Addressing Chest Radiograph Projection Bias in Deep Classification Models

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Abstract

Deep learning-based models are widely used for disease classification in chest radiographs. This exam can be performed in one of two projections (posteroanterior or anteroposterior), depending on the direction that the X-ray beam travels through the body. Since projection visibly affects the way anatomical structures appear in the scans, it may introduce bias in classifiers, especially when spurious correlations between a given disease and a projection occur. This paper examines the influence of chest radiograph projection on the performance of deep learning-based classification models and proposes an approach to mitigate projection-induced bias. Results show that a DenseNet-121 model is better at classifying images from the most representative projection in the data set, suggesting that projection is taken into account by the classifier. Moreover, this model can classify chest X-ray projection better than any of the fourteen radiological findings considered, without being explicitly trained for that task, putting it at high risk for projection bias. We propose a label-conditional gradient reversal framework to make the model insensitive to projection, by forcing the extracted features to be simultaneously good for disease classification and bad for projection classification, resulting in a framework with reduced projection-induced bias.

Keywords: chest x-ray, deep learning, disparity, anteroposterior, posteroanterior

1. Introduction

Artificial Intelligence (AI) revolutionized many fields, including medicine. It is crucial to ensure that AI-based methods are not only accurate but also unbiased and ethically compliant. Biased diagnoses can have serious consequences, and the potential sources of bias are countless, ranging from biological attributes (age, gender) to socioeconomic factors (race, income) and clinical factors (exam conditions, medical institution). When AI models are trained on biased data, they become prone to shortcut learning: instead of learning meaningful features for the issue at hand, models base their predictions on biases in the data, which are typically easier to learn than meaningful features. Not only this poses serious ethical concerns but, consequentially, these models will fail in data where the same types of biases are not present.

In this paper, we focus on the bias that projection can inject in deep learning models for frontal chest X-ray (CXR) classification. These scans can be performed in one of two projections. In the posteroanterior (PA) projection (Figure 1a), the X-ray beam transverses the patient from posterior to anterior, which is the gold standard projection for frontal CXRs. However, it is not always possible to perform PA CXRs, especially when the patient is not able to stand. When that is the case, an anteroposterior (AP) projection (Figure 1b)

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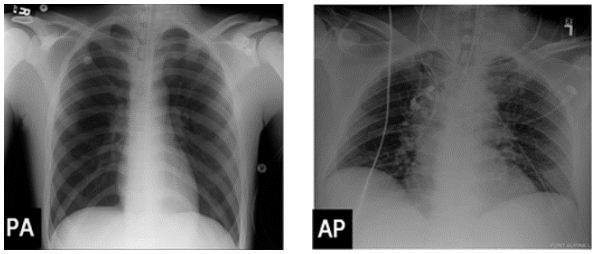


(a) Posteroanterior scan (b) Anteroposterior scan

Figure 1: Examples of chest radiographs taken in both projections.

is used, which does not require the patient to stand up, enabling the use of portable X-ray units. There are some key differences between both views. In the AP view, the scapulae are over the lung fields, which can interfere with the reading and interpretation of the scan. In the PA view, the scapulae are away from the lung fields. The clavicles are over the lung apex in the PA view, while in the AP they are above it. The heart appears enlarged in the AP view due to the shorter distance between the patient and the X-ray source. Finally, the appearance of the ribs also differs among projections, as the anterior ribs are clearer in AP and the posterior ribs are clearer in PA. Considering that these differences are immediately clear to a radiologist and possibly even to individuals with no training in radiology, a deep learning model can also easily learn them if that benefits its performance.

1.1. Related Work

Chest radiography data sets typically contain both PA and AP images (Irvin et al., 2019; Wang et al., 2017; Johnson et al., 2019), but may include exclusively PA images (Nguyen et al., 2022). Some authors choose to only include PA CXRs in their studies (Punn and Agarwal, 2021). This choice, motivated by the higher quality of the PA projection, severely limits the applicability of AI models in real clinical settings because only patients able to stand up will benefit from the algorithm to its fullest extent. The CXR projection may be a source of bias when correlations among projection and radiological findings exist in the data, and especially when the bias patterns are easier to learn than the disease patterns. However, there are no studies analyzing the impact of projection on disease classification, or if it encompasses bias. Kim et al. (2019) showed that CXR projection can be classified with very high accuracy, which further motivated our study.

Mehrabi et al. (2021) make an extensive review on bias and fairness in machine learning. They categorize bias into three types, according to its source: the data, the algorithm, and the user. The bias that CXR projection may inject in disease classification models arises from two sources: the first is the user, which may create representation bias when collecting the data, generating spurious correlations between radiological findings and projection. The second comes from the data itself, which may contain population bias when certain radiological findings are more common in a specific projection. For example, AP scans are typically more biased towards disease because they are only performed when a patient cannot stand. Multiple approaches to mitigate or reduce bias in deep classification models have been proposed. Gradient reversal was introduced by (Ganin and Lempitsky,

2014), initially for adversarial domain adaptation but later adapted for bias removal (Raff and Sylvester, 2019; Ueda et al., 2021; Rundo et al., 2021), including in medical imaging applications (Bevan and Atapour-Abarghouei, 2022). This method aims at generating predictive features that cannot be used to distinguish between different data domains, thereby allowing for effective data domain adaptation. The framework combines the optimization of underlying features with two discriminative classifiers: a label predictor that predicts the class labels and a domain classifier that predicts the source of the data. The goal of the network is to minimize the loss of the label predictor, while maximizing the loss of the domain classifier, such that the learned features are discriminative for the main task but not for domain classification. In the case of bias removal, instead of having a source and target domain, two sub-groups of a single domain are separable by a protected attribute to which models should be insensitive to, and the domain classifier is framed instead as a protected attribute classifier, whose loss shall be maximized.

1.2. Contributions

In this paper, we pioneer the study of the effect of CXR projection in classification models. Our contributions are three-fold: (1) We show that projection is easier to learn than any of the radiological findings considered, even when a model is not trained for such a task. This puts models at high risk for projection bias, especially when projection and disease information correlate, so models tend to learn projection instead of meaningful disease features. (2) We also show that models for CXR classification are better at classifying images in the projection they were presented the most during training, suggesting that patient projection is a source of bias in the model's decisions and thus influences predictions, supporting (1). (3) We propose a debiasing approach that discourages the model from learning projection-relevant information when learning disease-relevant information, based on gradient reversal. Moreover, we show that by using the proposed approach, our model successfully *unlearns* projection, resulting in a less biased model that performs more equally between AP and PA projections.

2. Methods

2.1. Data and Preprocessing

We use the ChestX-Ray14 multi-label data set (Wang et al., 2017), which contains 112,120 frontal-view X-ray images of 30,805 patients, labeled for the presence of fourteen radiological findings and disease labels. The images are first resized to a height of 256 pixels (preserving aspect ratio) and then cropped to 224×224 pixels. The data is then split into five stratified folds, without patient overlap. Table 1 details the number of occurrences of each label in each fold and the percentage of PA images ($\%AP = 100 - \%PA$). Random horizontal flips ($p = 1\%$) and random rotations ($\pm 20^\circ$ range) were performed to augment the data set.

2.2. Experiments

Two models were developed, both based on an ImageNet (Deng et al., 2009) pretrained DenseNet-121 (Huang et al., 2017) feature extractor, widely used in the literature for this data set (Rajpurkar et al., 2017; Baltruschat et al., 2019) and other CXR data sets (Irvin

Table 1: Number of occurrences per fold of each label and percentage of PA occurrences.

Label	Occurrences	% PA
Hernia	45 ± 10	85.28 ± 4.11
Cardiomegaly	555 ± 7	56.33 ± 3.96
Edema	461 ± 3	11.98 ± 1.47
Pneumothorax	1,060 ± 6	64.26 ± 2.36
Nodule	1,266 ± 9	65.98 ± 2.55
Emphysema	503 ± 6	59.59 ± 3.74
Infiltration	3,979 ± 7	47.01 ± 1.32
Atelectasis	2,312 ± 9	49.55 ± 1.26
Fibrosis	337 ± 3	83.52 ± 1.56
Consolidation	933 ± 8	32.58 ± 1.36
Mass	1,156 ± 11	61.68 ± 1.37
Pleural Thickening	677 ± 5	71.43 ± 2.01
Pneumonia	286 ± 6	44.05 ± 3.56
Effusion	2,663 ± 6	49.48 ± 1.52
No Finding	12,072 ± 0.75	65.11 ± 0.70

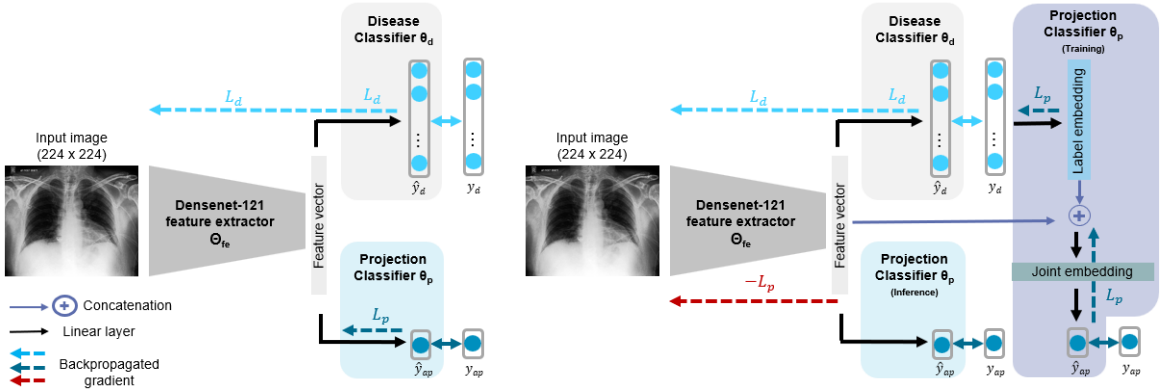
et al., 2019; Alam et al., 2022). Both models contain three modules: a **feature extractor** θ_{fe}, a **disease classifier** θ_d and a **projection classifier** θ_p (Figure 2). θ_d contains 14 output neurons (one per disease label) and is used to predict a probability for each label $y_d = [y_1, y_{,2}, ..., y_{14}]$. The cross entropy loss between $\hat{y_d}$ and corresponding ground-truth y_d, L_d, is used to train θ_{fe} and θ_d. θ_p and has a single output neuron for predicting the probability of an image being of the AP projection y_{ap} ($P(PA) = 1 - P(AP)$). The cross entropy loss between $\hat{y}_{ap}$ and corresponding ground-truth y_{ap}, L_p, is used to update the parameters of θ_p. In the baseline model (Figure 2a), the goal of predicting CXR projection is to assess how good the model is at predicting projection with features that are trained exclusively for disease classification, and hence, this neuron's output should not be considered when calculating the gradients for updating the feature extractor. To achieve this, the gradient back-propagated from the projection output neuron is not propagated beyond θp, preventing feature updates based on projection information. The total loss of the baseline model is the sum of L_d and L_p, each referring to the parameters they update (Equation 1).

$$L = L_d(\theta_{fe}, \theta_d) + L_p(\theta_p) \tag{1}$$

We then propose a modified version of the baseline model with the goal of reducing projection-induced bias (Figure 2b). There are two modifications to the baseline model. First, a new loss component is introduced, where the gradients calculated based on L_p are inverted and used to update θ_{fe}, to remove information encoding projection from the feature extractor. The proposed model plays a min-max game when updating θ_{fe}, where it *unlearns* projection information while simultaneously learns to predict disease labels. The total loss of the proposed model therefore presented in Equation 2:

$$L = L_d(\theta_{fe}, \theta_d) + L_p(\theta_p) - L_p(\theta_{fe}) \tag{2}$$

The second modification takes place in θ_p, where y_d is encoded into an embedding that is concatenated with the feature vector. The concatenated vector is encoded into a joint



(a) Baseline model

(b) Proposed model

Figure 2: Forward and backward passes of both architectures, which share three main components: a feature extractor, a disease classifier and a projection classifier. The dashed arrows illustrate the parameters affected by each loss component from Eq. 1 and 2, respectively.

embedding and used as an input to predict $\hat{y}_{ap}$ (Figure 2b). Therefore, the output neuron of θ_p is now generating $P(AP|y_d)$ instead of $P(AP)$. By using $P(AP|y_d)$ as $\hat{y}_{ap}$, instead of $P(AP)$, we account for the conditional dependence between projection features and disease labels when computing L_p, ensuring that the alignment between the AP and PA feature spaces is adapted according to the diseases present in each image. During inference, we do not use y_d as an input for predicting $\hat{y}_{ap}$, and the model behaves exactly like the baseline model, in order to assess how well the model can classify projection independently of the disease, and to compare it to the baseline model.

We run both models (baseline and proposed) on the five-folded data. We report the Area Under the Receiver Operating Characteristic Curve (AUC) and for every disease label and for the projection label. To measure bias, considering projection as the protected attribute of interest P, we calculate the True Positive Rate (TPR) Disparity between AP and PA images (Equation 3) (Raff and Sylvester, 2019; Mehrabi et al., 2021; Ruan et al., 2022; Rodolfa et al., 2021). This metric is based on the Equal Opportunity definition of fairness, introduced by (Hardt et al., 2016). This definition states that each group of P should get a positive outcome at equal rates ($P(Y = 1|P = 0, Y = 1) = P(Y = 1|P = 1, Y = 1)$).

$$TPRDisp = |TPR_{AP} - TPR_{PA}| \tag{3}$$

Even though the goal is to obtain a model with less bias, predictive performance on the main task cannot be neglected. Motivated by this, and inspired by (Raff and Sylvester, 2019), we also report $\delta = AUC - TRPDisp$, in order to consider a trade-off between predictive performance and equality of opportunity.

2.3. Model Training Details

All the models were trained for eight epochs with a batch size of 32 and a learning rate of $1e^{-4}$ for the *learning* loss components $L_d(\theta_{fe}, \theta_d)$ and $L_p(\theta_p)$, and $1e^{-5}$ for the *unlearning*

loss component $-L_p(\theta_{fe})$. The learning rates are reduced twice by a factor of ten after four and six epochs. Checkpoints are performed every 6,400 images. For the baseline, we select the weights from the checkpoint with the lowest L_d validation loss, since L_p does not affect the training of θ_{fe} nor θ_d. For our proposed model, both L_d and L_p affect θ_{fe}. However, their magnitude and decrease speed vary significantly, and finding a way to combine them into a single monitoring quantity is hard and empirical, a common problem in adversarial settings like ours (Zhan et al., 2018; Mao et al., 2022). For this reason, we select the weights from the checkpoint with the highest δ. The models were created using the PyTorch framework and run on an NVIDIA GeForce RTX 3080 10 GB Graphics Processing Unit. Binary predictions are generated by thresholding based on the best operating point of the per-label Receiver Operating Characteristic curve.

3. Results and Discussion

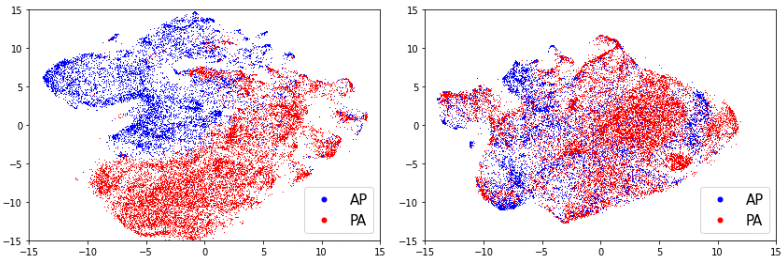
We start by analyzing the results obtained with the baseline model, followed by the results obtained with the proposed model. Table 2 shows the results obtained with the baseline model for each label, as well as the macro-averaged results across disease labels and also the AUC for projection classification. For each label, predictive performance is worse in images from the projection that is less prevalent in the data (Table 1). For example, most of the "Hernia" cases are PA, and therefore its TPR is much higher in PA scans. The opposite happens for "Edema", which contains many more AP instances. For labels in which the proportion of AP and PA scans is balanced, the TPR Disparity is smaller ("Cardiomegaly", for example). Note that the AUC for projection classification is very high, although the feature extractor was not explicitly trained for this task. This indicates that predicting projection from disease-related features is extremely easy, putting the model at high risk for shortcut learning. Considering that the key differences between AP and PA scans (Figure 1) are easier to grasp to the inexperienced human eye than those of most disease labels, it is not surprising that deep learning models can easily distinguish between the two types of scans. These results highlight the need to take CXR projection into account when creating or choosing a data set for training a machine learning model. For example, a model trained on a data set containing mostly AP scans may perform well in an intensive care unit setting, where most patients will be in a critical state and won't be able to stand up, which means most scans will be taken using the AP projection. However, the same model will most likely perform poorly in a triage setting, where most patients are able to stand and thus a PA projection will be preferred.

The proposed framework aims at generating features that do not encode projection information, and thus it is expected that the projection AUC decreases when compared to the baseline model. Results show that is the case, with projection AUC dropping from 99% to 61% (Table 3). To investigate if the features from the proposed model are more well aligned between the two groups of scans (AP and PA), t-distributed Stochastic Neighbor Embedding (t-SNE) plots (van der Maaten and Hinton, 2008) of the features of the baseline and proposed model for one fold were generated and can be found in Figure 3. There is a clear separability among the features of AP and PA instances for most data points in the baseline features (Figure 3a), indicating that projection is being encoded into the disease features. However, in features of the proposed model (Figure 3b), the AP and PA feature

Table 2: Mean and standard deviation 5-fold cross validation results of the baseline model.

	AUC (%)	TPR AP (%)	TPR PA (%)	TPR Disparity	δ
Hernia	90.32±2.46	55.0±16.24	81.89±6.84	27.56±21.34	62.77±19.96
Cardiomegaly	91.63±0.53	81.97±4.31	89.95±3.0	7.97±3.75	83.65±4.22
Edema	90.49±0.37	89.75±2.43	52.22±10.49	37.53±9.21	52.96±9.22
Pneumothorax	88.85±0.96	71.01±4.84	83.07±2.99	12.06±4.21	76.78±5.03
Nodule	78.31±0.31	65.97±5.16	68.58±1.86	3.39±3.13	74.92±3.36
Emphysema	92.63±0.97	85.43±4.46	82.69±1.15	3.01±4.66	89.63±3.75
Infiltration	72.47±0.32	81.9±2.73	42.72±4.79	39.18±2.84	33.29±3.08
Atelectasis	82.56±0.21	82.12±2.16	73.91±2.73	8.21±2.26	74.34±2.46
Fibrosis	82.32±0.83	45.23±15.2	77.19±2.14	31.96±14.94	50.35±15.32
Consolidation	81.24±0.84	87.7±1.62	53.33±5.0	34.36±4.8	46.88±5.08
Mass	86.14±0.09	71.93±3.74	80.45±3.11	8.52±4.03	77.61±3.94
Pleural_Thickening	81.35±0.67	65.75±6.65	80.0±4.13	14.25±4.67	67.1±4.43
Pneumonia	76.89±1.11	78.78±3.2	54.51±4.25	24.27±3.6	52.62±4.27
Effusion	88.81±0.43	84.2±2.03	82.74±1.33	2.32±1.46	86.49±1.39
Macro average	84.57±0.2	74.77±1.5	71.66±1.26	18.19±2.05	66.39±1.97
Projection	99.28±0.21				

spaces are completely overlapped. These results suggest that the proposed technique can be used to regularize the features of models trained in data sets with high projection imbalance, but that are meant to be used in a scenario where both AP and PA settings are present.



(a) Baseline model (b) Proposed model

Figure 3: t-SNE plots showing the 2-D projected feature spaces of the models.

The proposed model shows a decrease in the TRP disparity (Table 3), especially in labels with the highest projection imbalance, indicating that the equality of opportunity among AP and PA scans increased. In most cases, there is a trade-off between predictive performance (AUC) and disparity. This is expected especially for labels with high projection imbalance because forcing the model to perform equally among both projections will make it perform better in scans from the underrepresented projection and worse in those from the overrepresented projection, leading to a decrease in the global label AUC but also to an increase in TPR parity.

Table 3: Mean and standard deviation 5-fold cross validation results of the proposed model.

	AUC (%)	TPR AP (%)	TPR PA (%)	TPR Disparity	δ
Hernia	90.63±2.94	80.56±7.08	83.1±7.58	3.21±4.23	87.42±4.61
Cardiomegaly	91.14±0.82	81.45±5.58	88.28±3.08	6.83±4.17	84.31±4.9
Edema	87.58±1.52	81.96±3.81	68.8±9.95	13.17±7.8	74.42±8.18
Pneumothorax	88.12±0.95	74.72±2.07	83.98±1.22	9.26±1.81	78.86±2.43
Nodule	77.45±0.39	66.46±6.58	64.39±2.39	4.61±2.24	72.84±2.37
Emphysema	92.23±0.59	86.88±5.0	83.17±3.8	3.71±4.86	88.52±4.55
Infiltration	71.8±0.81	78.0±0.74	46.75±4.74	31.25±4.33	40.55±4.77
Atelectasis	81.87±0.33	78.6±1.32	74.59±2.47	4.01±2.32	77.86±2.48
Fibrosis	79.92±1.57	70.39±7.71	72.55±5.64	6.33±5.02	73.59±4.6
Consolidation	79.67±0.78	84.13±1.41	66.64±3.92	17.49±3.4	62.18±3.11
Mass	85.81±0.44	69.63±6.06	76.22±3.6	6.92±6.55	78.89±6.23
Pleural_Thickening	79.97±1.52	71.01±2.07	72.29±2.36	2.82±2.36	77.15±2.23
Pneumonia	76.57±0.95	79.24±5.91	55.05±6.47	24.2±4.46	52.37±4.17
Effusion	88.52±0.47onl	81.93±1.93	81.05±2.44	1.89±0.47	86.63±0.69
Macro average	83.66±0.66	77.5±1.24	72.63±1.18	9.69±1.08	73.97±1.4
Projection	61.18±3.16				

4. Conclusions

Medical decision-making and diagnosis impacts people's lives significantly, and therefore bias in medical AI can have devastating consequences. Chest radiograph projection is a potential bias source for CXR classification models, a topic that had yet to be explored. In this work, we showed that not only is projection very easy to learn, but also that models perform better in scans from the most representative projection in the data set, indicating that projection is being encoded in the features and spuriously used to classify diseases. Finally, a strategy to address this problem was presented and discussed. This is, to our knowledge, the first study to address this topic. We conclude that the projection of CXRs in a given data set needs to be taken into account by machine learning practitioners, as it may significantly affect model performance. Further work will focus on exploring other data sets and on jointly debiasing models for other attributes that are commonly found in DICOMs, whether they are clinical (pose, scanner info), biological attributes (age, gender) or socio-economical (race, insurance policy).

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