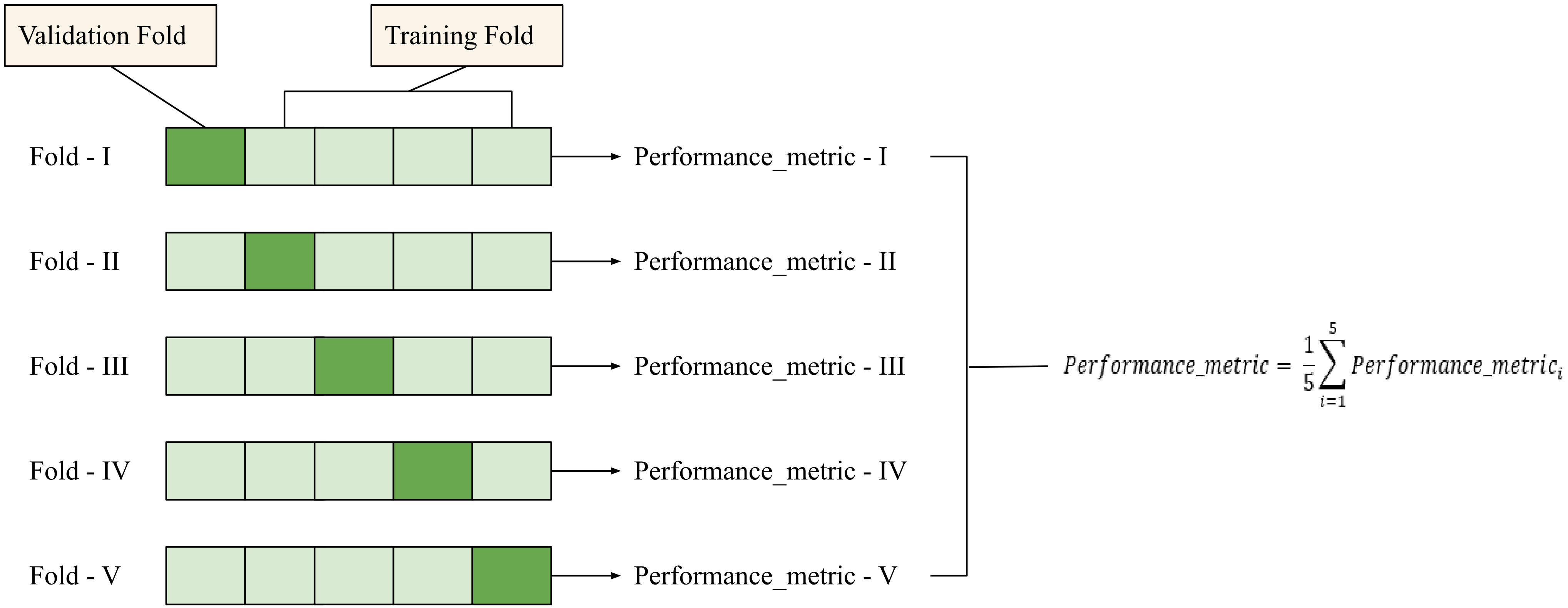
- Schematic representation of ResNet Architecture

VggNet Architecture



- Schematic representation of VggNet Architecture

Training



- Schematic representation of cross validation
- We are using k-fold cross validation to make model more robust.

Experimental Setup

- $D_{Total} = \{D_{i=1}\}_{i=1}^{24}$

- $D_{i=1\ldots(j-1)} = D_j$
- $D_{j=3} = \{D_1, D_2\}$
- $D_{j=4} = \{D_1, D_2, D_3\}$

Dataset	Size	Balanced Data (+ve)	Balanced Data (-ve)
D_1	200	100	100
D_2	400	200	200
D_3	600	300	300
D_4	800	400	400
D_5	1000	500	500
D_6	1200	600	600
……..	…….	……	……
D_{19}	3800	1900	1900
D_{20}	4000	2000	2000
D_{21}	4200	2100	2100
D_{22}	4400	2200	2200
D_{23}	4600	2300	2300
D_{24}	4716	2358	2358

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Results

Dataset	Model	Fold 1				Fold 2				Fold 3				Fold 4				Fold 5				Average				Standard Deviation			
		ACC	AUC	SEN	SPEC	ACC	AUC	SEN	SPEC	ACC	AUC	SEN	SPEC	ACC	AUC	SEN	SPEC	ACC	AUC	SEN	SPEC	ACC	AUC	SEN	SPEC	ACC	AUC	SEN	SPEC
D1	ChexNet	52.50%	0.5	0	0	60%	0.69	0.82	0.6	55.00%	0.57	0.55	0.6	55.00%	0.69	0.47	0.77	85.00%	0.91	0.77	1	**61.50%**	0.672	0.522	0.594	**0.134**	0.156	0.326	0.370
	DenseNet169	43.75%	0.43	0.43	0.31	40.63%	0.41	0.41	0	46.88%	0.62	0.81	0.47	43.75%	0.44	0.44	0	62.50%	0.66	1	0.31	**47.50%**	0.512	0.618	0.218	**0.087**	0.118	0.271	0.209
	ResNet50	50.00%	0.47	0.5	0.5	53.13%	0.53	1	0.53	43.75%	0.5	1	0	31.25%	0.33	0.31	0.09	62.50%	0.63	0.63	0.63	**48.13%**	0.492	0.688	0.35	**0.116**	0.109	0.307	0.284
	Vgg16	50.00%	0.52	0.5	0.53	46.88%	0.5	0.47	0	43.75%	0.44	0.44	0	43.75%	0.44	0.44	0	62.50%	0.63	0.63	0.63	**49.38%**	0.506	0.496	0.232	**0.078**	0.078	0.079	0.320
D2	ChexNet	46.25%	0.71	0.39	0.44	76.25%	0.69	0.86	0.52	98.75%	0.98	0.95	0.99	96.25%	0.97	0.96	0.96	98.75%	0.99	0.99	0.99	**83.25%**	0.868	0.83	0.78	**0.227**	0.154	0.251	0.276
	DenseNet169	56.25%	0.74	0.48	0.48	48.44%	0.72	0.94	0.47	62.50%	0.64	0.75	0.53	93.75%	0.95	0.91	0.98	64.06%	0.65	0.64	0.69	**65.00%**	0.74	0.744	0.63	**0.172**	0.125	0.191	0.215
	ResNet50	50.00%	0.53	0.5	0	48.44%	0.48	0.48	0	53.13%	0.6	0.53	0.53	39.06%	0.39	0.39	0	65.63%	0.59	0.66	0.69	**51.25%**	0.518	0.512	0.244	**0.096**	0.086	0.098	0.339
	Vgg16	51.56%	0.5	0.52	0	54.69%	0.55	0.55	0.55	53.13%	0.53	0.53	0.53	50.00%	0.5	0.5	0.5	48.44%	0.48	0.48	0	**51.56%**	0.512	0.516	0.316	**0.025**	0.028	0.027	0.289
D3	ChexNet	96.67%	0.99	0.91	1	60%	0.61	0.6	0.63	74.17%	0.74	0.77	0.7	74.17%	0.74	0.77	0.7	95.83%	0.96	0.96	0.96	**80.17%**	0.808	0.802	0.798	**0.158**	0.162	0.141	0.169
	DenseNet169	53.13%	0.53	0.53	0.53	47.92%	0.63	0.48	0.33	97.92%	0.96	0.99	0.92	96.88%	0.97	0.97	0.97	100.00%	0.98	0.97	1	**79.17%**	0.814	0.788	0.75	**0.262**	0.217	0.259	0.302
	ResNet50	44.79%	0.46	0.45	0	46.88%	0.47	0.47	0.31	55.21%	0.55	0.55	0.55	56.25%	0.51	0.56	0.56	51.04%	0.45	0.51	0.51	**50.83%**	0.488	0.508	0.386	**0.050**	0.041	0.048	0.238
	Vgg16	44.79%	0.45	0.45	0	48.96%	0.49	0.49	0	51.04%	0.51	0.51	0.51	52.08%	0.52	0.52	0.52	59.38%	0.59	0.59	0.59	**51.25%**	0.512	0.512	0.324	**0.053**	0.051	0.051	0.297
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D22	ChexNet	98.51%	0.99	0.98	0.99	97.52%	0.98	0.97	0.98	99.01%	1	0.99	1	98.51%	0.99	0.99	0.99	99.01%	1	0.99	1	**98.51%**	0.992	0.984	0.992	**0.006**	0.008	0.009	0.008
	DenseNet169	99.17%	0.99	0.99	0.99	98.84%	0.99	0.98	1	98.02%	0.99	0.98	0.98	98.02%	0.99	0.98	0.99	98.84%	0.99	0.99	0.99	**98.58%**	0.99	0.984	0.99	**0.005**	0.000	0.005	0.007
	ResNet50	39.93%	0.4	0.4	0	56.36%	0.56	0.56	0.56	56.69%	0.57	0.57	0.57	60.50%	0.6	0.6	0.6	60.83%	0.61	0.61	0.61	**54.86%**	0.548	0.548	0.468	**0.086**	0.085	0.085	0.262
	Vgg16	60.23%	0.6	0.6	0.6	61.65%	0.62	0.62	0.62	57.02%	0.57	0.57	0.57	57.36%	0.57	0.57	0.57	56.03%	0.56	0.56	0.56	**0.58%**	0.584	0.584	0.584	**0.024**	0.025	0.025	0.025
D23	ChexNet	97.91%	0.98	0.99	0.97	98.87%	0.99	0.99	0.99	96.94%	0.98	0.98	0.97	98.87%	0.99	0.99	0.99	99.68%	1	1	1	**98.45%**	0.988	0.99	0.984	**0.011**	0.008	0.007	0.013
	DenseNet169	97.59%	0.98	0.97	0.98	97.26%	0.98	0.97	0.98	99.19%	0.99	0.99	0.99	98.07%	0.98	0.98	0.99	98.55%	0.99	0.98	1	**98.13%**	0.984	0.978	0.988	**0.008**	0.005	0.008	0.008
	ResNet50	60.61%	0.61	0.61	0.61	57.33%	0.57	0.57	0.57	58.29%	0.58	0.58	0.58	57.65%	0.58	0.58	0.58	62.00%	0.62	0.62	0.62	**59.18%**	0.592	0.592	0.592	**0.020**	0.022	0.022	0.022
	Vgg16	59.16%	0.59	0.59	0.59	57.00%	0.57	0.57	0.57	59.10%	0.59	0.59	0.59	56.52%	0.57	0.57	0.57	62.80%	0.63	0.63	0.63	**58.92%**	0.59	0.59	0.59	**0.025**	0.024	0.024	0.024
D24	ChexNet	96.67%	0.97	0.94	0.99	97.62%	0.98	0.98	0.97	98.10%	0.99	0.98	0.99	98.89%	0.99	0.99	0.99	97.62%	0.99	0.99	0.98	**97.78%**	0.984	0.976	0.984	**0.008**	0.009	0.021	0.009
	DenseNet169	97.94%	0.98	0.97	1	99.21%	0.99	0.99	0.99	98.25%	0.98	0.98	0.98	99.21%	0.99	0.98	0.99	99.84%	1	1	1	**98.89%**	0.988	0.984	0.992	**0.008**	0.008	0.011	0.008
	ResNet50	62.44%	0.62	0.62	0.68	57.37%	0.57	0.57	0.57	59.52%	0.6	0.6	0.6	58.25%	0.58	0.58	0.58	62.70%	0.63	0.63	0.63	**60.06%**	0.6	0.6	0.612	**0.024**	0.025	0.025	0.044
	Vgg16	58.95%	0.59	0.59	0.59	58.95%	0.59	0.59	0.59	58.10%	0.58	0.58	0.58	63.02%	0.63	0.63	0.63	60.00%	0.6	0.6	0.6	**59.80%**	0.598	0.598	0.598	**0.019**	0.019	0.019	0.019

Results

D_1

μ ± σ	AUC	ACC	SPEC	SEN
CheXNet	0.67 ± 0.156	61.5 ± 0.134	0.59 ± 0.37	0.52 ± 0.326
DenseNet169	0.51 ± 0.118	47.5 ± 0.087	0.22 ± 0.209	0.62 ± 0.271
ResNet50	0.49 ± 0.109	48.13 ± 0.116	0.35 ± 0.284	0.69 ± 0.307
VggNet16	0.51 ± 0.078	49.38 ± 0.078	0.23 ± 0.32	0.5 ± 0.079

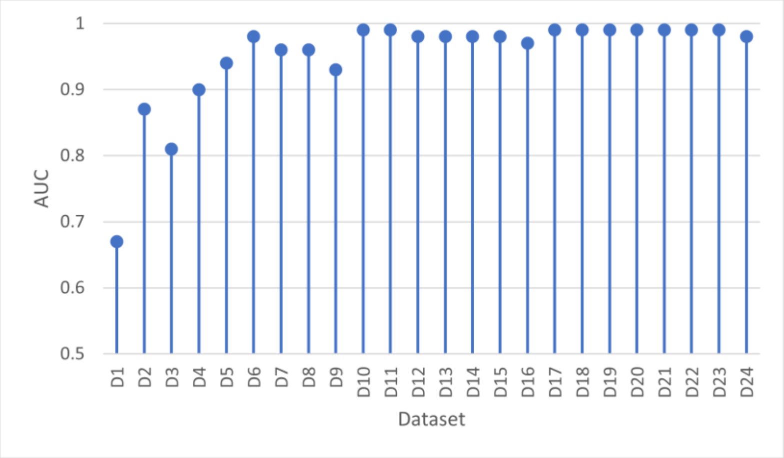
D_{24}

μ ± σ	AUC	ACC	SPEC	SEN
CheXNet	0.98 ± 0.009	97.78 ± 0.008	0.98 ± 0.009	0.98 ± 0.021
DenseNet169	0.99 ± 0.008	98.89 ± 0.008	0.99 ± 0.008	0.98 ± 0.011
ResNet50	0.6 ± 0.025	60.06 ± 0.024	0.612 ± 0.044	0.6 ± 0.025
VggNet16	0.6 ± 0.019	59.8 ± 0.019	0.6 ± 0.019	0.6 ± 0.019

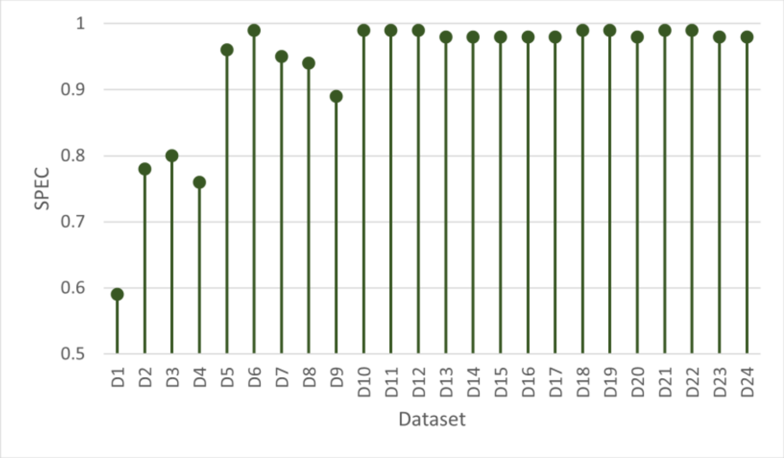
Comparison: AUC, ACC (in %), SPEC, and SEN of CheXNet, DenseNet169, ResNet50 and VggNet16 (Covid-19 vs Non-Covid-19)

Result Analysis-CheXNet

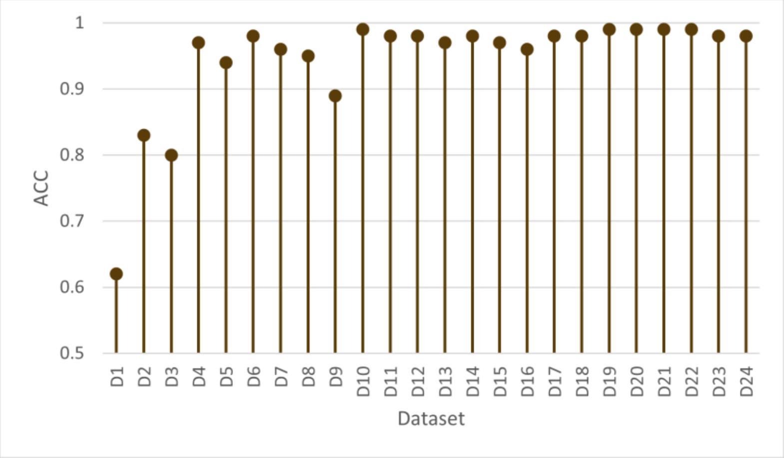
AUC



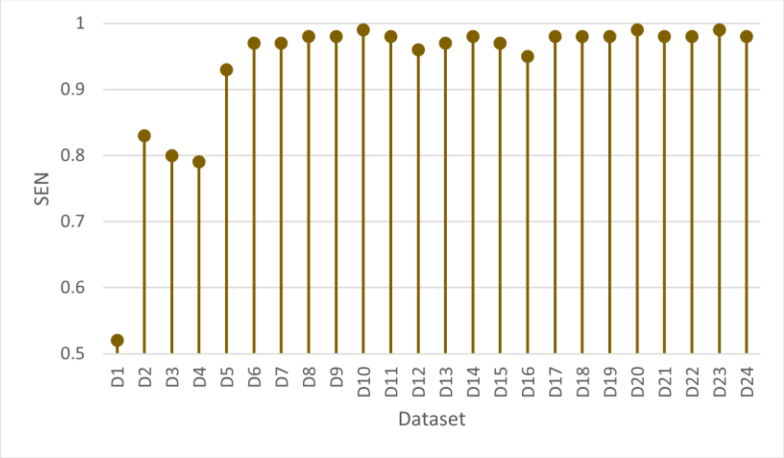
SPEC



ACC



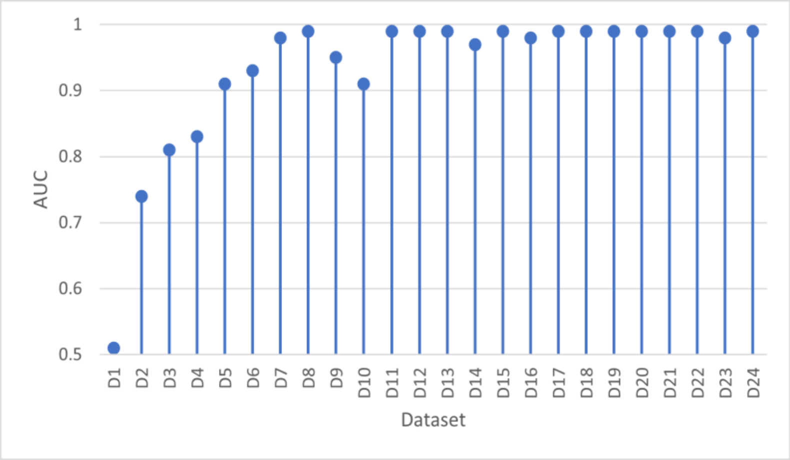
SEN

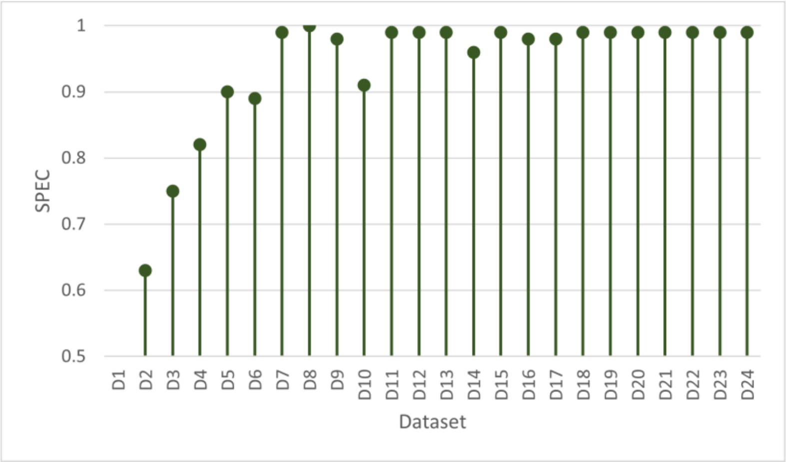


CheXNet: AUC, ACC, SPEC, and SEN

Result Analysis-DenseNet169

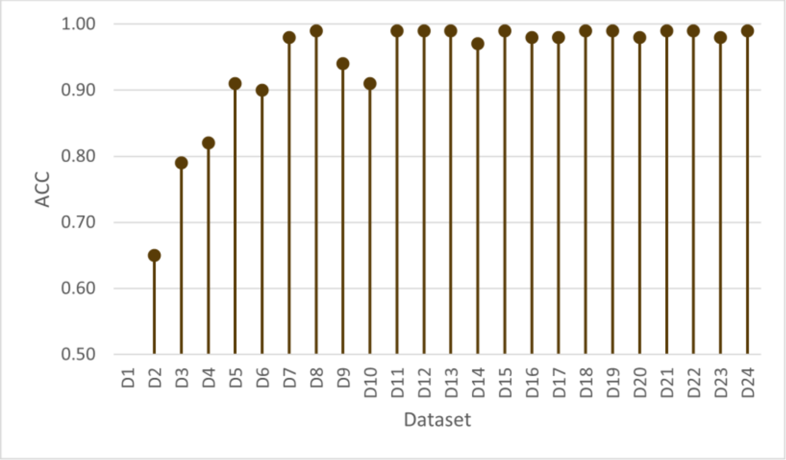
AUC

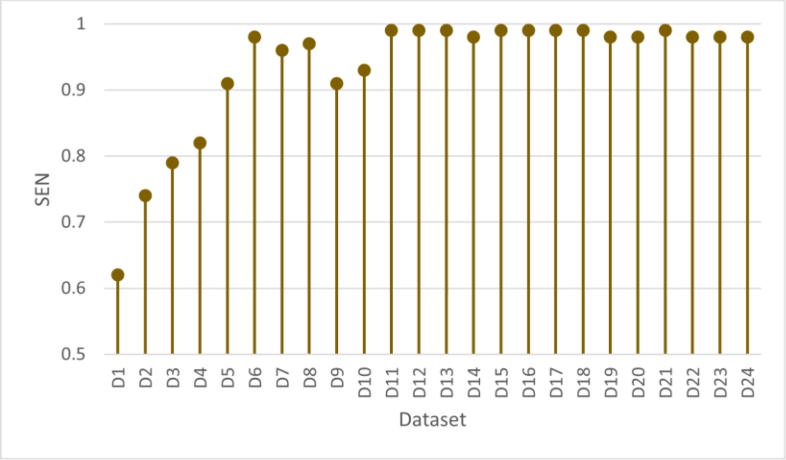




SPEC

ACC



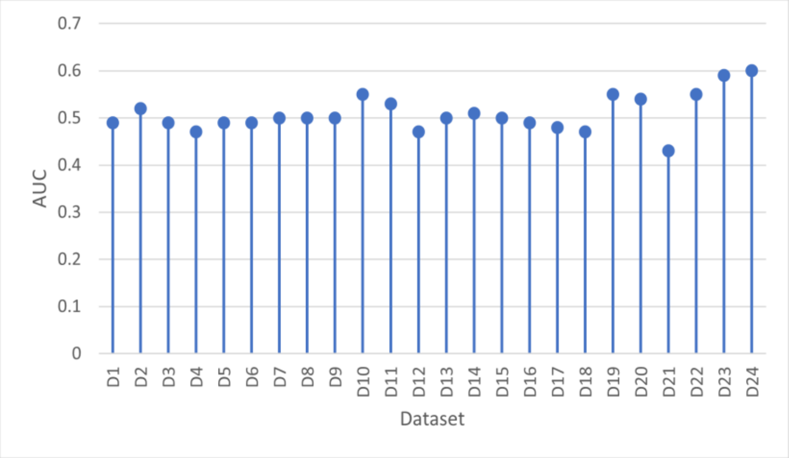


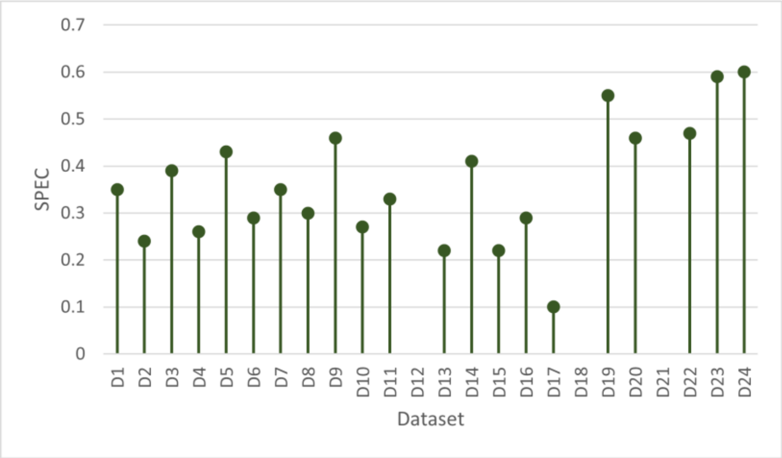
SEN

DenseNet169: AUC, ACC, SPEC, and SEN

Result Analysis-ResNet50

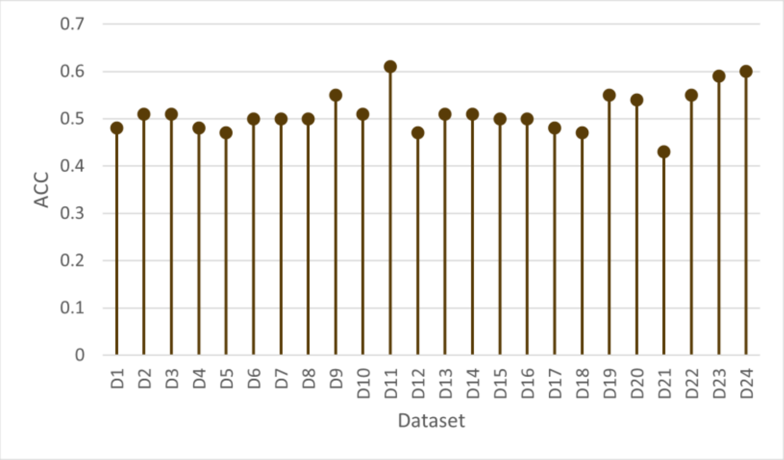
AUC

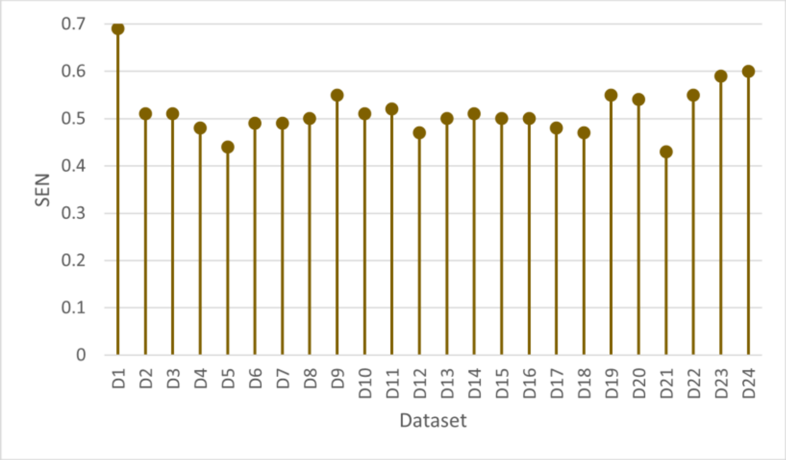




SPEC

ACC



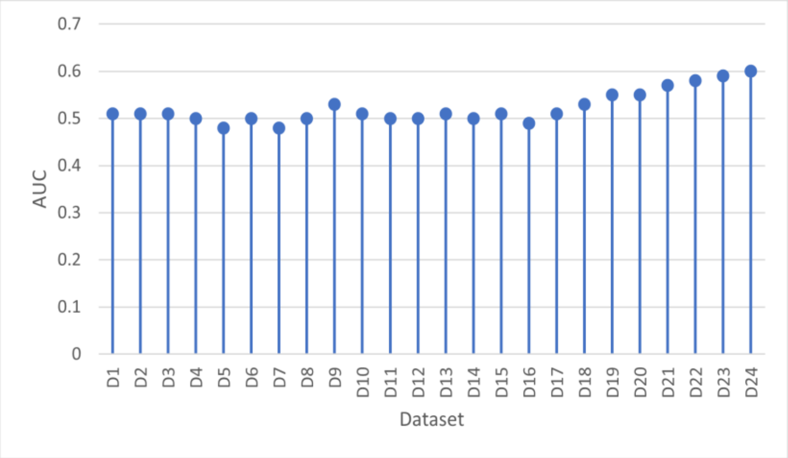


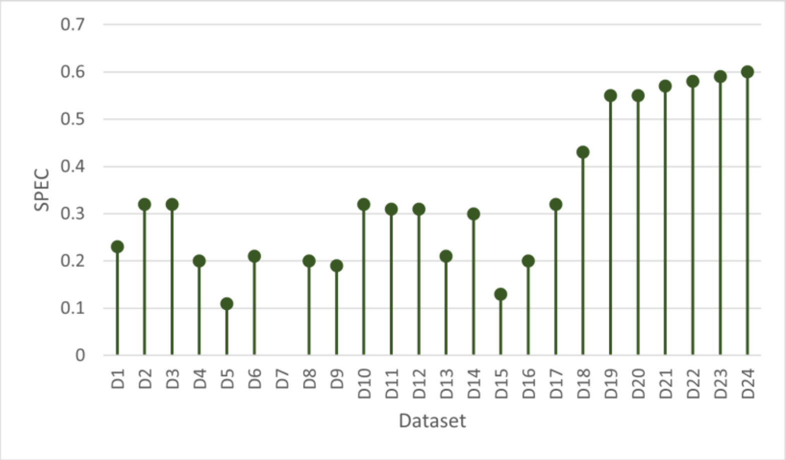
SEN

ResNet50: AUC, ACC, SPEC, and SEN

Result Analysis-VggNet16

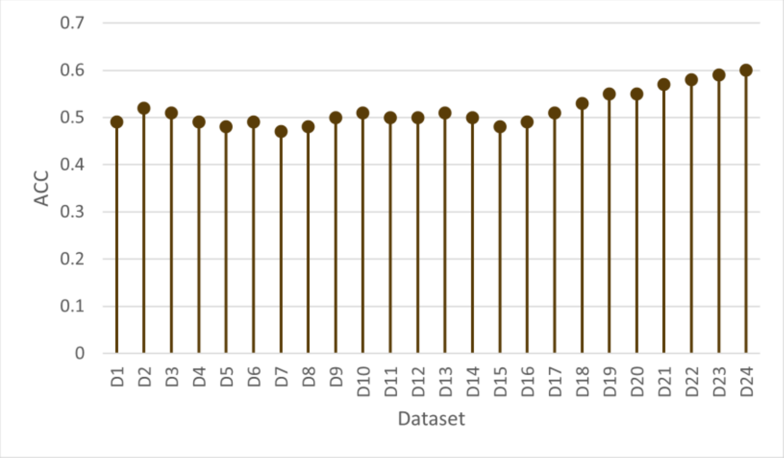
AUC

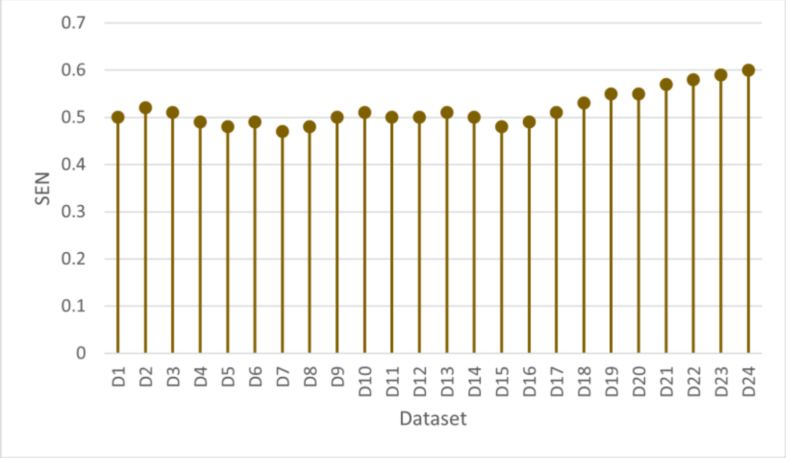




SPEC

ACC





SEN

VggNet16: AUC, ACC, SPEC, and SEN

Explainable AI (XAI)

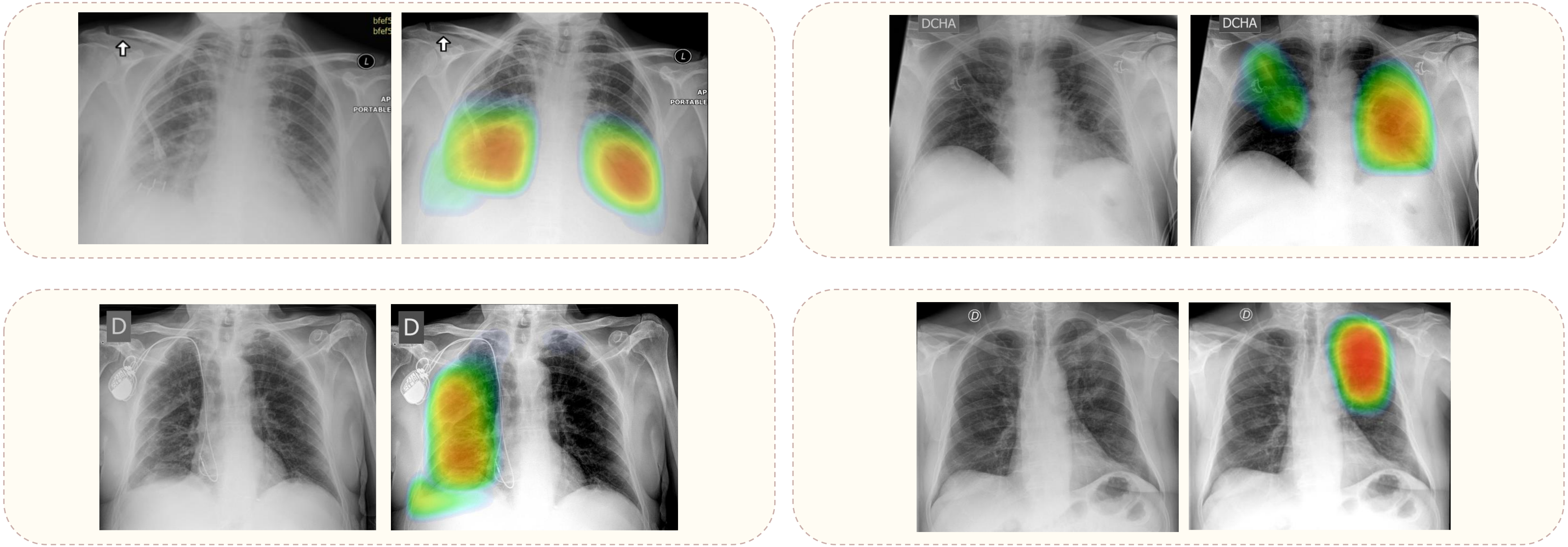
- Gradient-weighted Class Activation Mapping (Grad-CAM) helps establish trust and identify a ‘stronger’ model from a ‘weaker’ one though the visualization.
- Grad-CAM uses gradient information flowing from the last layer to understand the importance of each neuron for a decision of interest

First obtain class predictions from the image

Generate Grad-CAM maps for each of the predicted classes

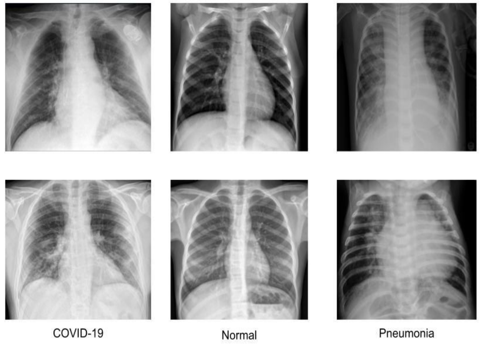
Draw bounding box around single largest connected segment of pixels

Explainable AI



Heatmap Representation

Deep Features to Analyze Pulmonary Abnormalities in Chest X-rays Due to Covid-19

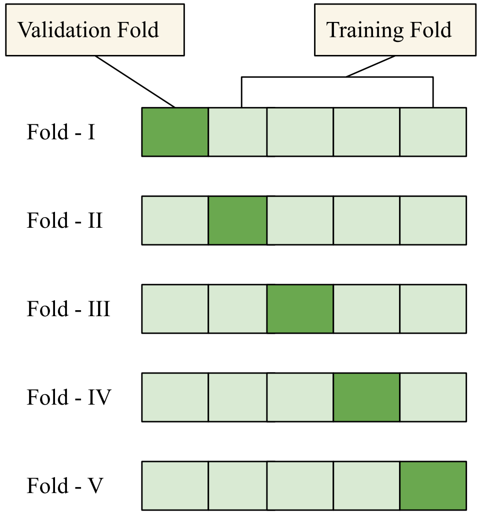


Data Collection → Data Pre-processing → Building and Training Model → Evaluating Model → Predict Covid-19 or non-Covid-19 → XAI

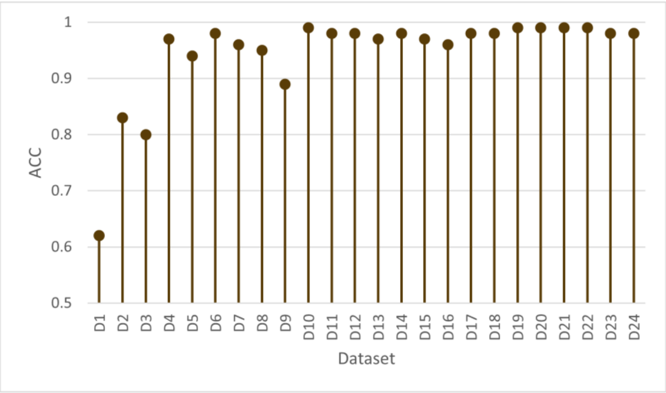
- **Data Collection:** Total = 4,716 (Covid-19: 2,358 Non-Covid-19: 2,358)
- **Data Pre-processing:** Image size 224 × 224
- **Building and Training Model:** Pre-trained Model (CheXNet, DenseNet169, Resnet50, Vgg16) (Add Dense Layer, Dropout Layer, Activation Function)
- **Evaluating Model:** k(=5)-Fold Cross Validation
- **Predict Covid-19 or non-Covid-19:** If Covid-19, forward for the next step for visualization of evidence
- **XAI:** Find evidence in Chest X-ray from Heatmap

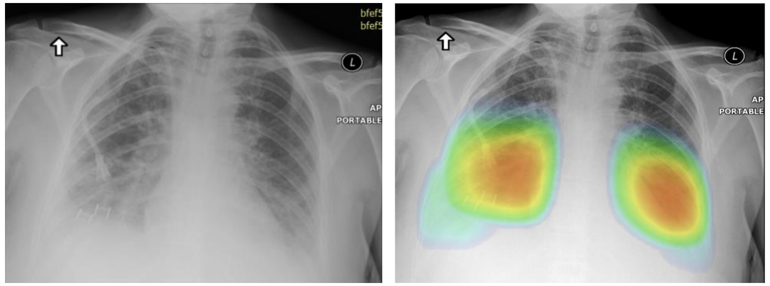
CheXNet	ChexNet is a 121-layer convolutional neural network that inputs a chest X-ray image and outputs the probability of disease.
DenseNet169	DenseNet169 is a network architecture where each layer is directly connected to every other layer in a feed-forward fashion
ResNet50	A residual neural network or ResNet is an artificial neural network (ANN) that is 50 layers deep.
VggNet16	Visual Geometry Group or VGG refers to the fact that it is 16 layers deep neural network.

Dataset	Size	Balanced Data (+ve)	(-ve)
D_1	200	100	100
D_2	400	200	200
D_3	600	300	300
D_4	800	400	400
D_5	1000	500	500
D_6	1200	600	600
……..	…….	……	……
D_{19}	3800	1900	1900
D_{20}	4000	2000	2000
D_{21}	4200	2100	2100
D_{22}	4400	2200	2200
D_{23}	4600	2300	2300
D_{24}	4716	2358	2358



CheXNet





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Future Work

- Based on the results, we would improve the model architecture to explore more features.
- We would be able to use our model in consumption with other models that work on diseases like Pneumonia, Tuberculosis, Lung Cancer x-ray images.
- Active Learning would be deployed in the model for screening and prediction.

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- I also thank lab members and researchers of Applied Artificial Intelligence Lab.
- Finally, I am grateful to the CS department and staffs.

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Thank you