

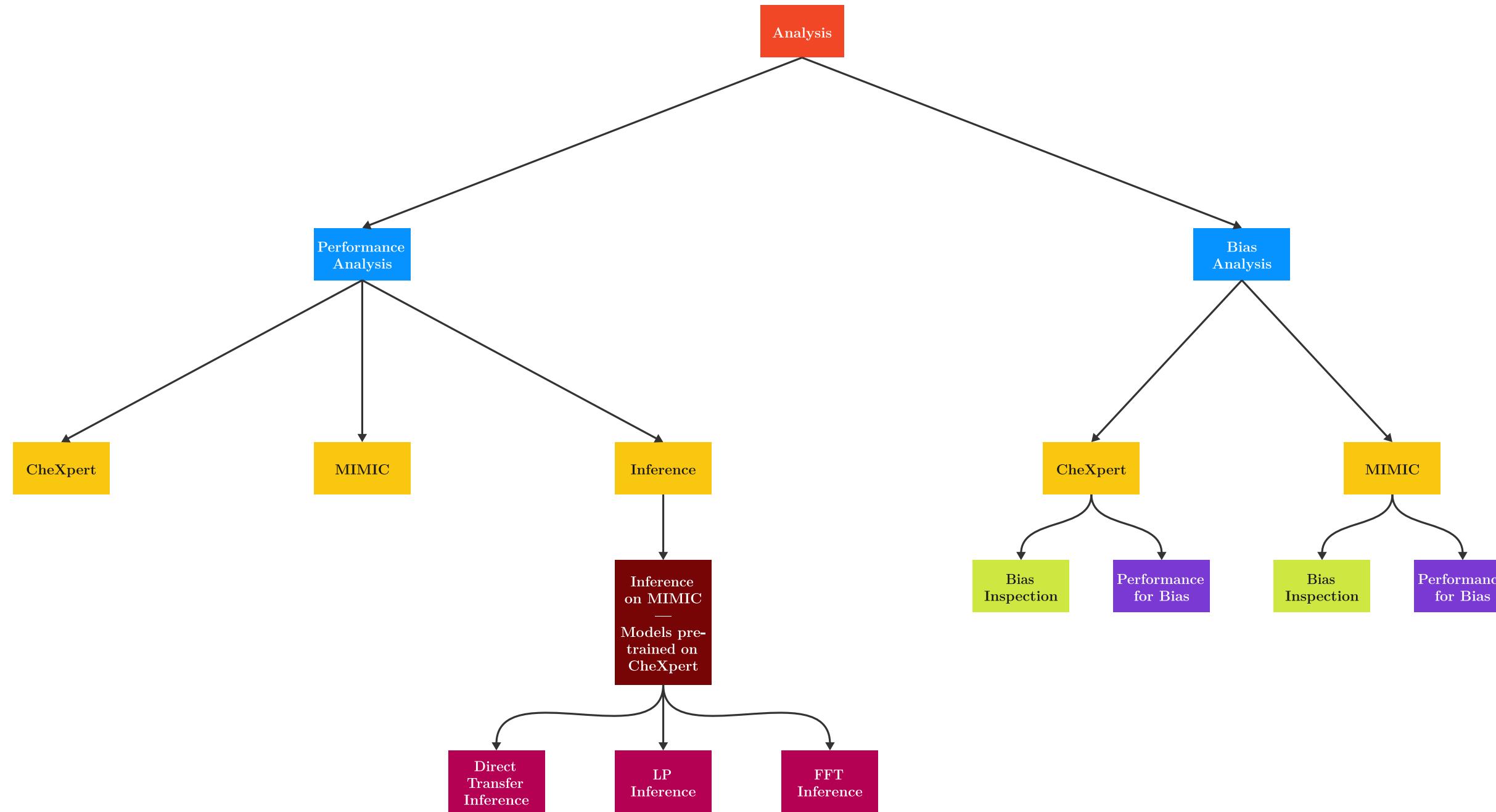
Foundation Models for Chest Radiography:

*Knowledge Distillation and Impacts on
Performance and Bias Propagation*

October 30th 2024

Fadi Zahar
BioMedIA Group,
Imperial College London

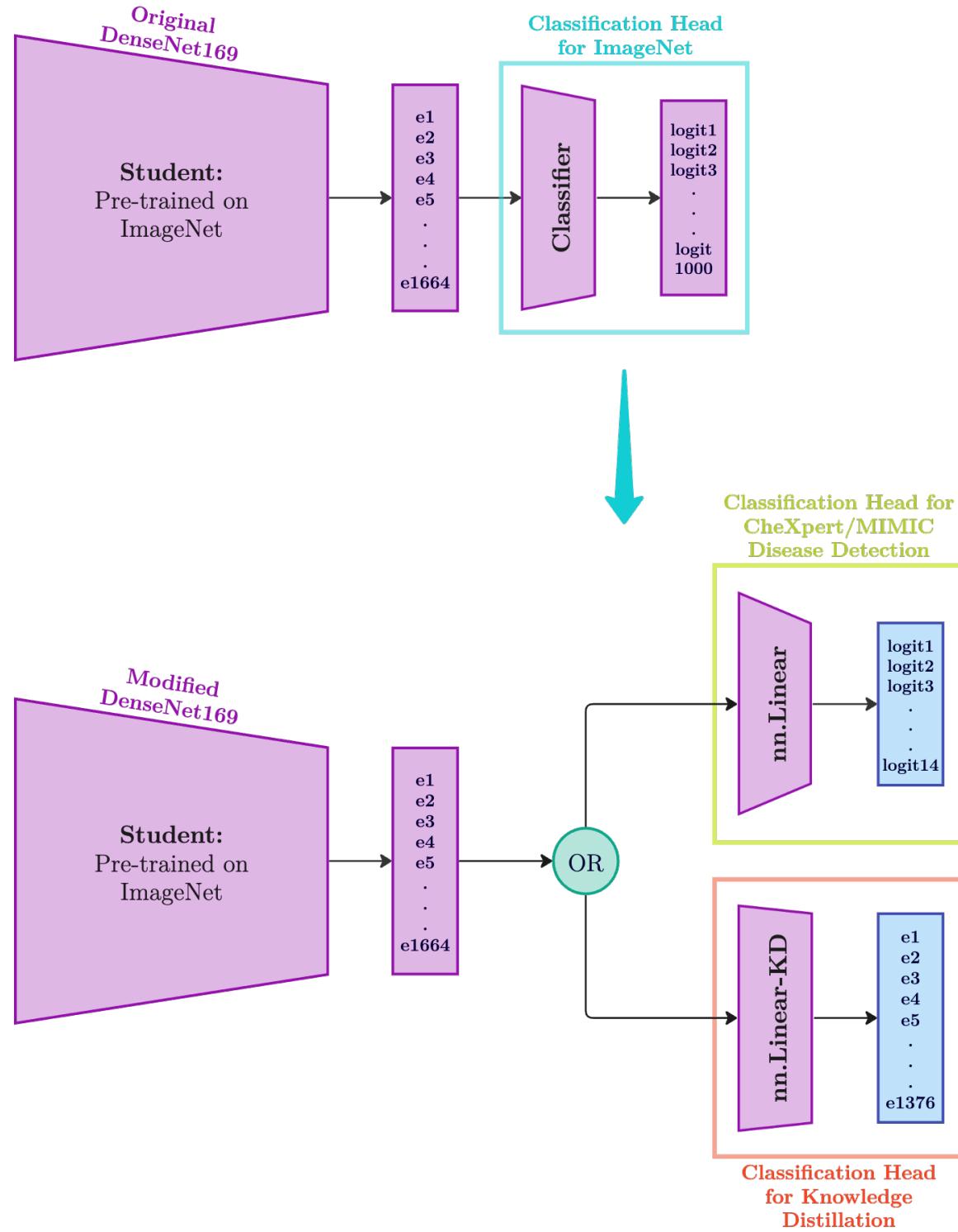
Project Overview



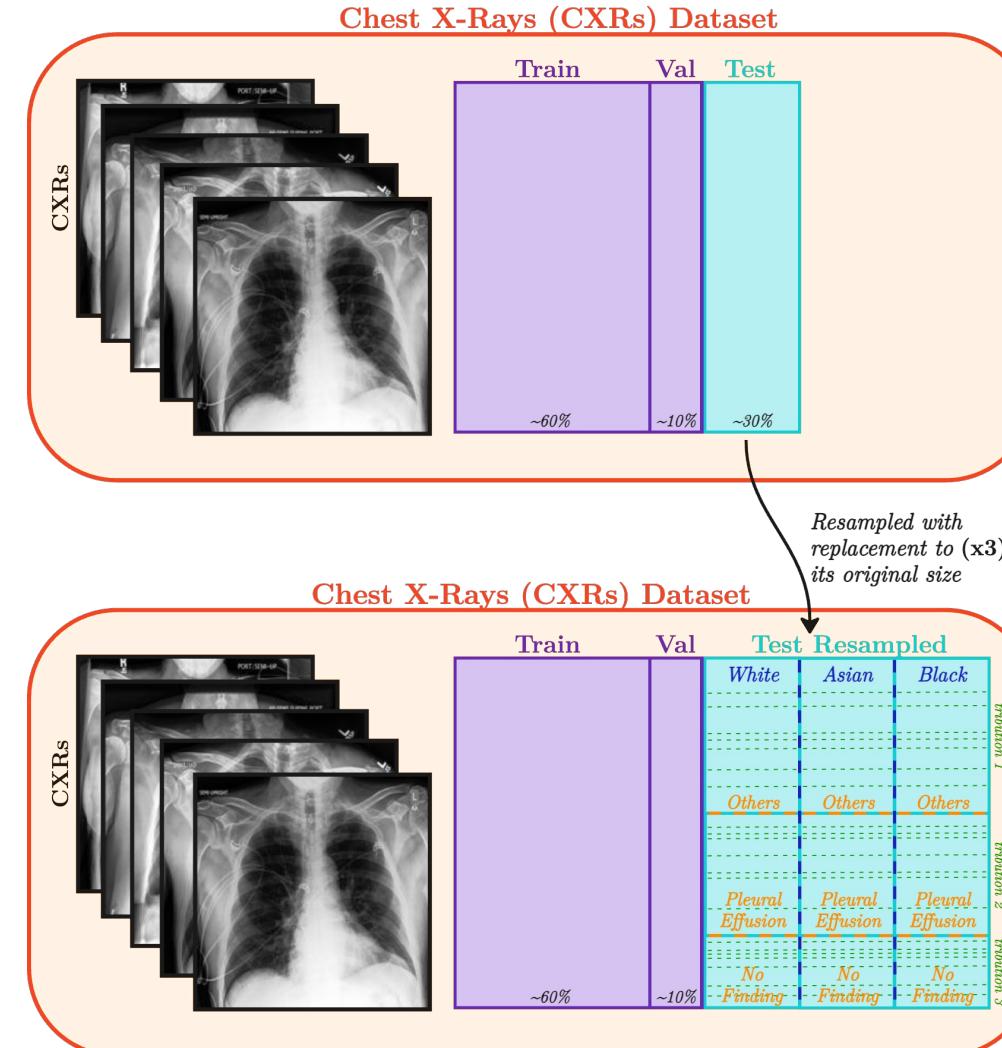
Nomenclature:

- **CXR**: Chest X-Ray
- **FM**: Foundation Model
- **CXR-FM**: Google's Chest X-Ray Foundation Model
- **KD**: Knowledge Distillation
- **LP**: Linear Probing
- **FFT**: Full Fine-Tuning
- **nn.Linear**: PyTorch Linear Layer—applies an affine linear transformation to the incoming data.
- **e1, e2, e3, ...** : 1st, 2nd, 3rd, ... components (values) of the **embedding** vector—the output from the penultimate layer, respectively.
- **logit1, logit2, logit3, ...** : 1st, 2nd, 3rd, ... components (values) of the **logits** vector—the raw output from the final layer, respectively.
- **p1, p2, p3, ...** : 1st, 2nd, 3rd, ... components (values) of the **predicted probabilities** vector—the result of applying the sigmoid function to the logits vector for *multilabel classification*, respectively.
- **y1, y2, y3, ...** : 1st, 2nd, 3rd, ... components (values) of the **ground truth/target labels** vector—the true labels, respectively.
- **BCE**: Binary Cross-Entropy Loss
- **MSE**: Mean Squared Error
- **MAE**: Mean Absolute Error
- **CS**: Cosine Similarity

Adapting DenseNet169 for Multilabel Disease Classification and Knowledge Distillation



Stratified Resampling for Demographic and Clinical Balance in Test Dataset

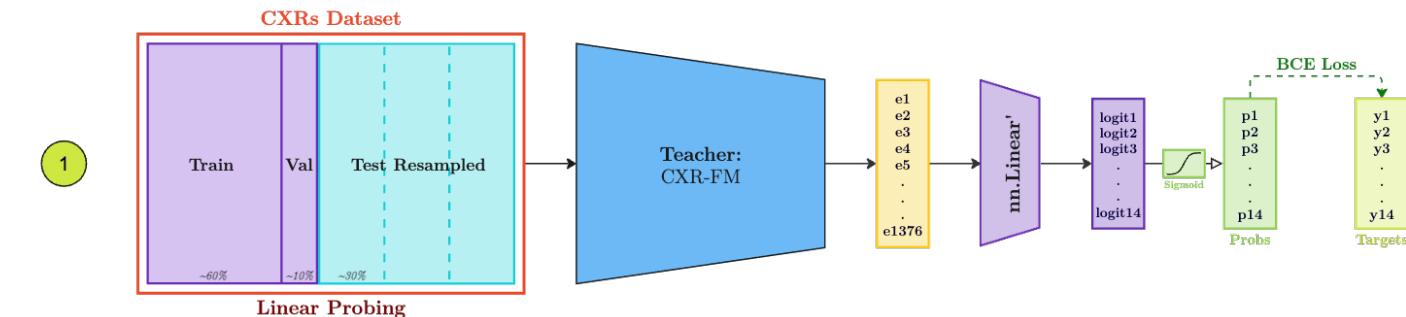


Test set has been resampled to ensure approximately:

- Equal **Race** proportions—of White, Asian, and Black
- Equal **Disease** prevalence within each **(race)**-subgroup
- Equal **Age-bin** distribution within each **(race, disease)**-subsubgroup

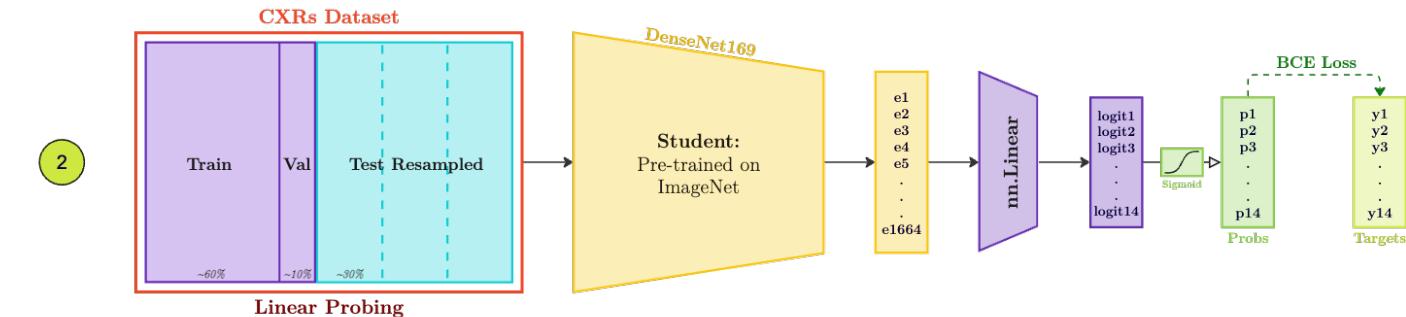
Models Architecture Overview

CXR-FM LP 



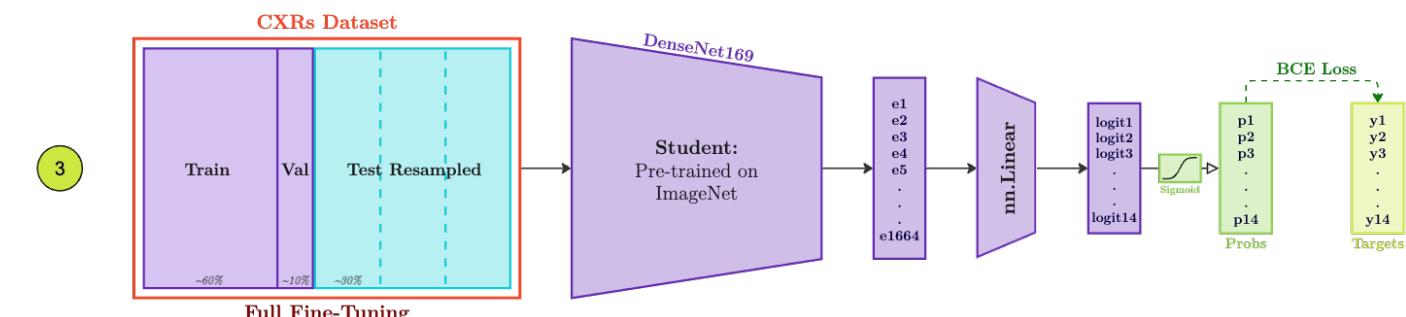
CXR-FM LP: output embedding size of **1376**

CXR-Model LP



DenseNet169: output embedding size of **1664**

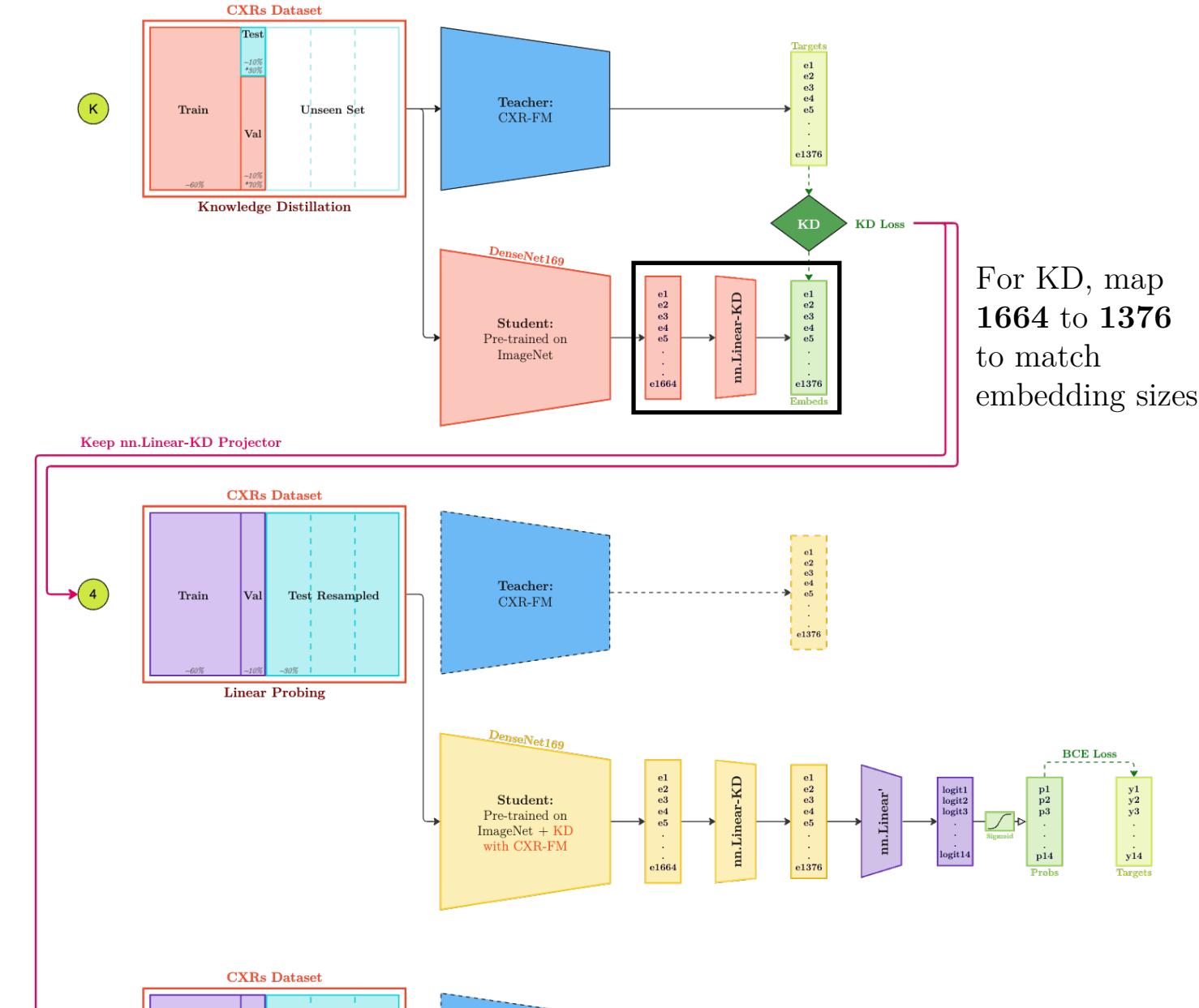
CXR-Model FFT



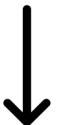
KD Losses:

- KD (MSE)
- KD (MAE)
- KD (HuberLoss)
- KD (CS)
- KD (MSE-CS Naive)
- KD (MSE-CS Learned)
- KD (MSE-CS | 0.5-0.5)
- KD (MSE-CS | 0.6-0.4)
- KD (MSE-CS | 0.7-0.3)
- KD (MSE-CS | 0.8-0.2)
- KD (MSE-CS | 0.9-0.1)

CXR-FMKD LP



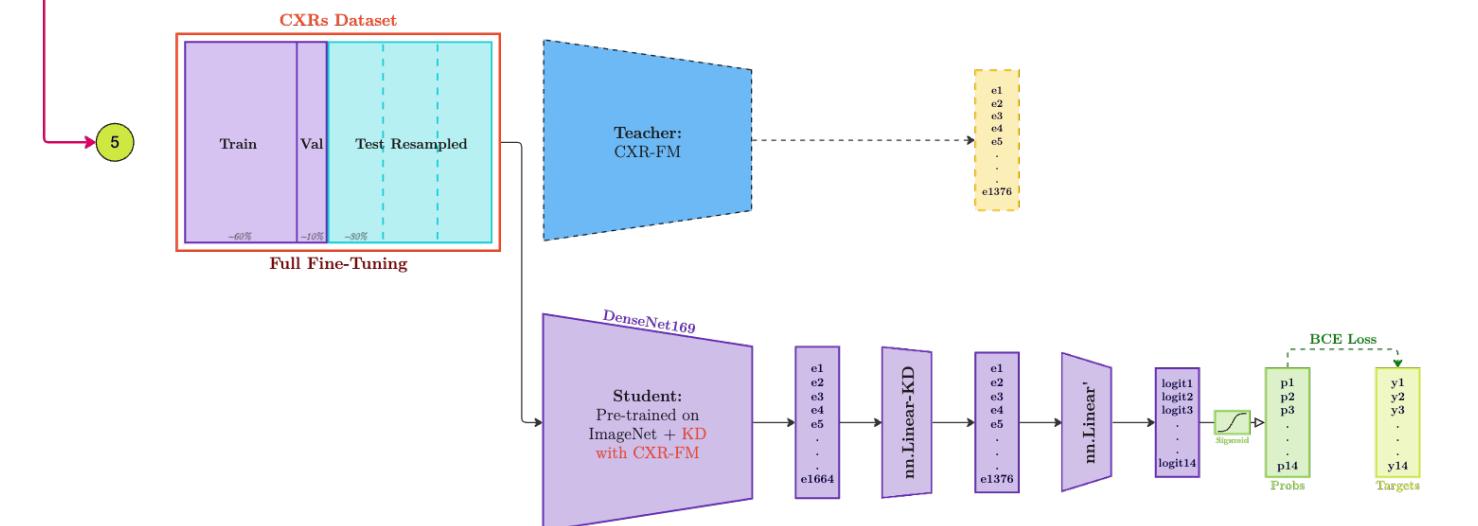
DenseNet169:
output embedding
size of **1664**



For KD, map
1664 to **1376**
to match
embedding sizes

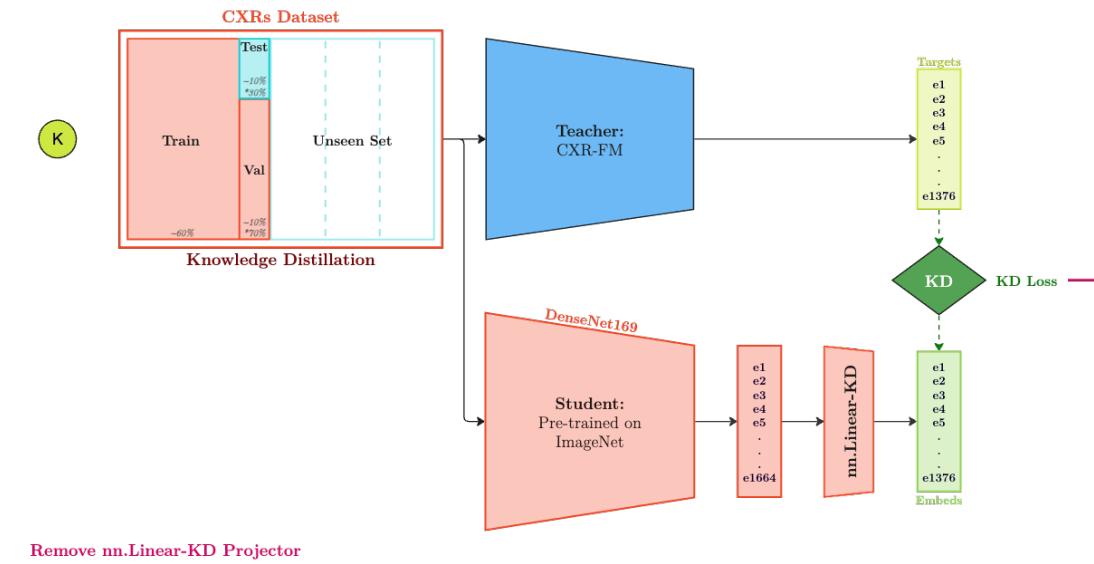
CXR-FM LP:
output embedding
size of **1376**

CXR-FMKD FFT

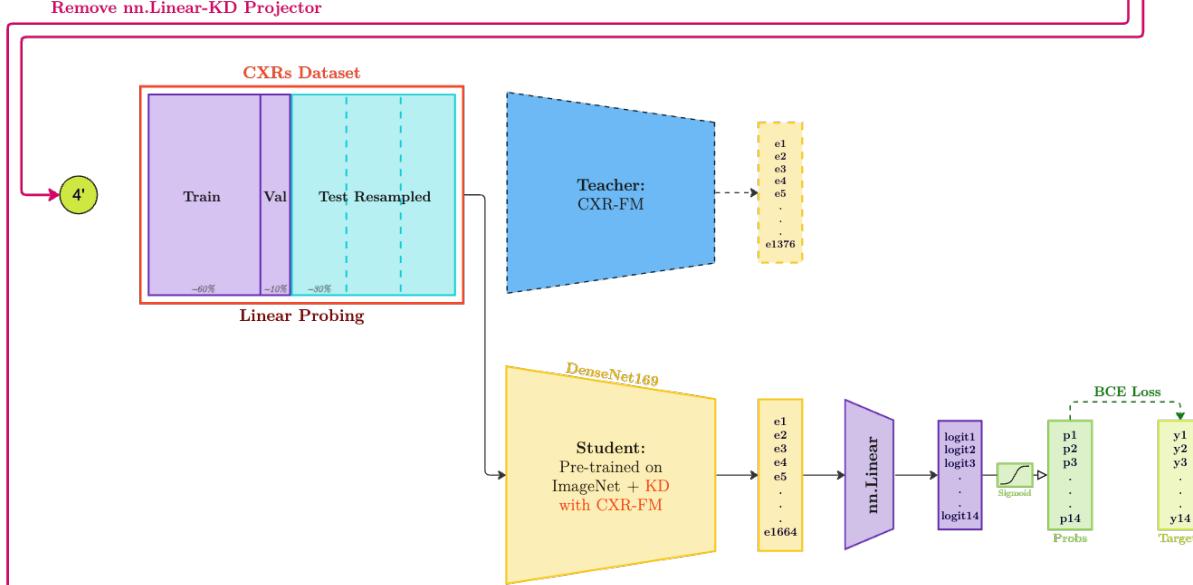


KD Losses:

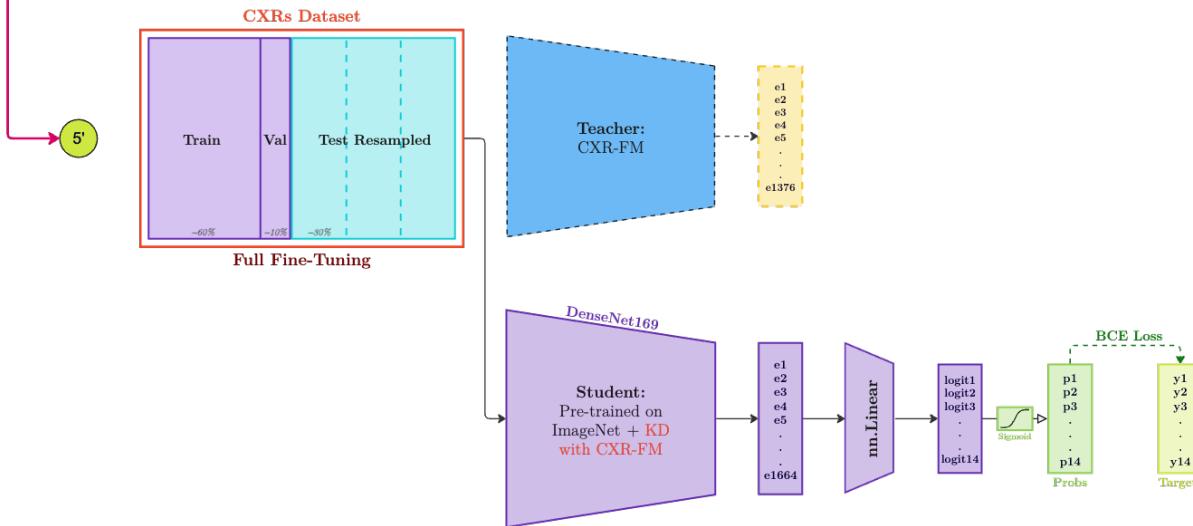
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- KD (MSE-CS | 0.8-0.2)
- KD (MSE-CS | 0.9-0.1)



CXR-FMKD-Direct LP

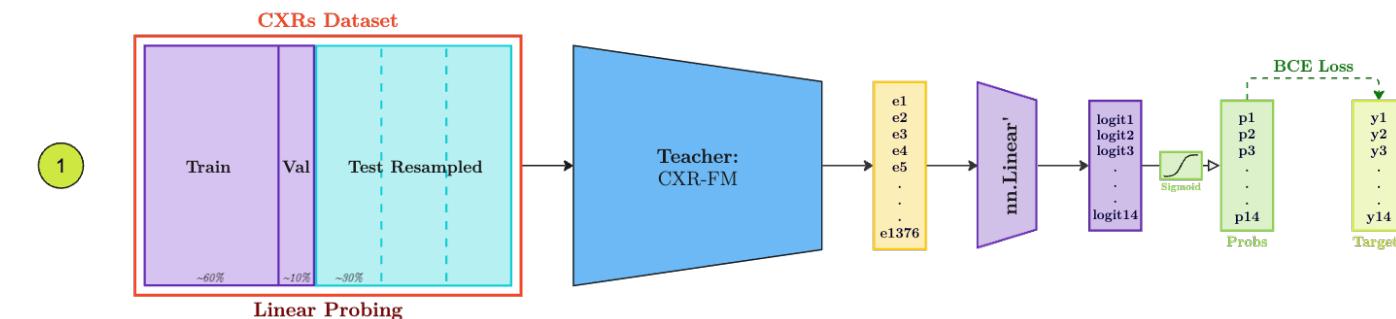


CXR-FMKD-Direct FFT

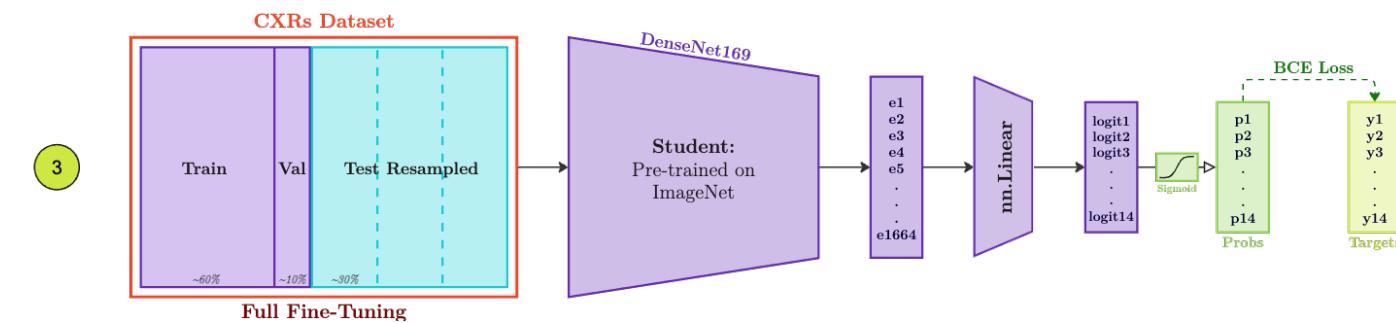


Selected Models (x5)

CXR-FM LP



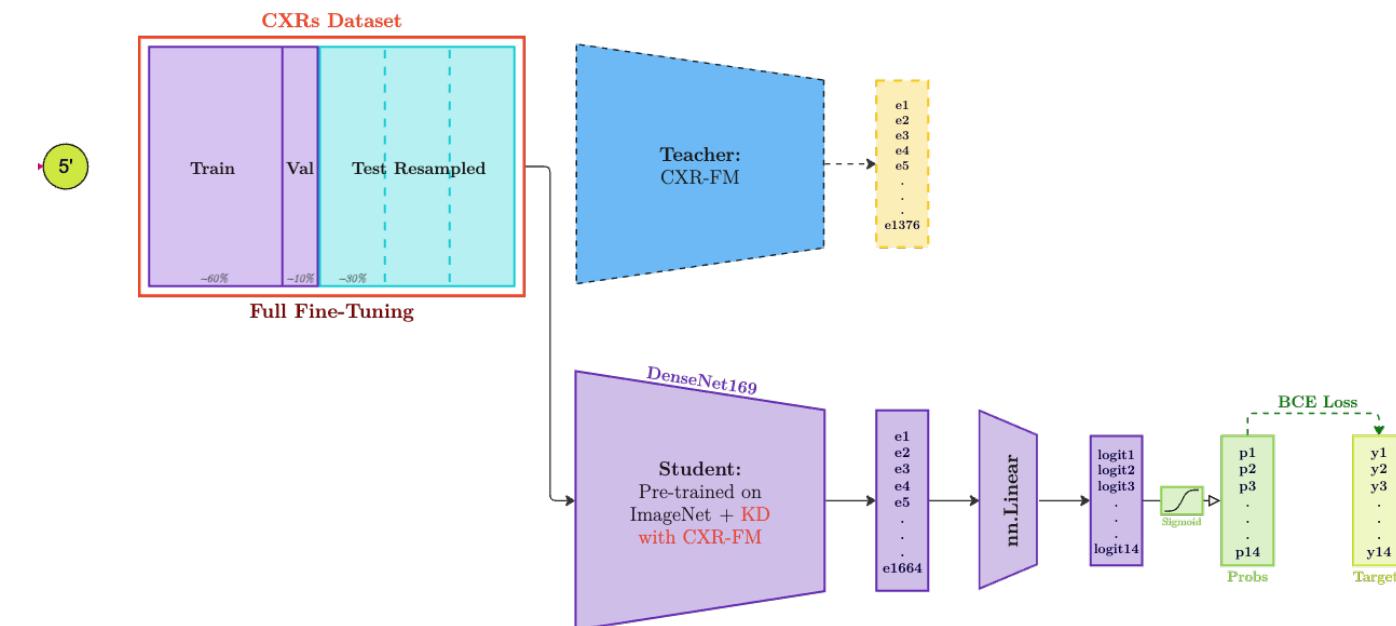
CXR-Model FFT



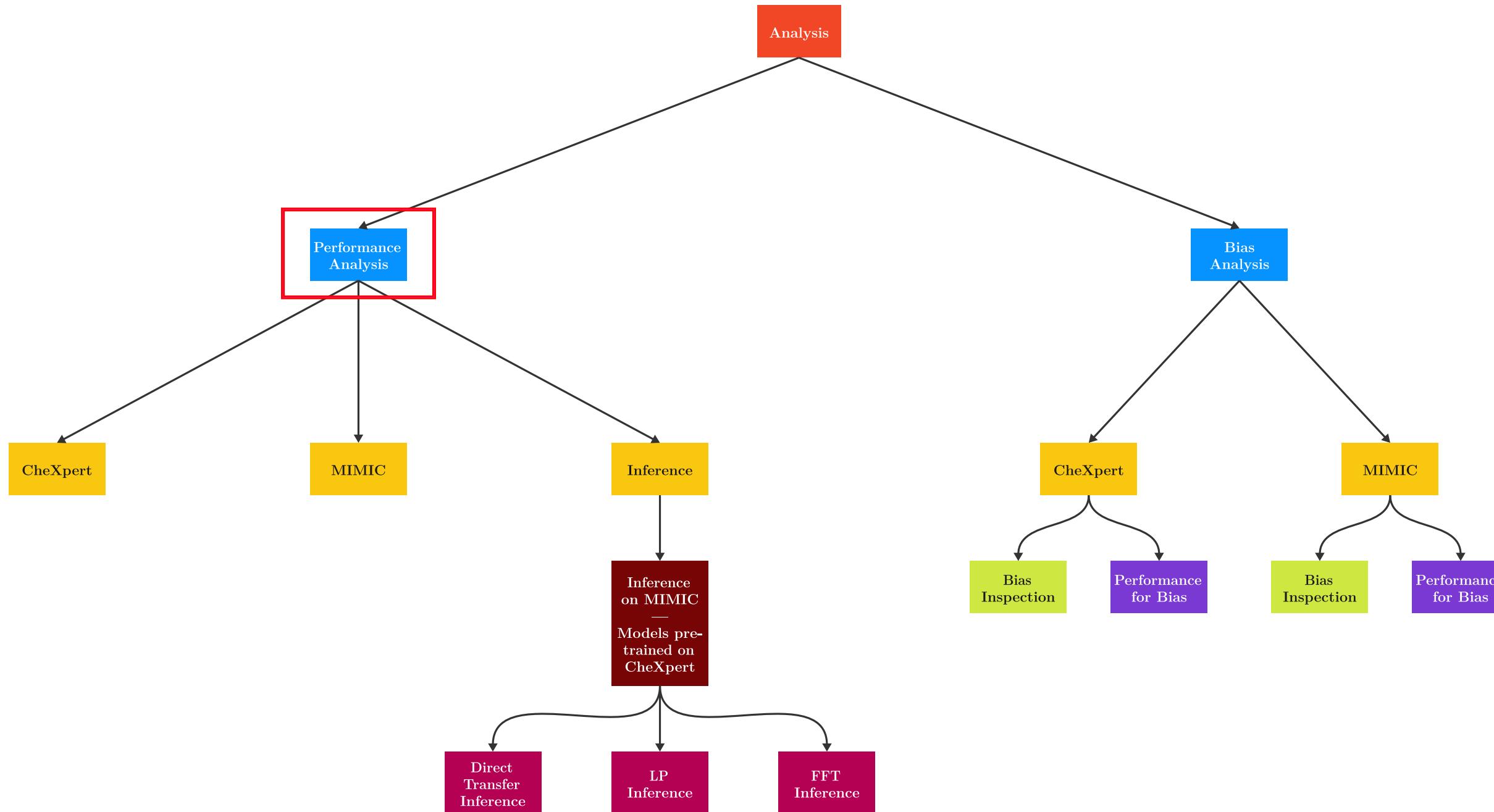
CXR-FMKD-Direct FFT

(x3):

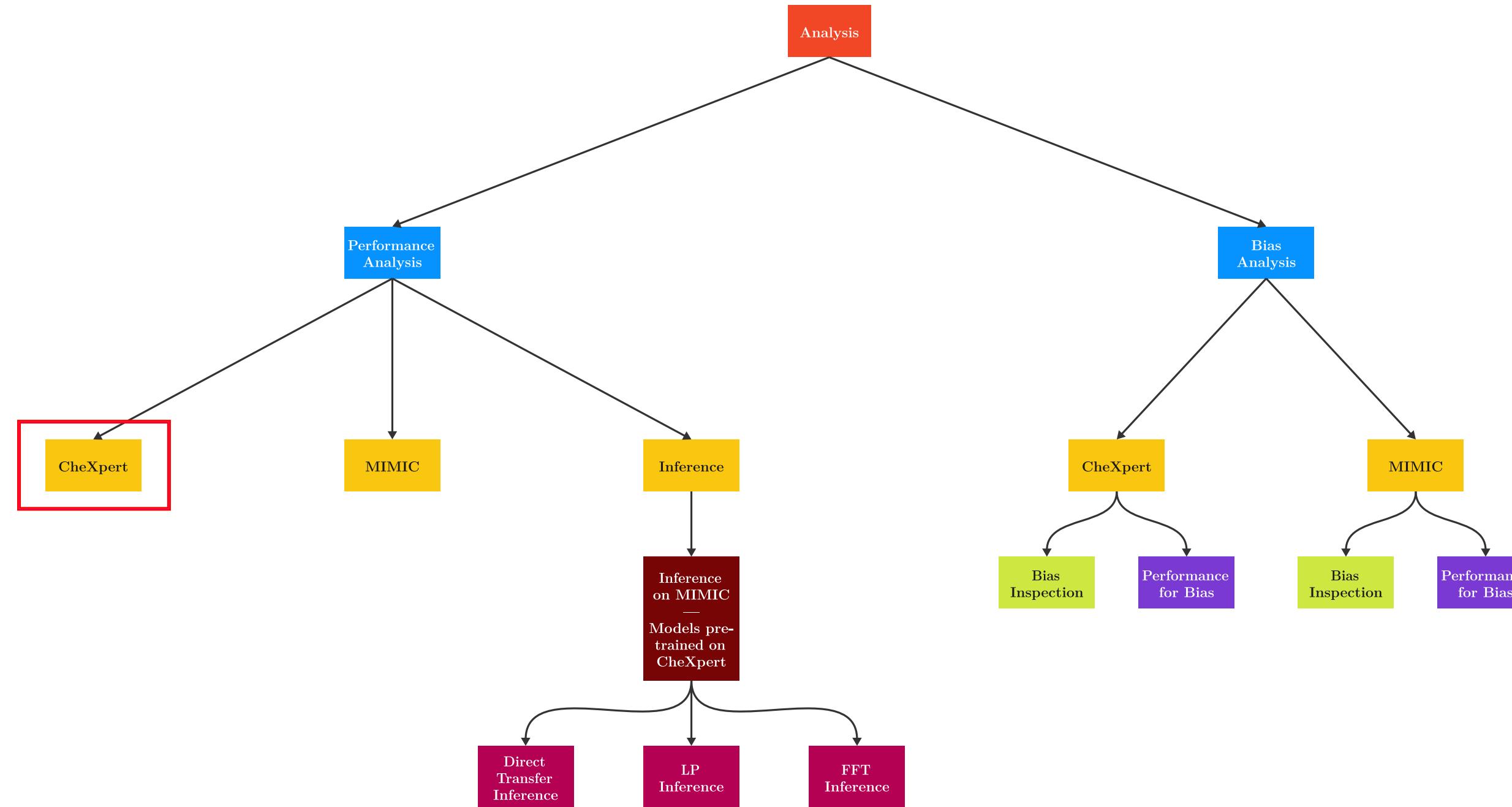
- (x1) KD-MSE
- (x1) KD-CS
- (x1) KD-MSE&CS

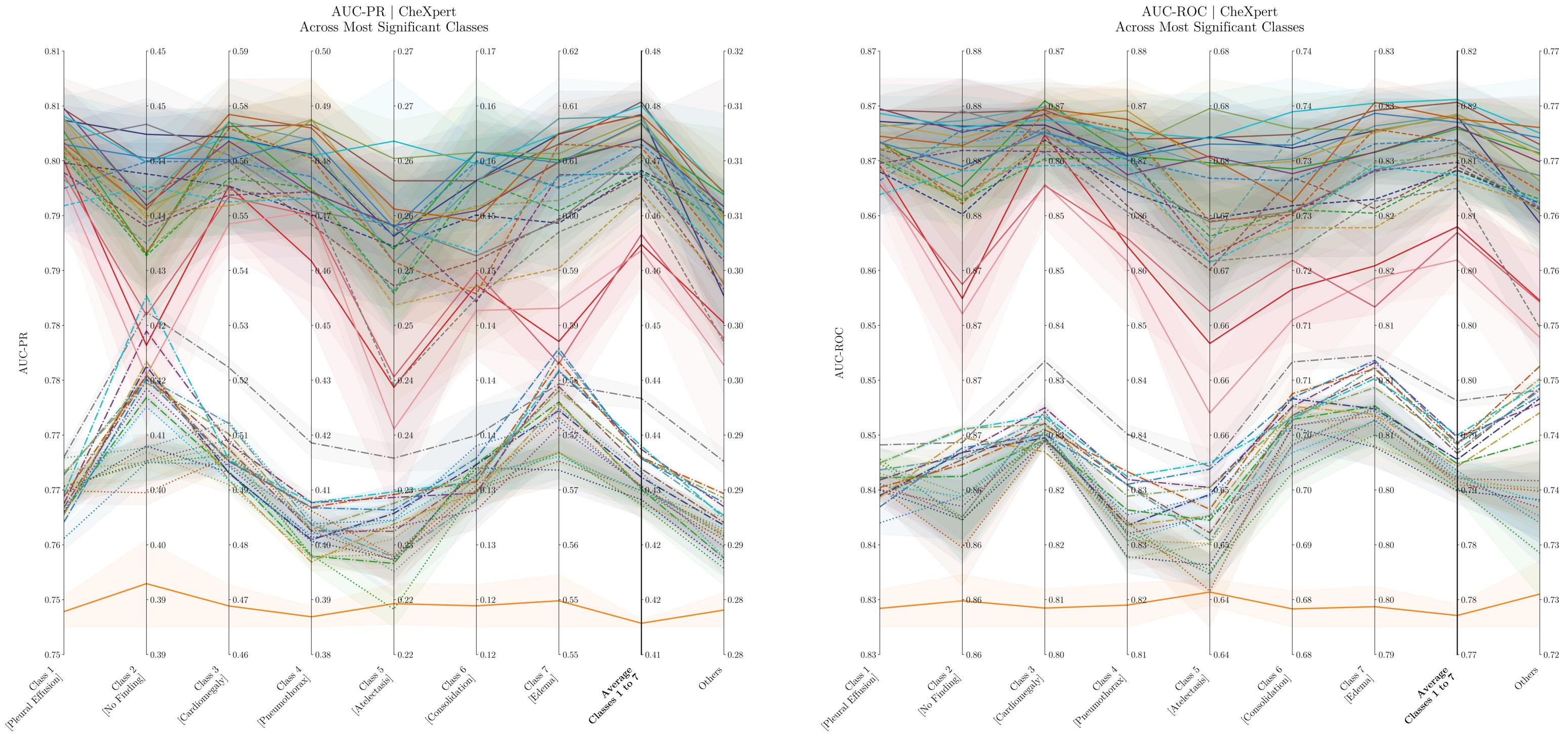


Project Overview

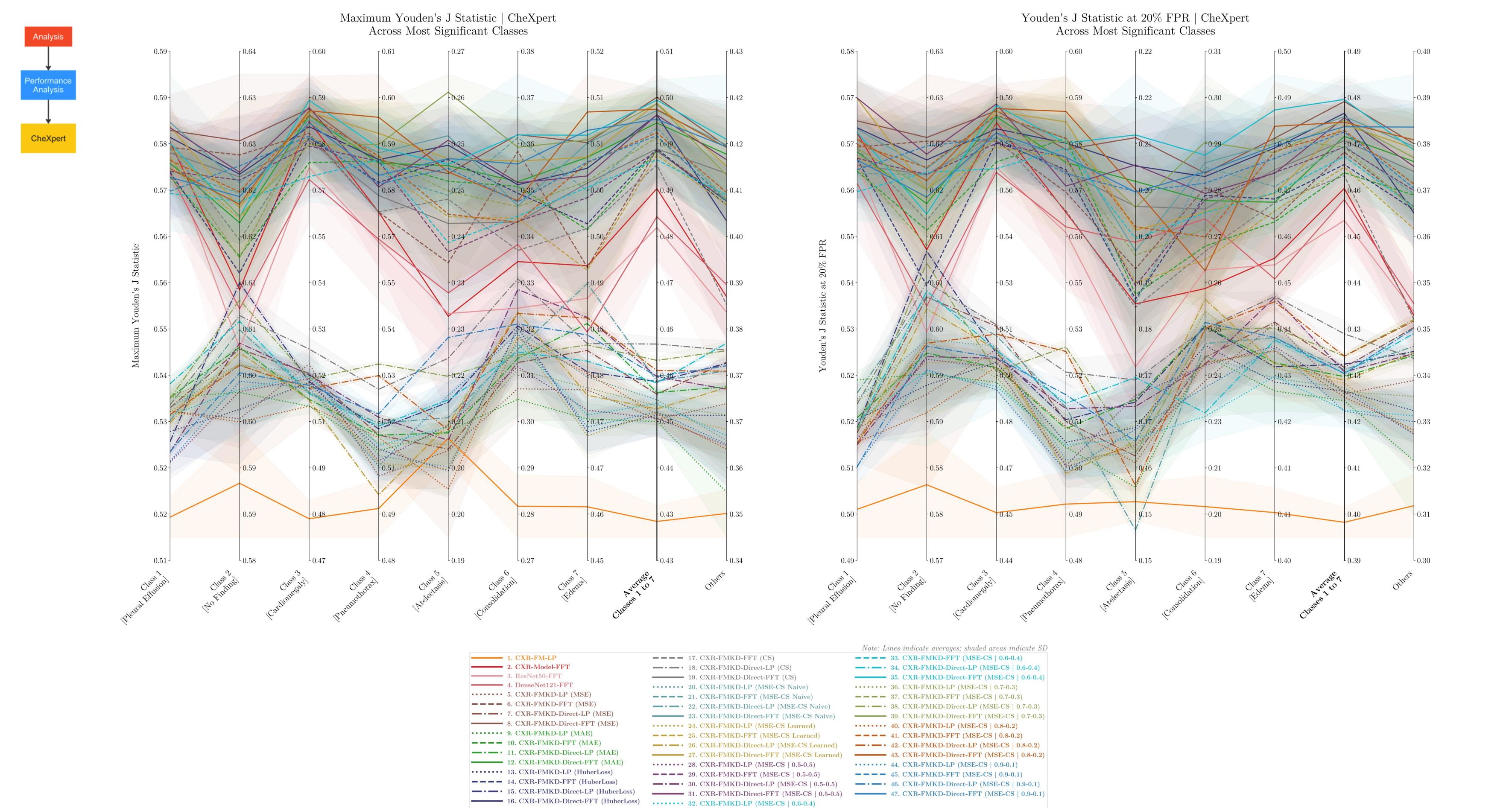


Project Overview



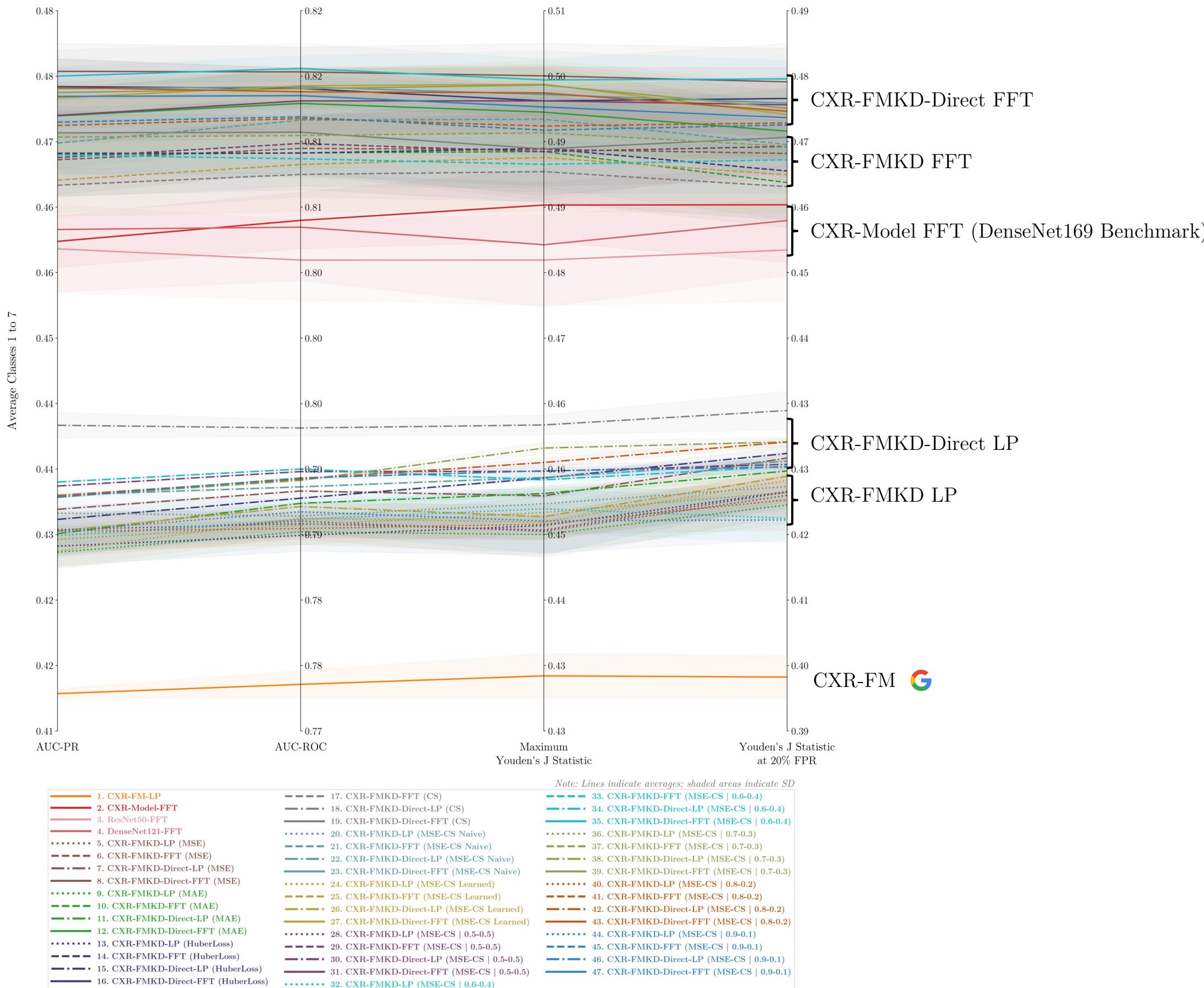


- Note: Lines indicate averages; shaded areas indicate SD
- | | |
|--|--|
| 1. CXR-FMKD-LP | 17. CXR-FMKD-FFT (CS) |
| 2. CXR-Model-FFT | 18. CXR-FMKD-Direct-LP (CS) |
| 3. ResNet50-FFT | 19. CXR-FMKD-Direct-FFT (CS) |
| 4. DenseNet121-FFT | 20. CXR-FMKD-LP (MSE-CS Naive) |
| 5. CXR-FMKD-LP (MSE) | 21. CXR-FMKD-FFT (MSE-CS Naive) |
| 6. CXR-FMKD-FFT (MSE) | 22. CXR-FMKD-Direct-LP (MSE-CS Naive) |
| 7. CXR-FMKD-Direct-LP (MSE) | 23. CXR-FMKD-Direct-FFT (MSE-CS Naive) |
| 8. CXR-FMKD-Direct-FFT (MSE) | 24. CXR-FMKD-LP (MSE-CS Learned) |
| 9. CXR-FMKD-LP (MAE) | 25. CXR-FMKD-FFT (MSE-CS Learned) |
| 10. CXR-FMKD-FFT (MAE) | 26. CXR-FMKD-Direct-LP (MSE-CS Learned) |
| 11. CXR-FMKD-Direct-LP (MAE) | 27. CXR-FMKD-Direct-FFT (MSE-CS Learned) |
| 12. CXR-FMKD-Direct-FFT (MAE) | 28. CXR-FMKD-LP (MSE-CS 0.5-0.5) |
| 13. CXR-FMKD-LP (HuberLoss) | 29. CXR-FMKD-FFT (MSE-CS 0.5-0.5) |
| 14. CXR-FMKD-FFT (HuberLoss) | 30. CXR-FMKD-Direct-LP (MSE-CS 0.5-0.5) |
| 15. CXR-FMKD-Direct-LP (HuberLoss) | 31. CXR-FMKD-Direct-FFT (MSE-CS 0.5-0.5) |
| 16. CXR-FMKD-Direct-FFT (HuberLoss) | 32. CXR-FMKD-LP (MSE-CS 0.6-0.4) |
| 33. CXR-FMKD-FFT (MSE-CS 0.6-0.4) | |
| 34. CXR-FMKD-Direct-LP (MSE-CS 0.6-0.4) | |
| 35. CXR-FMKD-Direct-FFT (MSE-CS 0.6-0.4) | |
| 36. CXR-FMKD-LP (MSE-CS 0.7-0.3) | |
| 37. CXR-FMKD-FFT (MSE-CS 0.7-0.3) | |
| 38. CXR-FMKD-Direct-LP (MSE-CS 0.7-0.3) | |
| 39. CXR-FMKD-Direct-FFT (MSE-CS 0.7-0.3) | |
| 40. CXR-FMKD-LP (MSE-CS 0.8-0.2) | |
| 41. CXR-FMKD-FFT (MSE-CS 0.8-0.2) | |
| 42. CXR-FMKD-Direct-LP (MSE-CS 0.8-0.2) | |
| 43. CXR-FMKD-Direct-FFT (MSE-CS 0.8-0.2) | |
| 44. CXR-FMKD-LP (MSE-CS 0.9-0.1) | |
| 45. CXR-FMKD-FFT (MSE-CS 0.9-0.1) | |
| 46. CXR-FMKD-Direct-LP (MSE-CS 0.9-0.1) | |
| 47. CXR-FMKD-Direct-FFT (MSE-CS 0.9-0.1) | |



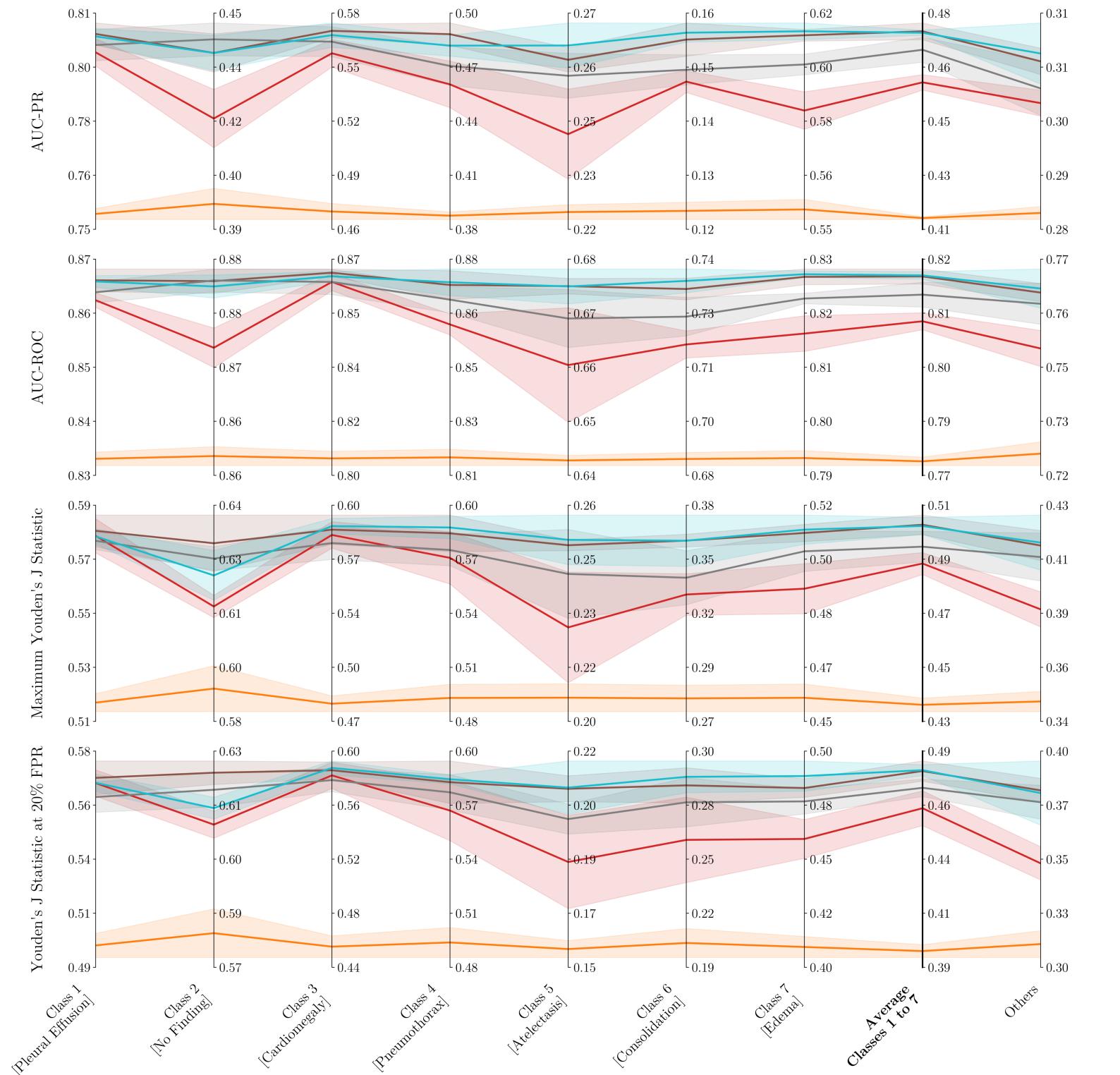


Performance Metrics | CheXpert
for Average of Classes 1 to 7





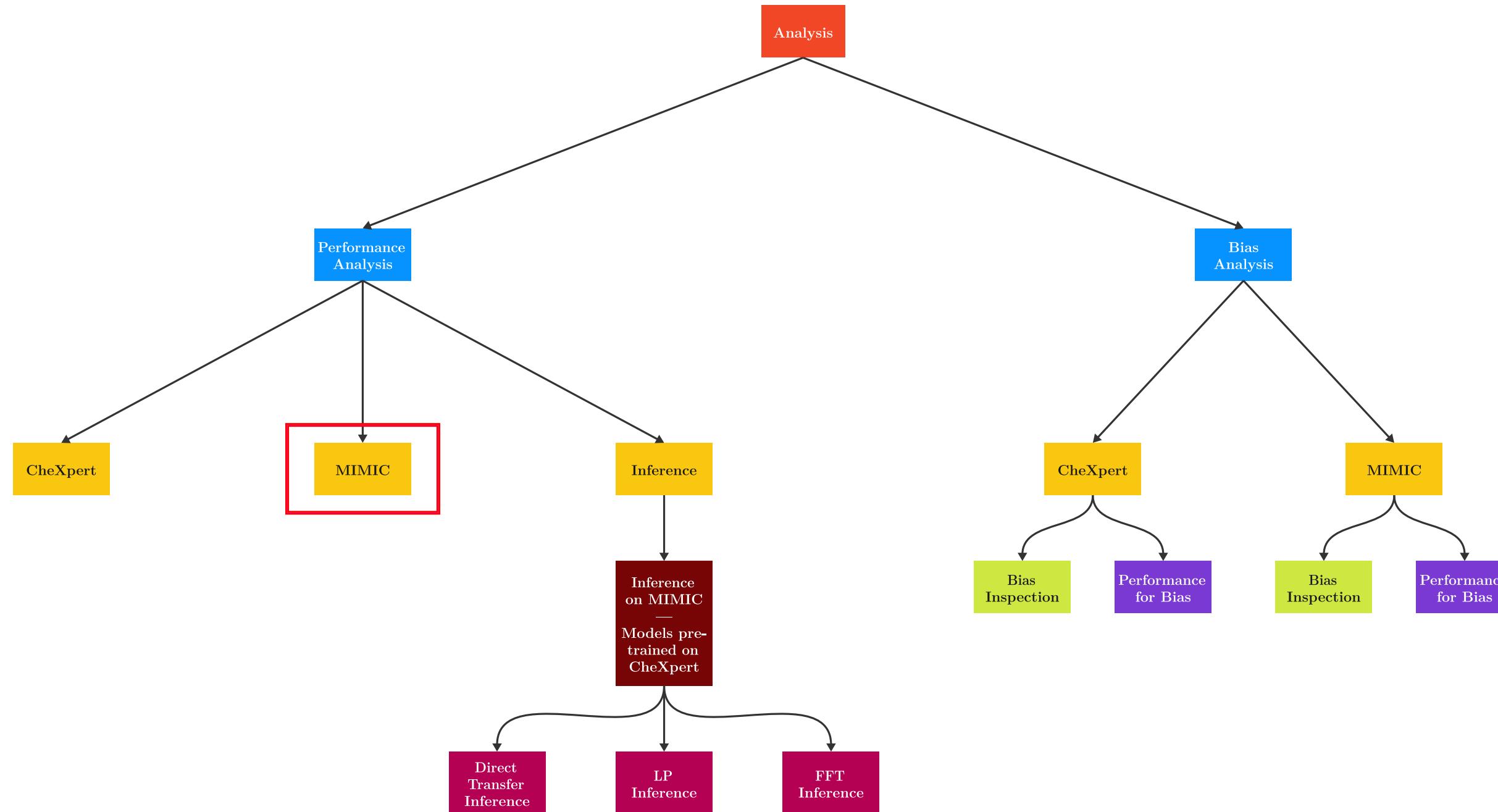
Performance Metrics | CheXpert
Across Most Significant Classes

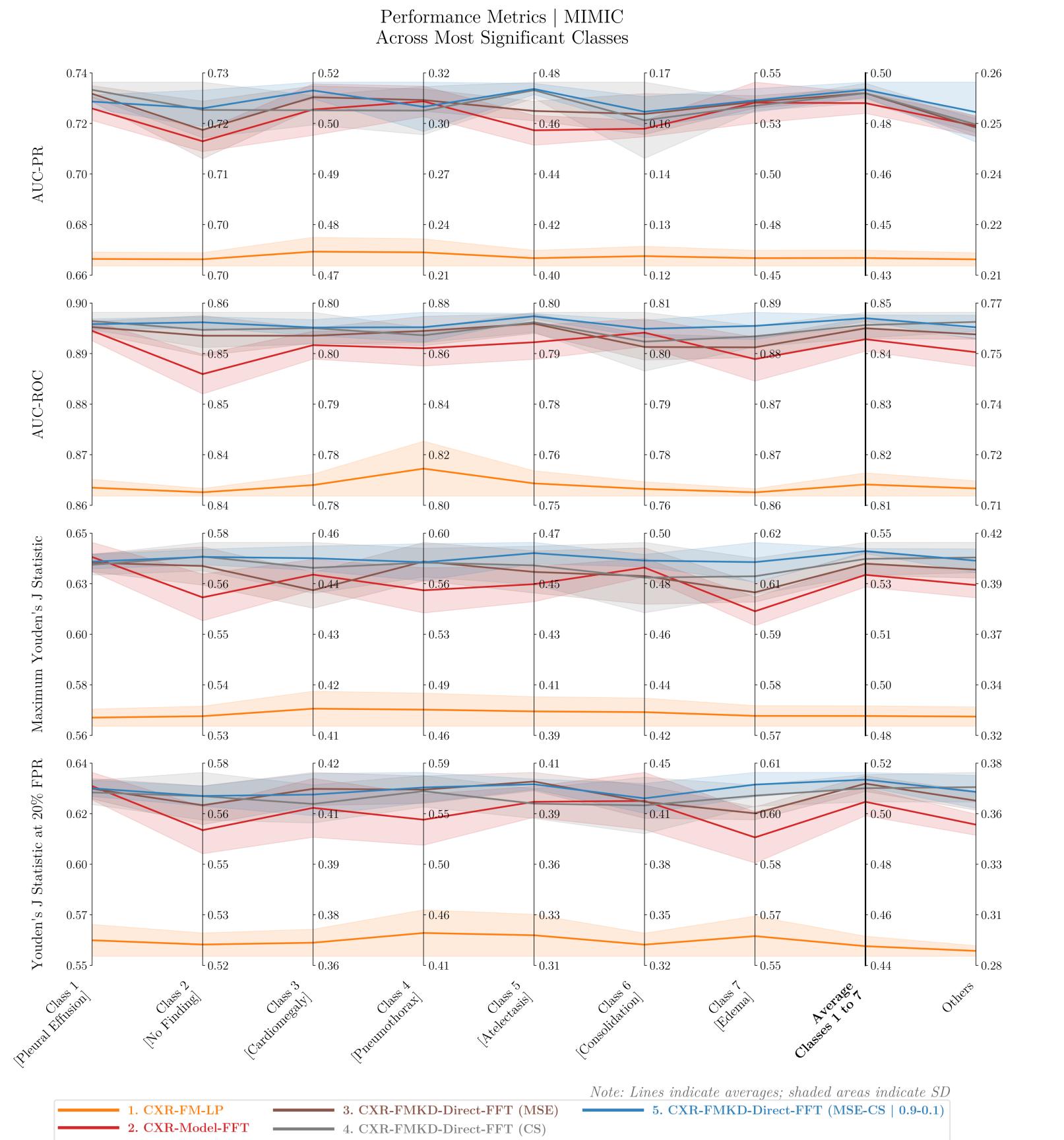


Note: Lines indicate averages; shaded areas indicate SD

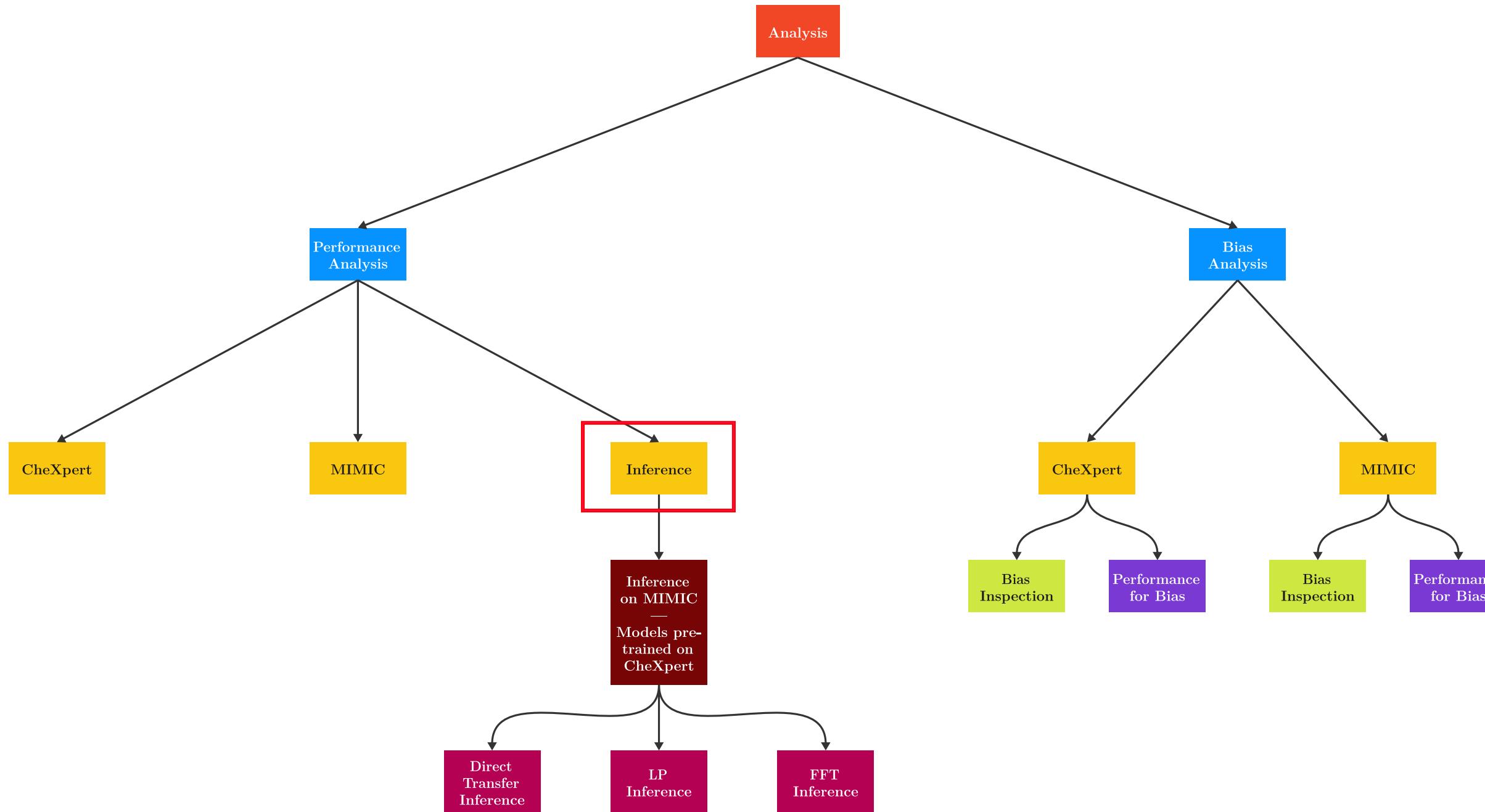
1. CXR-FM-LP	2. CXR-Model-FFT	3. CXR-FMKD-Direct-FFT (MSE)	4. CXR-FMKD-Direct-FFT (CS)	5. CXR-FMKD-Direct-FFT (MSE-CS 0.6-0.4)
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Project Overview

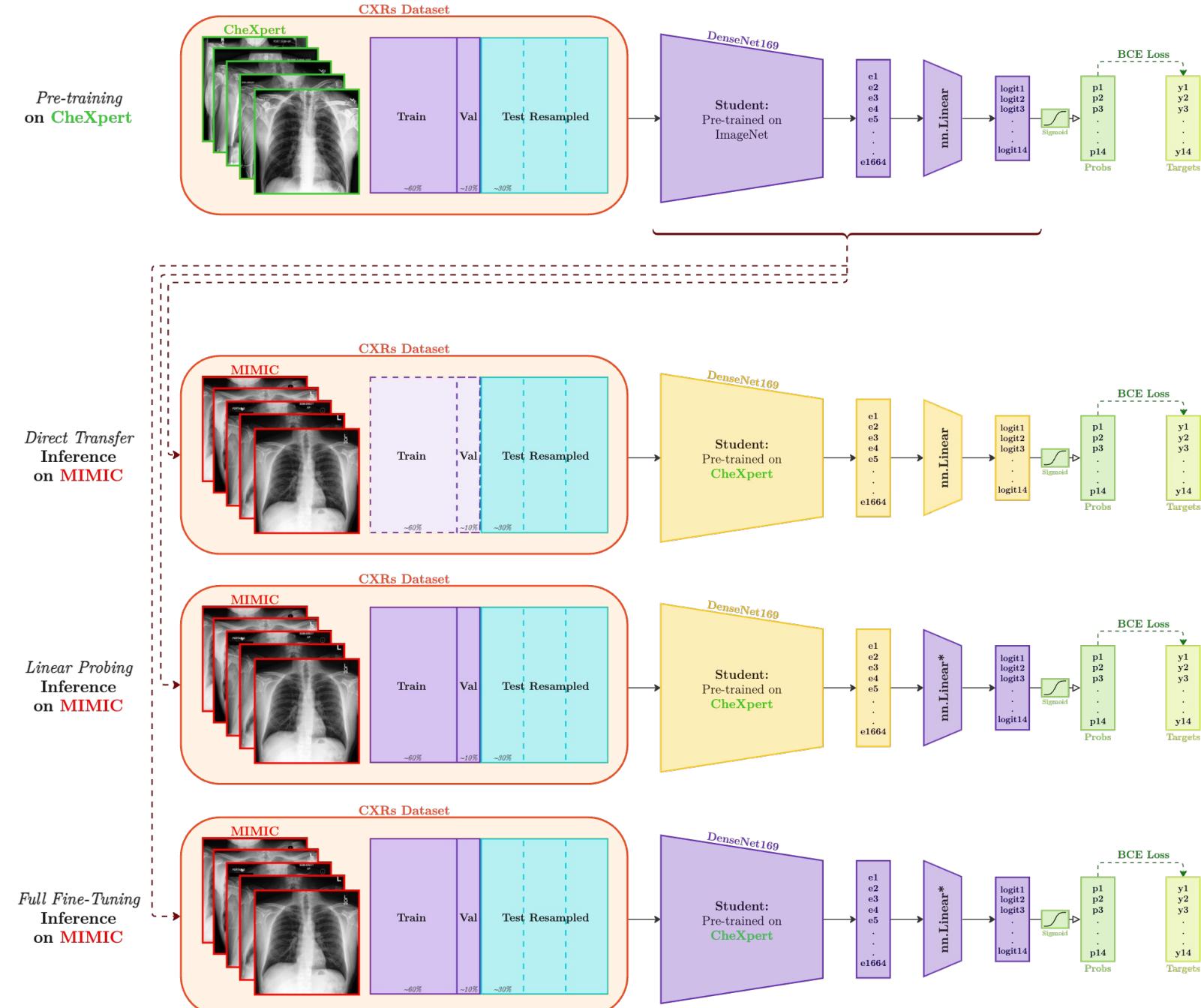


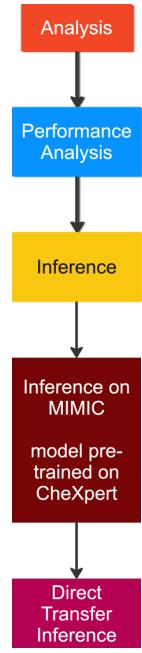


Project Overview

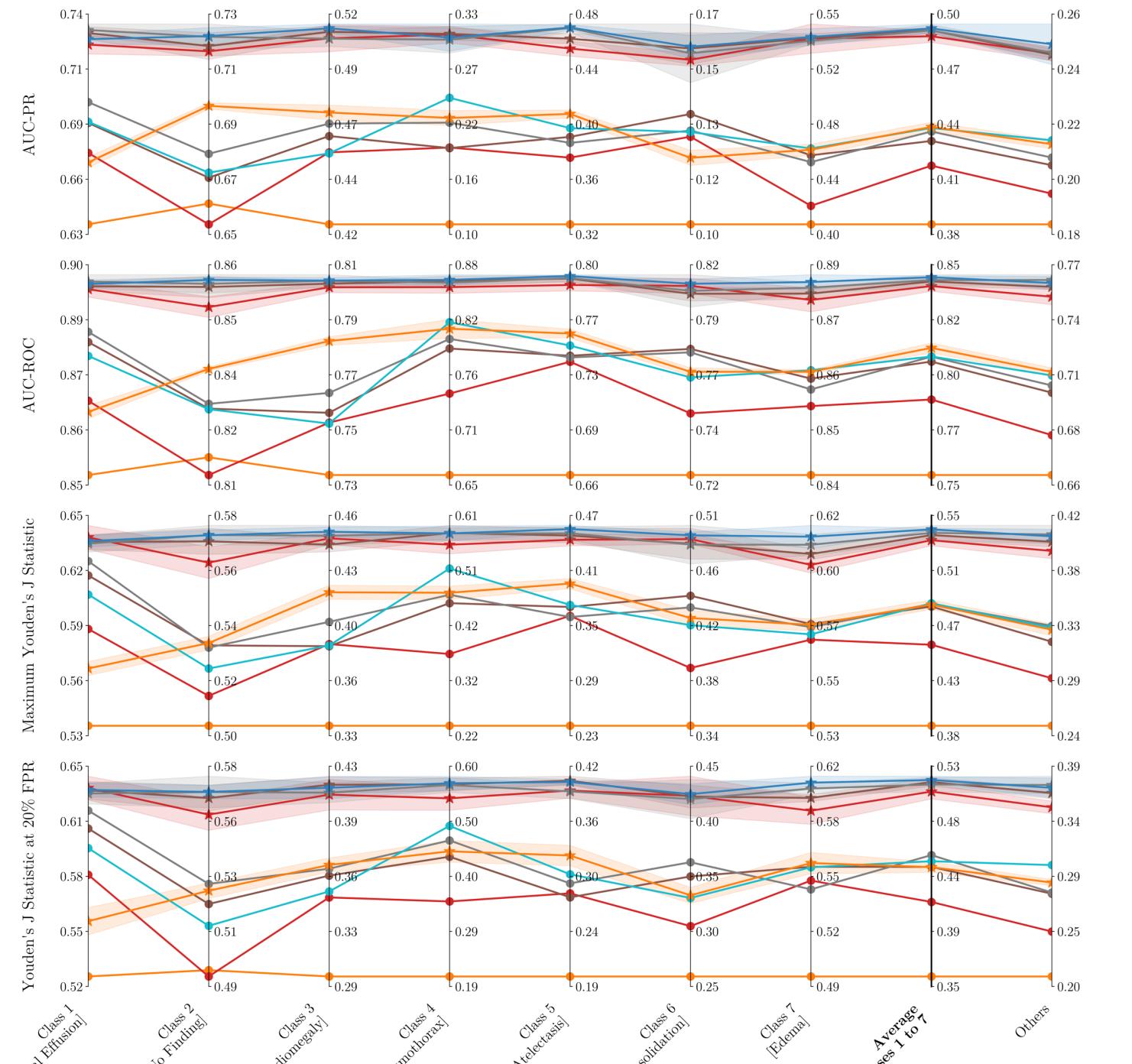


Inference Study on MIMIC Using Models Pre-trained on CheXpert: Evaluating Generalizability through Direct Transfer, Linear Probing, and Full Fine-Tuning





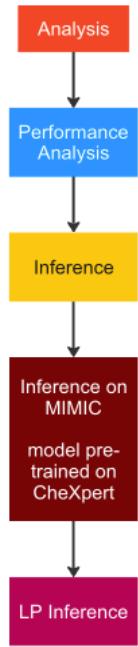
Performance Metrics | Direct Transfer Inference on MIMIC
Across Most Significant Classes



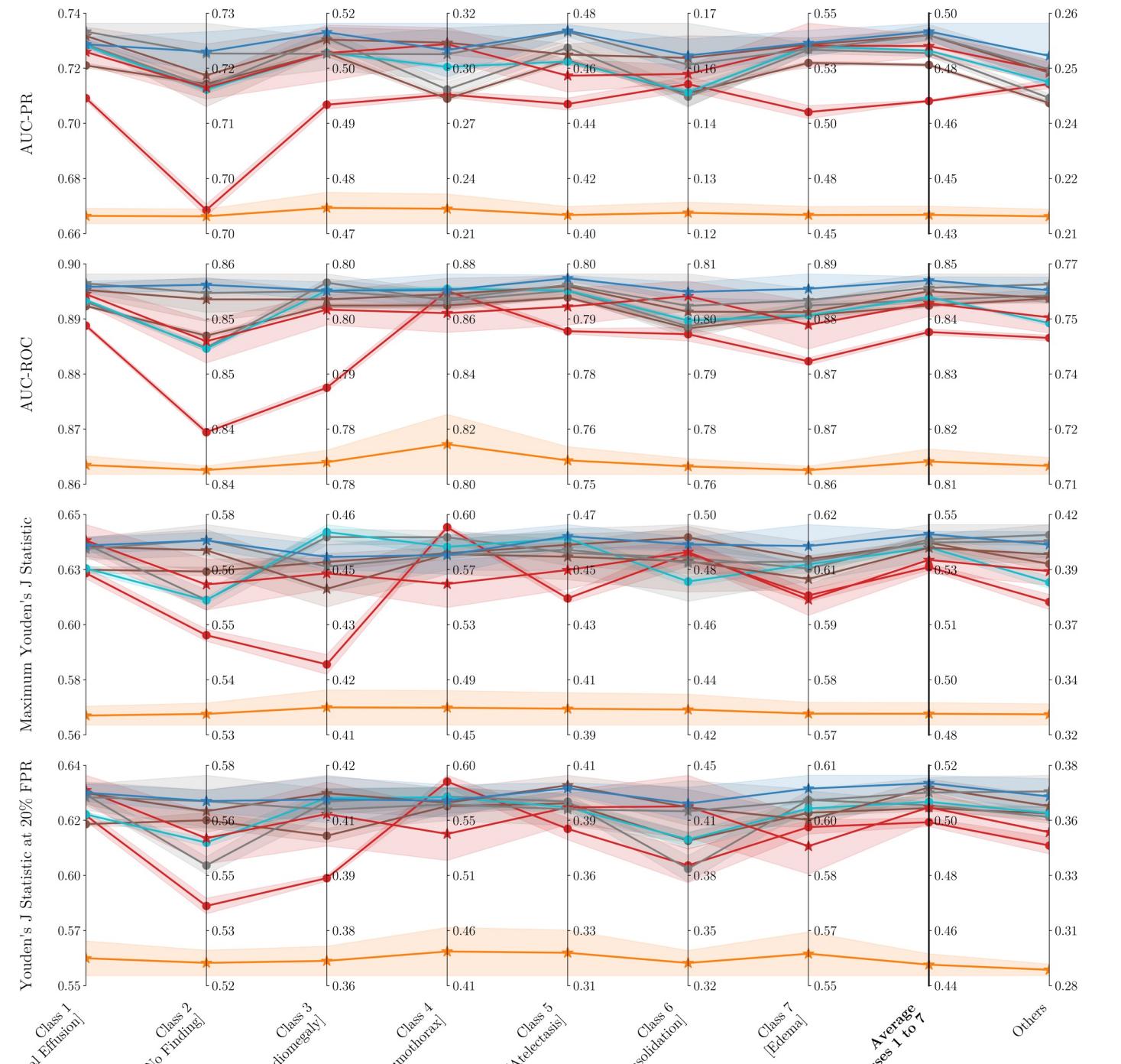
Note: Lines indicate averages; shaded areas indicate SD

● Models pre-trained on CheXpert, evaluated on MIMIC without adaptation	★ 'Benchmark' Models trained and evaluated exclusively on MIMIC
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● Models pre-trained on CheXpert, evaluated on MIMIC without adaptation
★ 'Benchmark' Models trained and evaluated exclusively on MIMIC



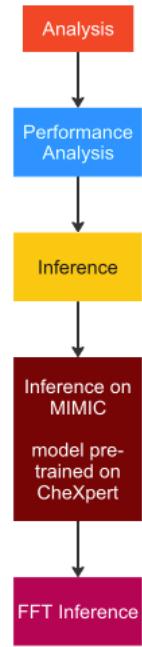
Performance Metrics | Linear Probing Inference on MIMIC
Across Most Significant Classes



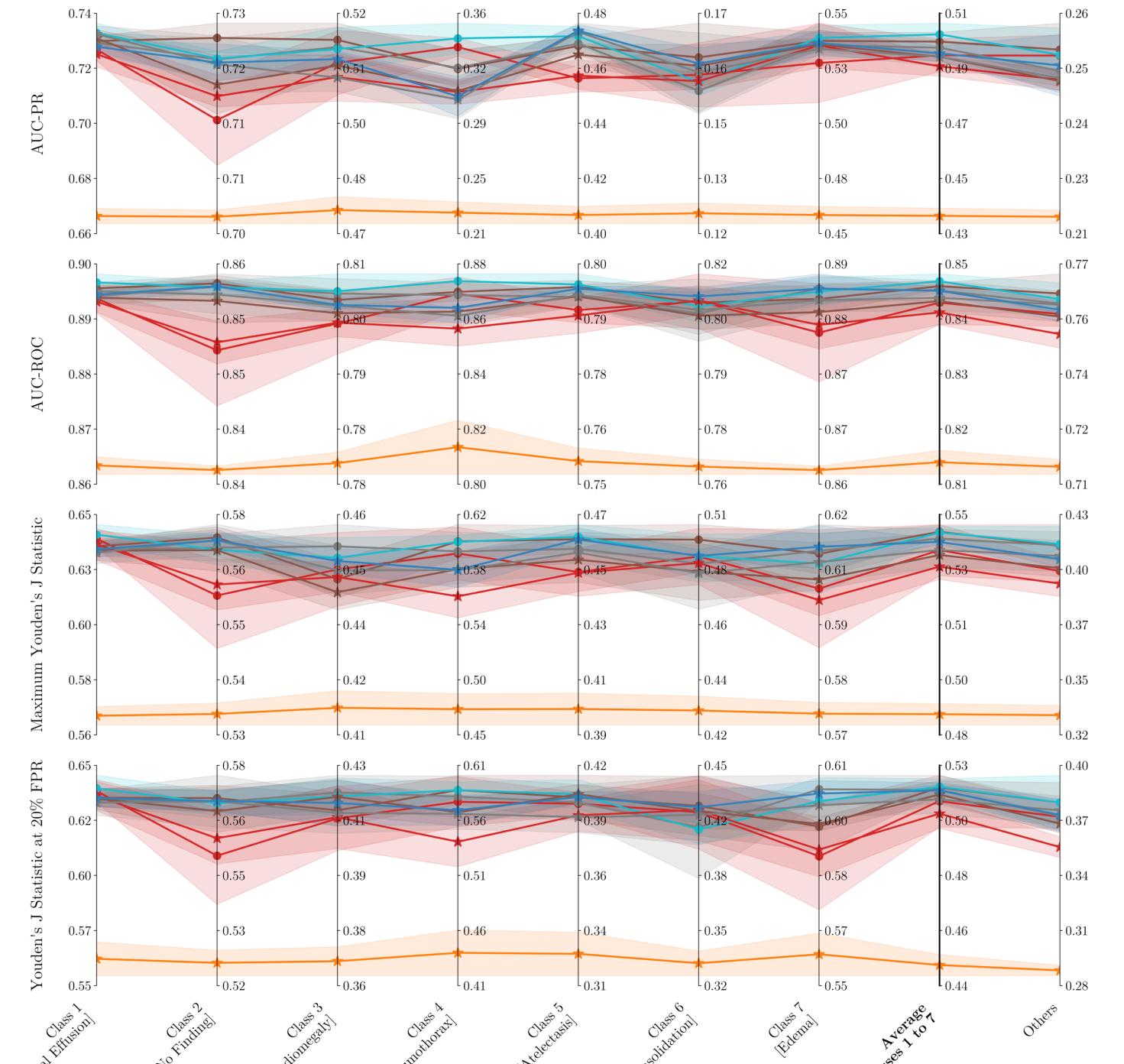
Note: Lines indicate averages; shaded areas indicate SD

● 1. CXR-Model-FFT	● 6. CXR-Model-FFT*
● 2. CXR-FMKD-Direct-FFT (MSE)	● 7. CXR-FMKD-Direct-FFT (MSE)*
● 3. CXR-FMKD-Direct-FFT (CS)	● 8. CXR-FMKD-Direct-FFT (CS)*
● 4. CXR-FMKD-Direct-FFT (MSE-CS 0.6-0.4)	● 9. CXR-FMKD-Direct-FFT (MSE-CS 0.9-0.1)*
★ 5. CXR-FM-LP*	

● Models pre-trained on CheXpert, fine-tuned on MIMIC using only the final classifier layer
★ 'Benchmark' Models trained and evaluated exclusively on MIMIC



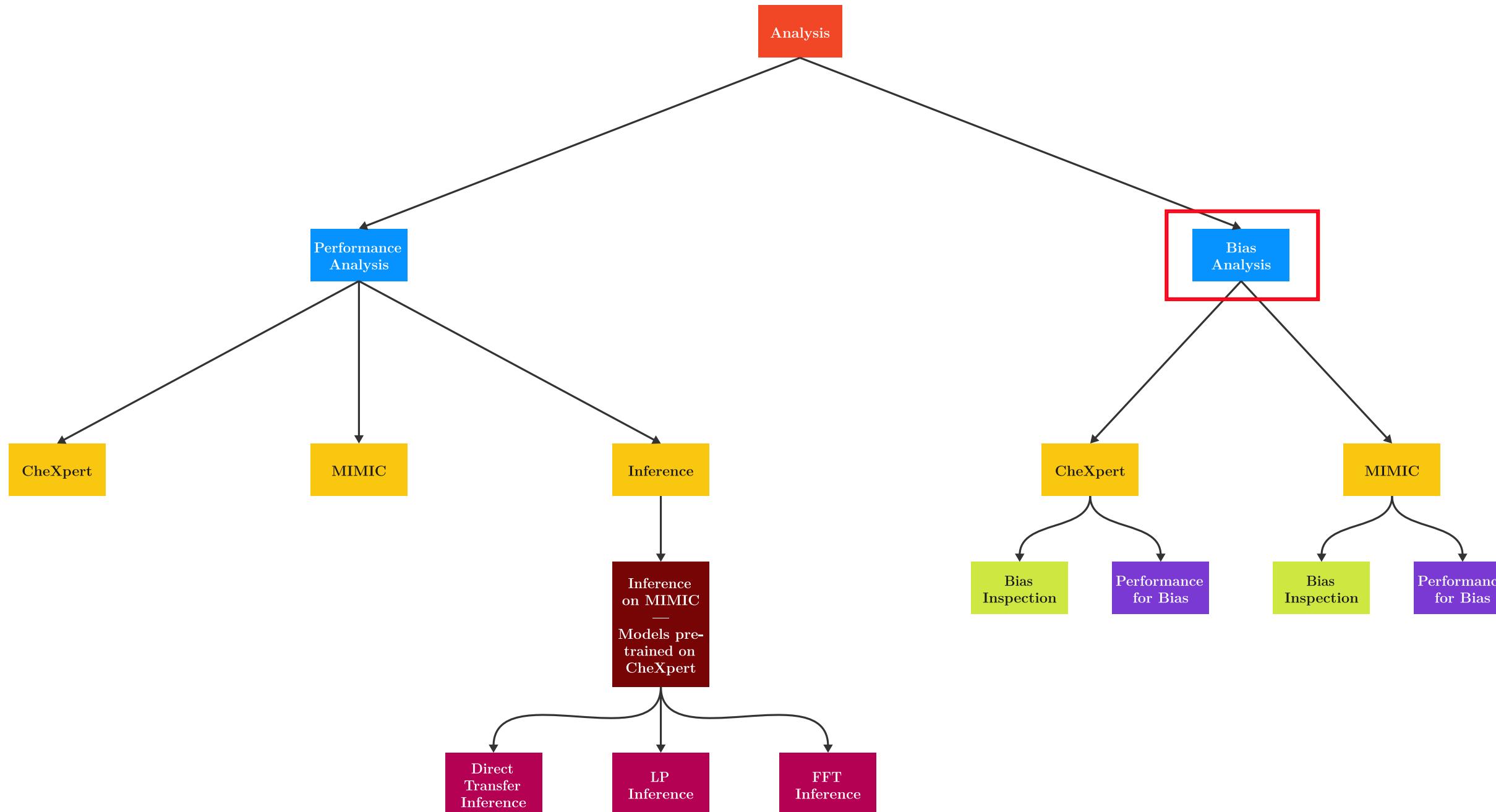
Performance Metrics | Full Fine-Tuning Inference on MIMIC
Across Most Significant Classes



- Note: Lines indicate averages; shaded areas indicate SD
- | | |
|---|--|
| ● 1. CXR-Model-FFT | ● 6. CXR-Model-FFT* |
| ● 2. CXR-FMKD-Direct-FFT (MSE) | ● 7. CXR-FMKD-Direct-FFT (MSE)* |
| ● 3. CXR-FMKD-Direct-FFT (CS) | ● 8. CXR-FMKD-Direct-FFT (CS)* |
| ● 4. CXR-FMKD-Direct-FFT (MSE-CS 0.6-0.4) | ● 9. CXR-FMKD-Direct-FFT (MSE-CS 0.9-0.1)* |
| ● 5. CXR-FM-LP* | |

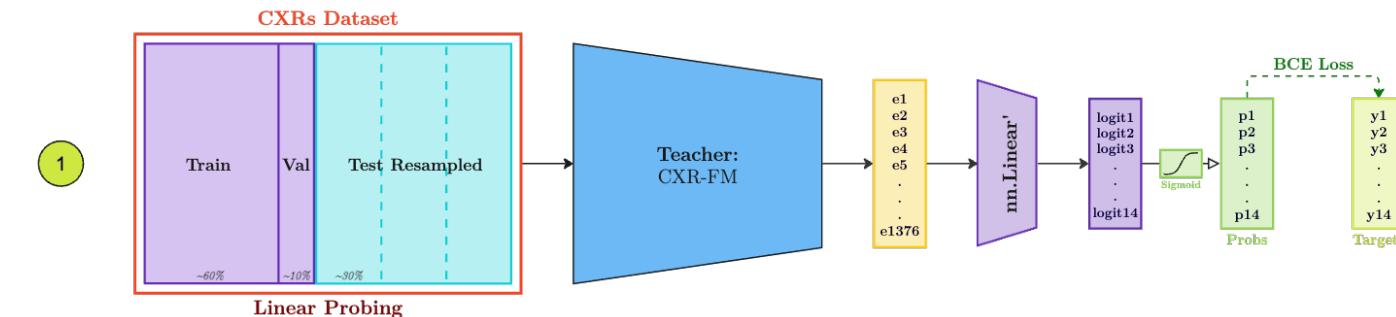
● Models pre-trained on CheXpert, fine-tuned on MIMIC across all layers
 ★ 'Benchmark' Models trained and evaluated exclusively on MIMIC

Project Overview

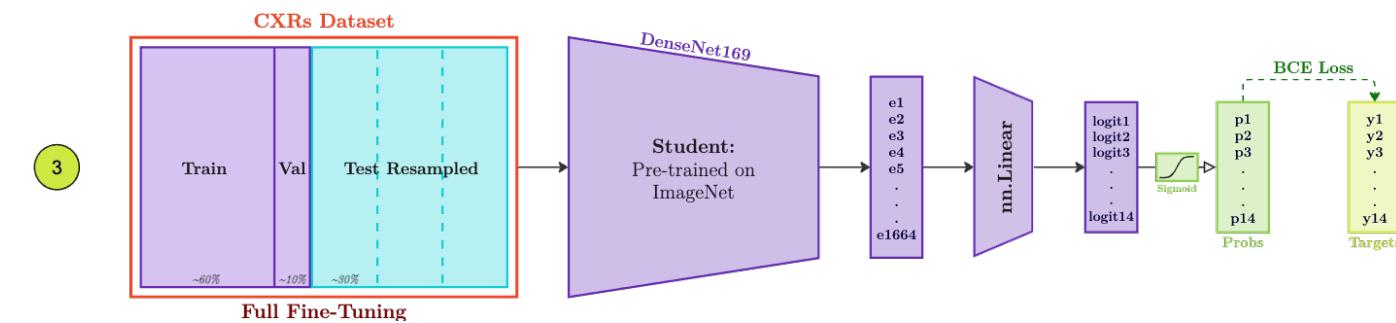


Selected Models (x5)

CXR-FM LP



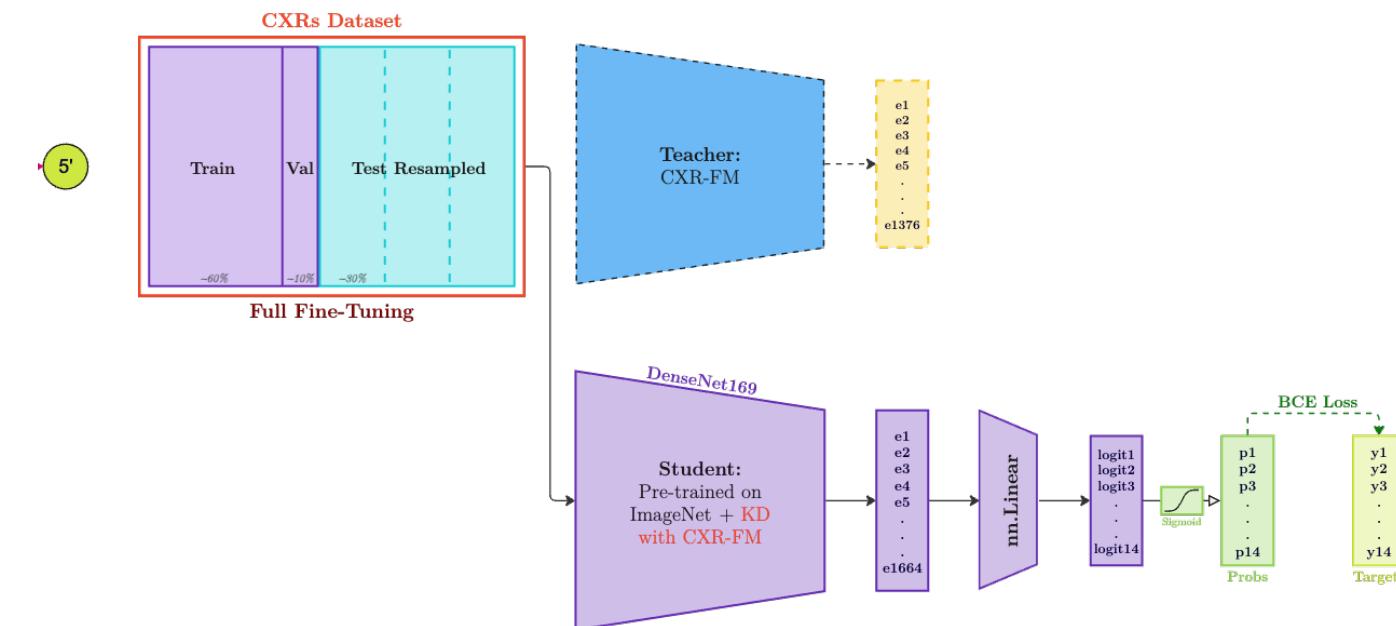
CXR-Model FFT



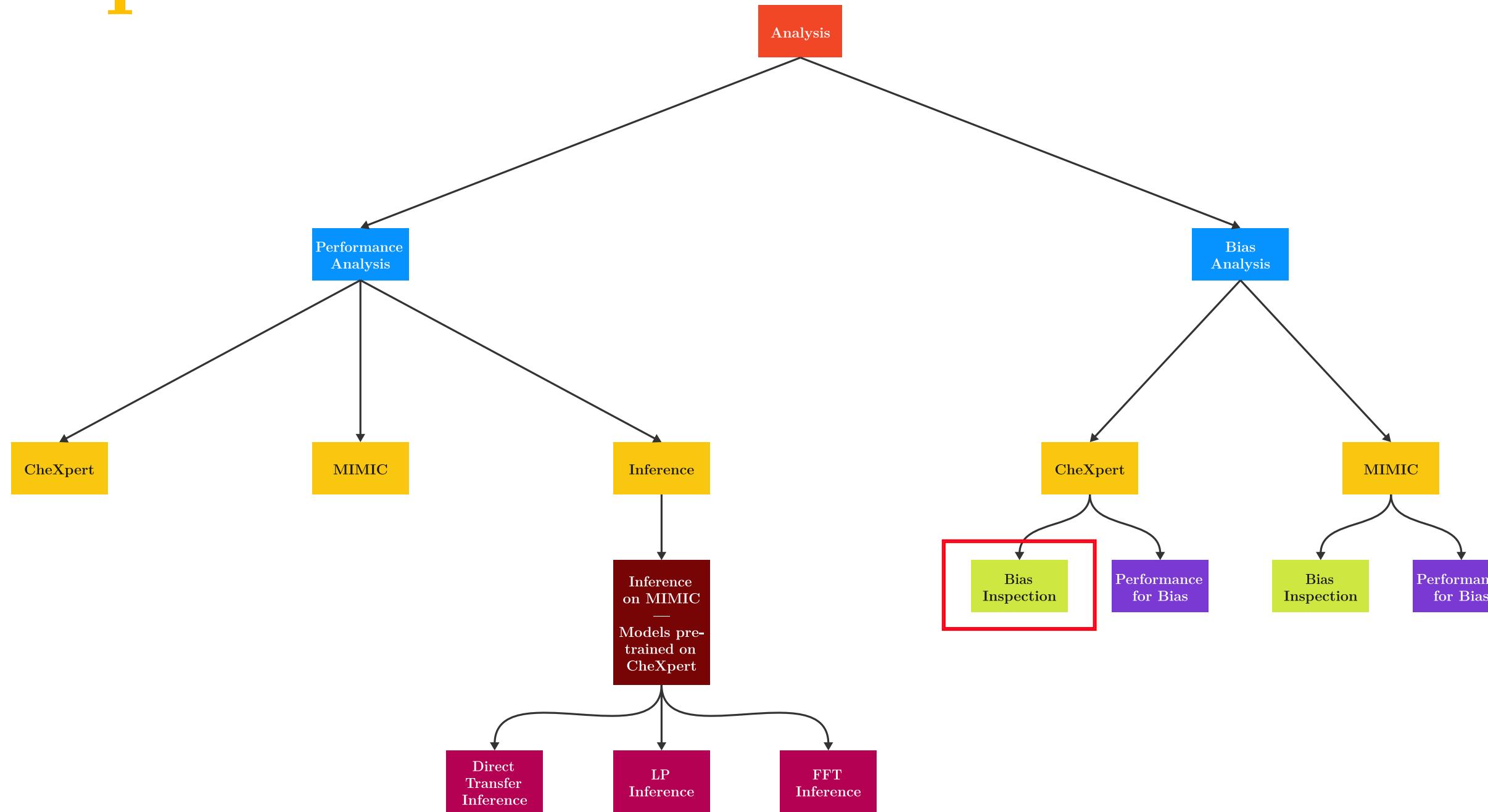
CXR-FMKD-Direct FFT

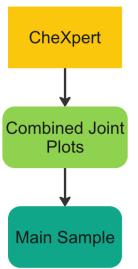
(x3):

- (x1) KD-MSE
- (x1) KD-CS
- (x1) KD-MSE&CS

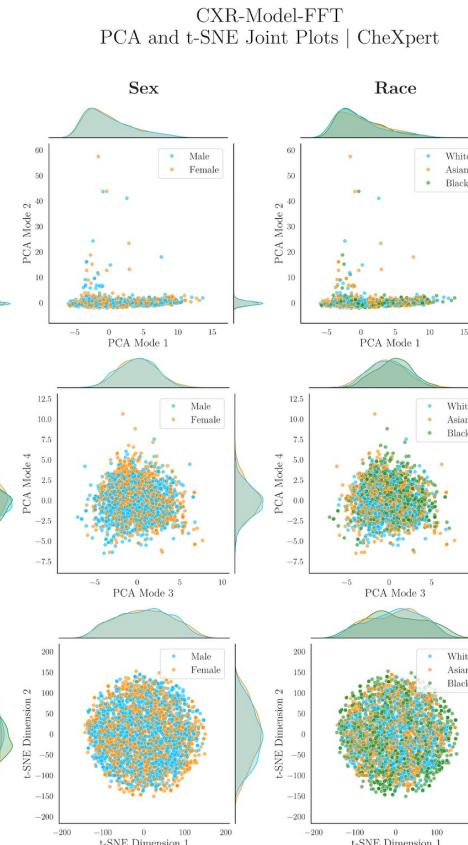
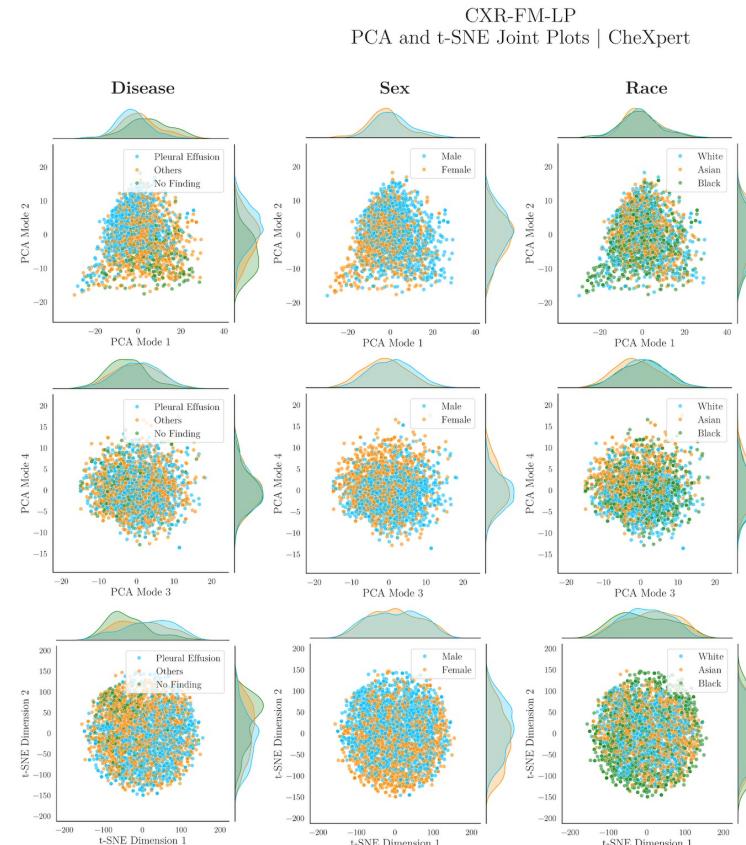


CheXpert

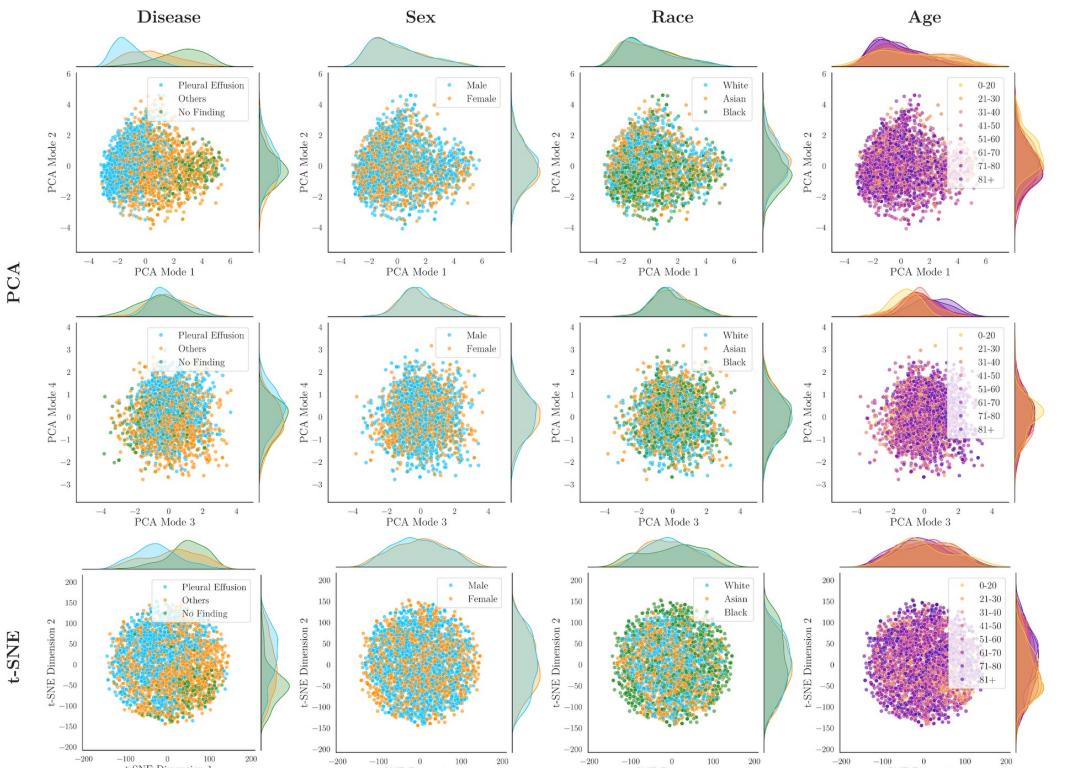




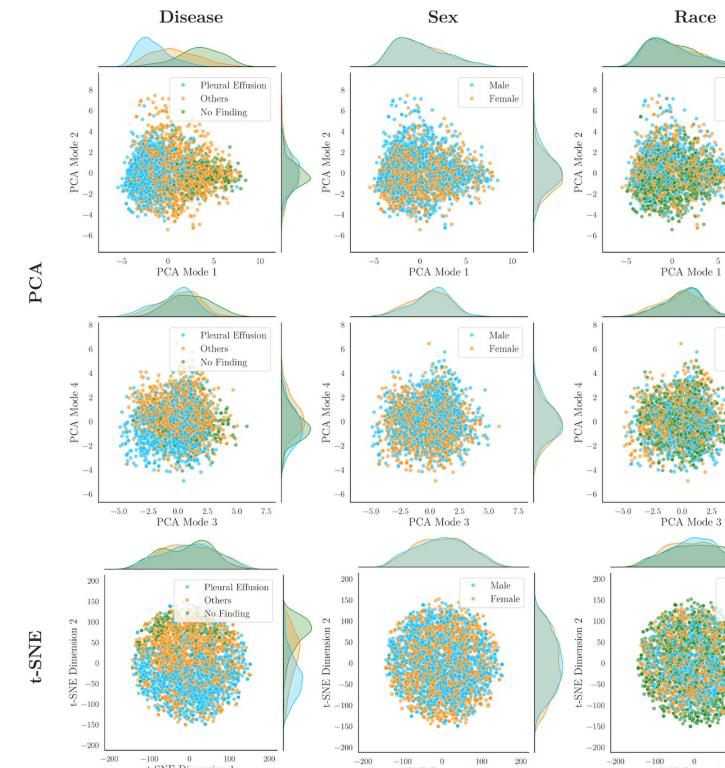
SAMPLED



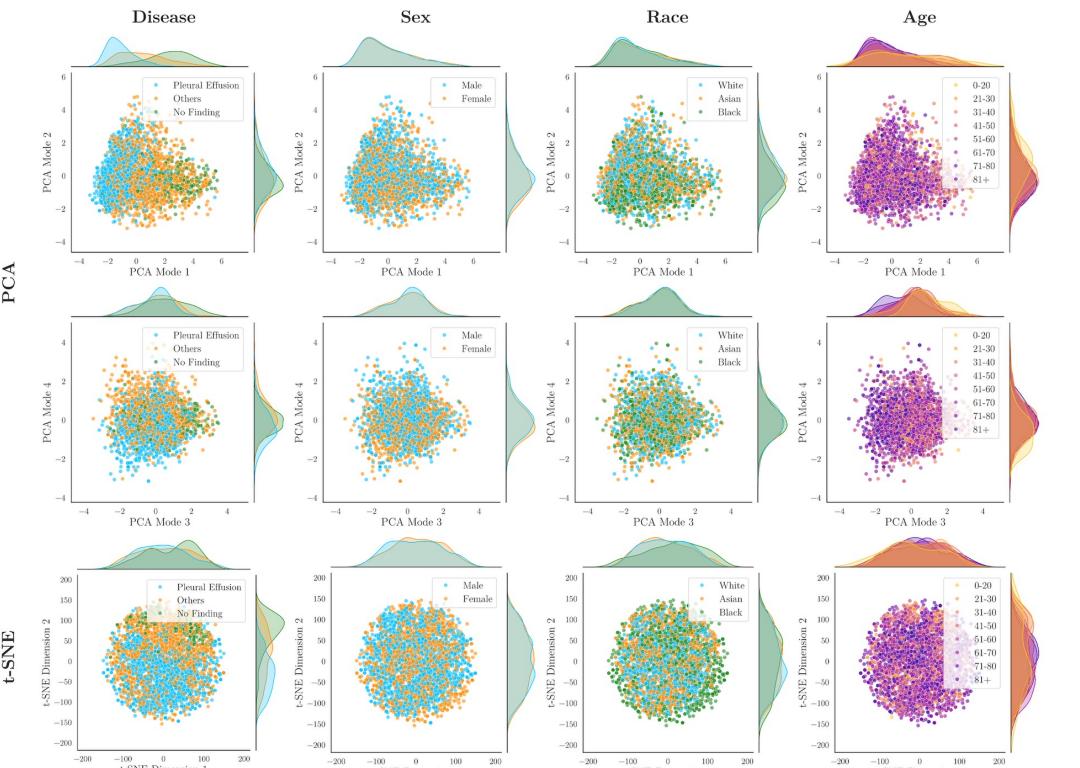
CXR-FMKD-Direct-FFT (MSE)
PCA and t-SNE Joint Plots | CheXpert

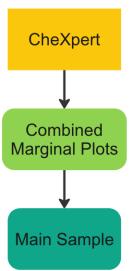


CXR-FMKD-Direct-FFT (CS)
PCA and t-SNE Joint Plots | CheXpert

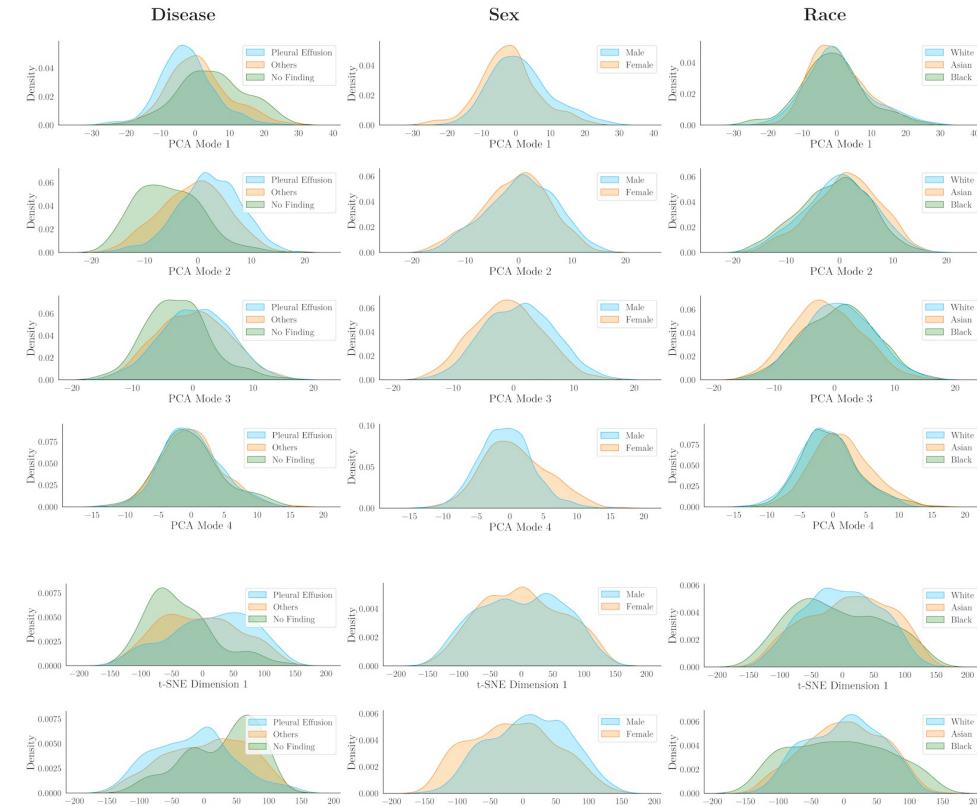


CXR-FMKD-Direct-FFT (MSE-CS | 0.6-0.4)
PCA and t-SNE Joint Plots | CheXpert

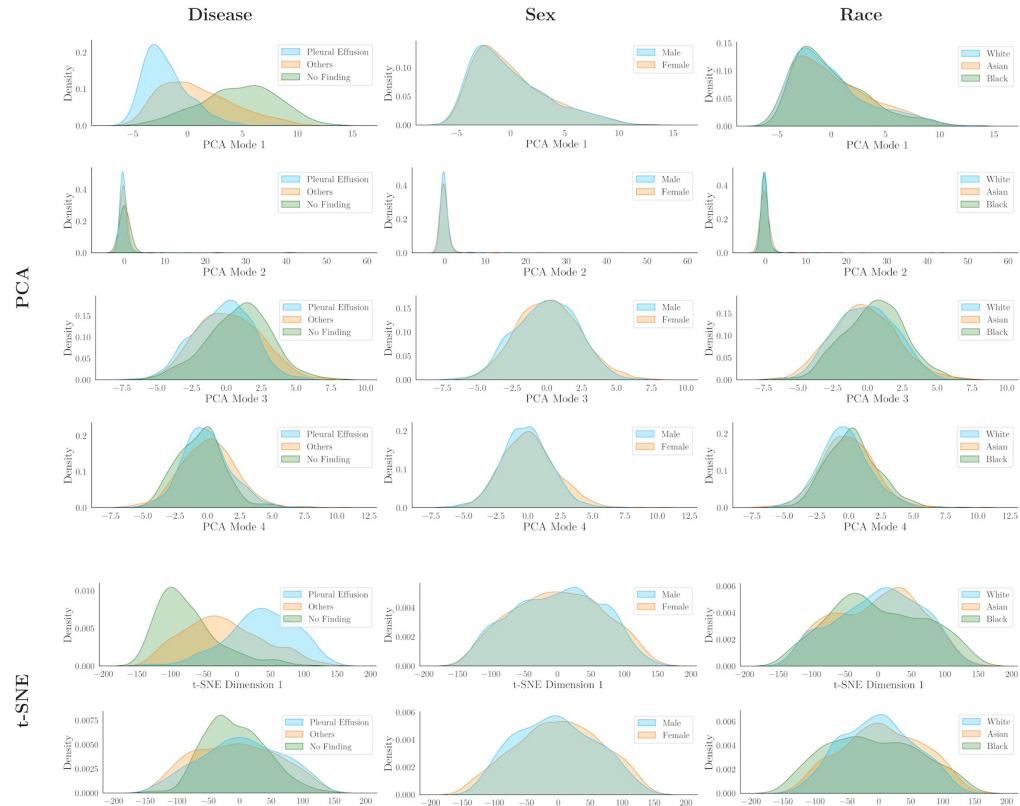




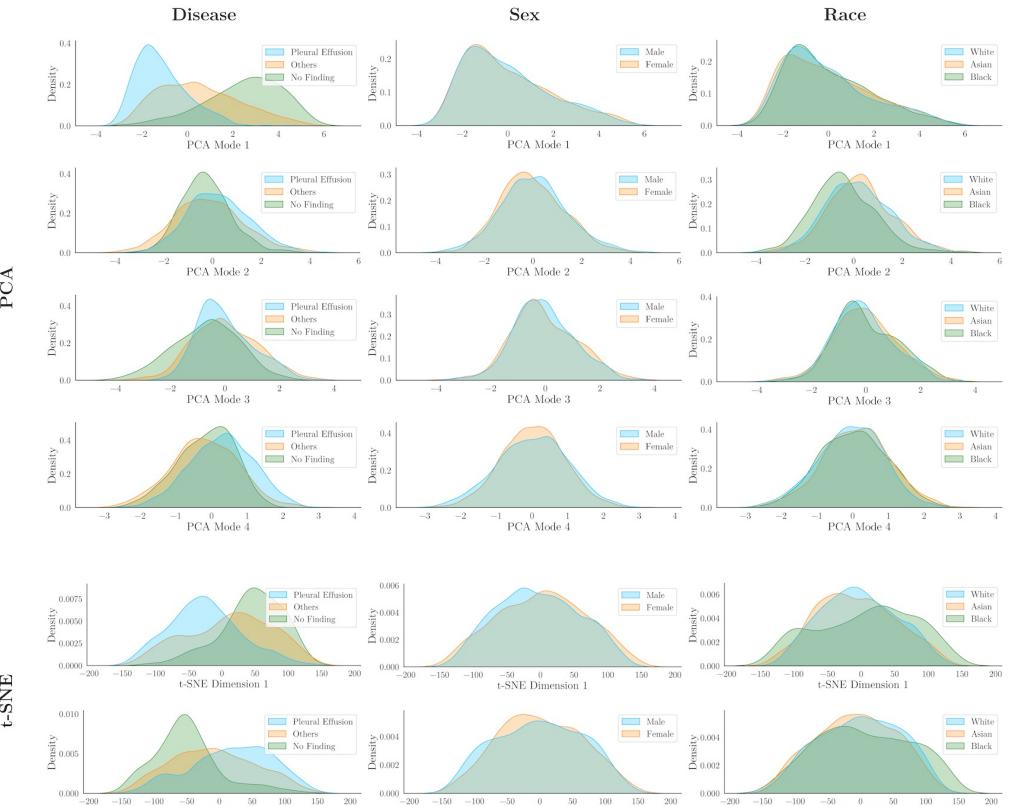
CXR-FM-LP
PCA and t-SNE Marginal Plots | CheXpert



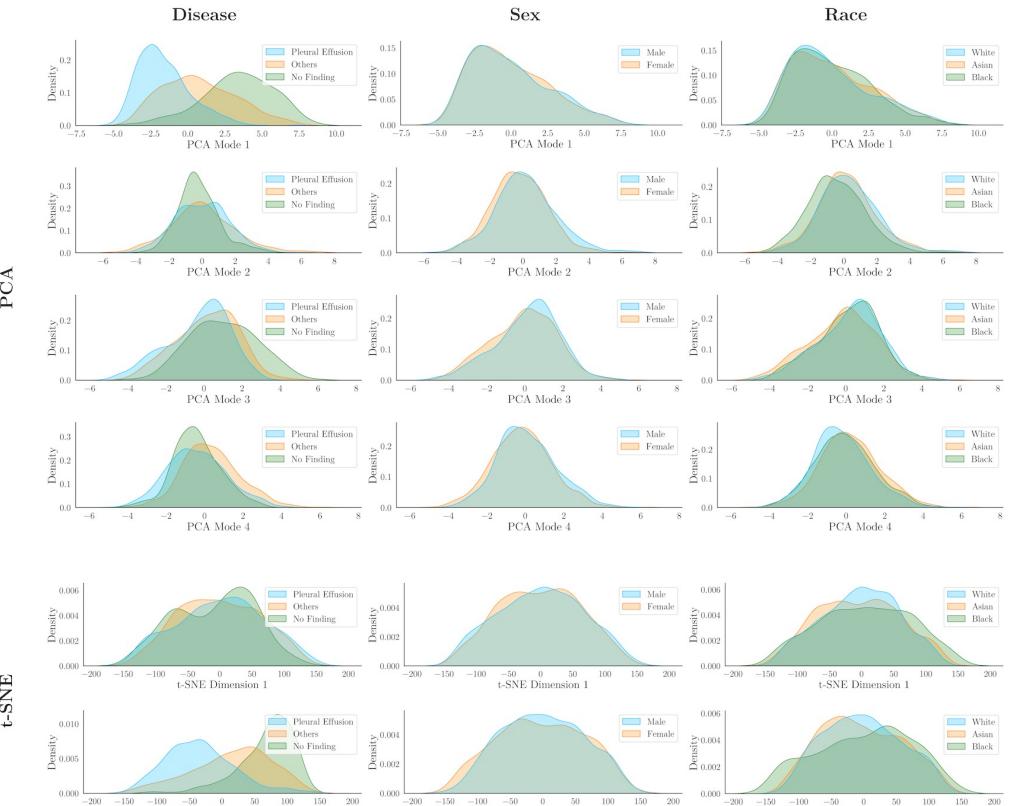
CXR-Model-FFT
PCA and t-SNE Marginal Plots | CheXpert



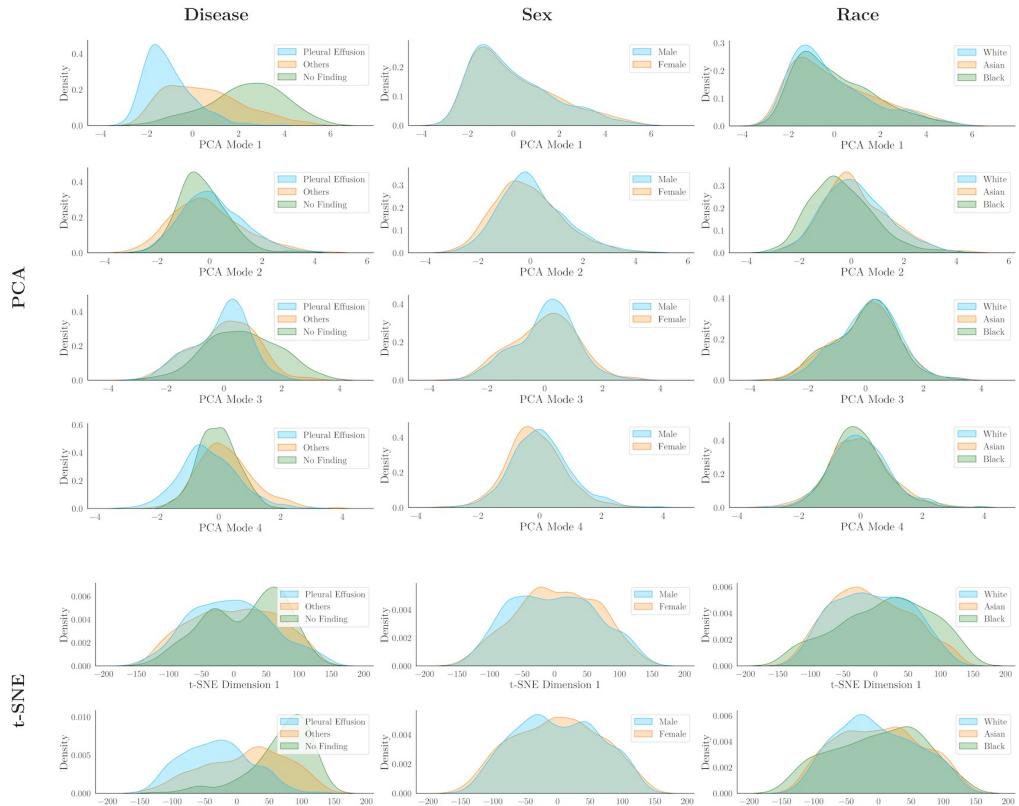
CXR-FMKD-Direct-FFT (MSE)
PCA and t-SNE Marginal Plots | CheXpert



CXR-FMKD-Direct-FFT (CS)
PCA and t-SNE Marginal Plots | CheXpert



CXR-FMKD-Direct-FFT (MSE-CS | 0.6-0.4)
PCA and t-SNE Marginal Plots | CheXpert



Model Shortname	Statistical Test Applied	Mode	Explained Variance	Pleural Effusion vs No Finding	White vs Asian	White vs Black	Asian vs Black	Male vs Female
CXR-FMKD-Direct-FFT (MSE)	ks	PCA Mode 1	0.19472402077103000	TRUE+	FALSE	FALSE	FALSE	FALSE
CXR-FMKD-Direct-FFT (MSE)	ks	PCA Mode 2	0.09954503143241190	TRUE+	FALSE	TRUE+	TRUE+	FALSE
CXR-FMKD-Direct-FFT (MSE)	ks	PCA Mode 3	0.071614824018345	TRUE+	FALSE	TRUE	TRUE	FALSE
CXR-FMKD-Direct-FFT (MSE)	ks	PCA Mode 4	0.0495928964818764	TRUE+	FALSE	FALSE	FALSE	FALSE



Kolmogorov–Smirnov test

P-value > 0.05:

FALSE

No significant differences in marginal distributions (i.e., '**unbiased**')

0.001 < P-value < 0.05:

TRUE

Significant differences in marginal distributions (i.e., '**biased**')

P-value < 0.001:

TRUE+

Very Significant differences in marginal distributions (i.e., '**significantly biased**')

Sample from the dataset, 1000 from each race, 3000 data points in total

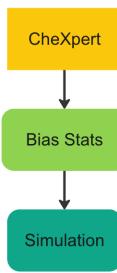
Model Shortname	Statistical Test Applied	Mode	Explained Variance	Pleural Effusion vs No Finding	White vs Asian	White vs Black	Asian vs Black	Male vs Female
CXR-FMKD-Direct-FFT (MSE)	ks	PCA Mode 1	0.19472402077103000	TRUE+	FALSE	FALSE	FALSE	FALSE
CXR-FMKD-Direct-FFT (MSE)	ks	PCA Mode 2	0.09954503143241190	TRUE+	FALSE	TRUE+	TRUE+	FALSE
CXR-FMKD-Direct-FFT (MSE)	ks	PCA Mode 3	0.071614824018345	TRUE+	FALSE	TRUE	TRUE	FALSE
CXR-FMKD-Direct-FFT (MSE)	ks	PCA Mode 4	0.0495928964818764	TRUE+	FALSE	FALSE	FALSE	FALSE



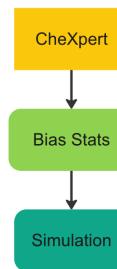
5000 simulations (5000 different seeds for sampling)

Model Shortname	Statistical Test Applied	Mode	Explained Variance	Pleural Effusion vs No Finding	White vs Asian	White vs Black	Asian vs Black	Male vs Female
CXR-FMKD-Direct-FFT (MSE)	ks	PCA Mode 1	0.19472402077103000	FALSE : 0 [0.00%] TRUE : 0 [0.00%] TRUE+ : 5000 [100.00%]	FALSE : 4961 [99.22%] TRUE : 39 [0.78%] TRUE+ : 0 [0.00%]	FALSE : 4938 [98.76%] TRUE : 61 [1.22%] TRUE+ : 1 [0.02%]	FALSE : 4875 [97.50%] TRUE : 121 [2.42%] TRUE+ : 4 [0.08%]	FALSE : 4938 [98.76%] TRUE : 61 [1.22%] TRUE+ : 1 [0.02%]
CXR-FMKD-Direct-FFT (MSE)	ks	PCA Mode 2	0.09954503143241190	FALSE : 0 [0.00%] TRUE : 0 [0.00%] TRUE+ : 5000 [100.00%]	FALSE : 4761 [95.22%] TRUE : 231 [4.62%] TRUE+ : 8 [0.16%]	FALSE : 0 [0.00%] TRUE : 0 [0.00%] TRUE+ : 5000 [100.00%]	FALSE : 0 [0.00%] TRUE : 0 [0.00%] TRUE+ : 5000 [100.00%]	FALSE : 4474 [89.48%] TRUE : 499 [9.98%] TRUE+ : 27 [0.54%]
CXR-FMKD-Direct-FFT (MSE)	ks	PCA Mode 3	0.071614824018345	FALSE : 0 [0.00%] TRUE : 41 [0.82%] TRUE+ : 4959 [99.18%]	FALSE : 4974 [99.48%] TRUE : 26 [0.52%] TRUE+ : 0 [0.00%]	FALSE : 3956 [79.12%] TRUE : 996 [19.92%] TRUE+ : 48 [0.96%]	FALSE : 4367 [87.34%] TRUE : 609 [12.18%] TRUE+ : 24 [0.48%]	FALSE : 4792 [95.84%] TRUE : 202 [4.04%] TRUE+ : 6 [0.12%]
CXR-FMKD-Direct-FFT (MSE)	ks	PCA Mode 4	0.0495928964818764	FALSE : 0 [0.00%] TRUE : 5 [0.10%] TRUE+ : 4995 [99.90%]	FALSE : 4382 [87.64%] TRUE : 570 [11.40%] TRUE+ : 48 [0.96%]	FALSE : 4786 [95.72%] TRUE : 207 [4.14%] TRUE+ : 7 [0.14%]	FALSE : 4982 [99.64%] TRUE : 18 [0.36%] TRUE+ : 0 [0.00%]	FALSE : 4428 [88.56%] TRUE : 542 [10.84%] TRUE+ : 30 [0.60%]

How to quantify?

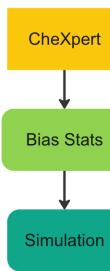


Model Name	Mode	Explained Variance (ExpVar)		Disease Detection		Race Attribute			Sex Attribute	
				Pleural Eff. vs No Finding		White vs Asian	White vs Black	Asian vs Black	Male vs Female	
CXR-FMKD-Direct-FFT (MSE)	PCA Mode 1	19.47%	FALSE		0	4961	4938	4875	4938	
			TRUE		0	39	61	121	61	
			TRUE+	5000	0	1	4	1		
CXR-FMKD-Direct-FFT (MSE)	PCA Mode 2	9.95%	FALSE		0	4761	0	0	4474	
			TRUE		0	231	0	0	499	
			TRUE+	5000	8	5000	5000	27		
CXR-FMKD-Direct-FFT (MSE)	PCA Mode 3	7.16%	FALSE		0	4974	3956	4367	4792	
			TRUE		41	26	996	609	202	
			TRUE+	4959	0	48	24	6		
CXR-FMKD-Direct-FFT (MSE)	PCA Mode 4	4.96%	FALSE		0	4382	4786	4982	4428	
			TRUE		5	570	207	18	542	
			TRUE+	4995	48	7	0	30		



Model Name	Mode	Explained Variance (ExpVar)		Disease Detection		Race Attribute			Sex Attribute	
				0	4961	4938	4875	4938		
CXR-FMKD-Direct-FFT (MSE)	PCA Mode 1	19.47%	FALSE	0	4961	4938	4875	4938		
			TRUE	0	39	61	121	61		
			TRUE+	5000	0	1	4	1		
CXR-FMKD-Direct-FFT (MSE)	PCA Mode 2	9.95%	FALSE	0	4761	0	0	0	4474	
			TRUE	0	231	0	0	0	499	
			TRUE+	5000	8	5000	5000	27		
CXR-FMKD-Direct-FFT (MSE)	PCA Mode 3	7.16%	FALSE	0	4974	3956	4367	4792		
			TRUE	41	26	996	609	202		
			TRUE+	4959	0	48	24	6		
CXR-FMKD-Direct-FFT (MSE)	PCA Mode 4	4.96%	FALSE	0	4382	4786	4982	4428		
			TRUE	5	570	207	18	542		
			TRUE+	4995	48	7	0	30		

Model Name	Mode	Explained Variance (ExpVar)		Pleural Eff. vs No Finding	White vs Asian	White vs Black	Asian vs Black	Male vs Female	
CXR-FMKD-Direct-FFT (MSE)	PCA Mode 1	19.47%	FALSE	0%	99%	99%	98%	99%	
			TRUE	0%	1%	1%	2%	1%	
			TRUE+	100%	0%	0%	0%	0%	
CXR-FMKD-Direct-FFT (MSE)	PCA Mode 2	9.95%	FALSE	0%	95%	0%	0%	89%	
			TRUE	0%	5%	0%	0%	10%	
			TRUE+	100%	0%	100%	100%	1%	
CXR-FMKD-Direct-FFT (MSE)	PCA Mode 3	7.16%	FALSE	0%	99%	79%	87%	96%	
			TRUE	1%	1%	20%	12%	4%	
			TRUE+	99%	0%	1%	0%	0%	
CXR-FMKD-Direct-FFT (MSE)	PCA Mode 4	4.96%	FALSE	0%	88%	96%	100%	89%	
			TRUE	0%	11%	4%	0%	11%	
			TRUE+	100%	1%	0%	0%	1%	

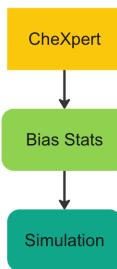


Model Name	Mode	Explained Variance (ExpVar)		Disease Detection		Race Attribute		Sex Attribute	
				Pleural Eff. vs No Finding	White vs Asian	White vs Black	Asian vs Black	Male vs Female	
CXR-FMKD-Direct-FFT (MSE)	PCA Mode 1	19.47%	FALSE	0	4961	4938	4875	4938	
			TRUE	0	39	61	121	61	
			TRUE+	5000	0	1	4	1	
CXR-FMKD-Direct-FFT (MSE)	PCA Mode 2	9.95%	FALSE	0	4761	0	0	4474	
			TRUE	0	231	0	0	499	
			TRUE+	5000	8	5000	5000	27	
CXR-FMKD-Direct-FFT (MSE)	PCA Mode 3	7.16%	FALSE	0	4974	3956	4367	4792	
			TRUE	41	26	996	609	202	
			TRUE+	4959	0	48	24	6	
CXR-FMKD-Direct-FFT (MSE)	PCA Mode 4	4.96%	FALSE	0	4382	4786	4982	4428	
			TRUE	5	570	207	18	542	
			TRUE+	4995	48	7	0	30	

Model Name	Mode	Explained Variance (ExpVar)		%	%	%	%	%	%
CXR-FMKD-Direct-FFT (MSE)	PCA Mode 1	19.47%	FALSE	0%	99%	99%	98%	99%	
			TRUE	0%	1%	1%	2%	1%	
			TRUE+	100%	0%	0%	0%	0%	
CXR-FMKD-Direct-FFT (MSE)	PCA Mode 2	9.95%	FALSE	0%	95%	0%	0%	89%	
			TRUE	0%	5%	0%	0%	10%	
			TRUE+	100%	0%	100%	100%	1%	
CXR-FMKD-Direct-FFT (MSE)	PCA Mode 3	7.16%	FALSE	0%	99%	79%	87%	96%	
			TRUE	1%	1%	20%	12%	4%	
			TRUE+	99%	0%	1%	0%	0%	
CXR-FMKD-Direct-FFT (MSE)	PCA Mode 4	4.96%	FALSE	0%	88%	96%	100%	89%	
			TRUE	0%	11%	4%	0%	11%	
			TRUE+	100%	1%	0%	0%	1%	

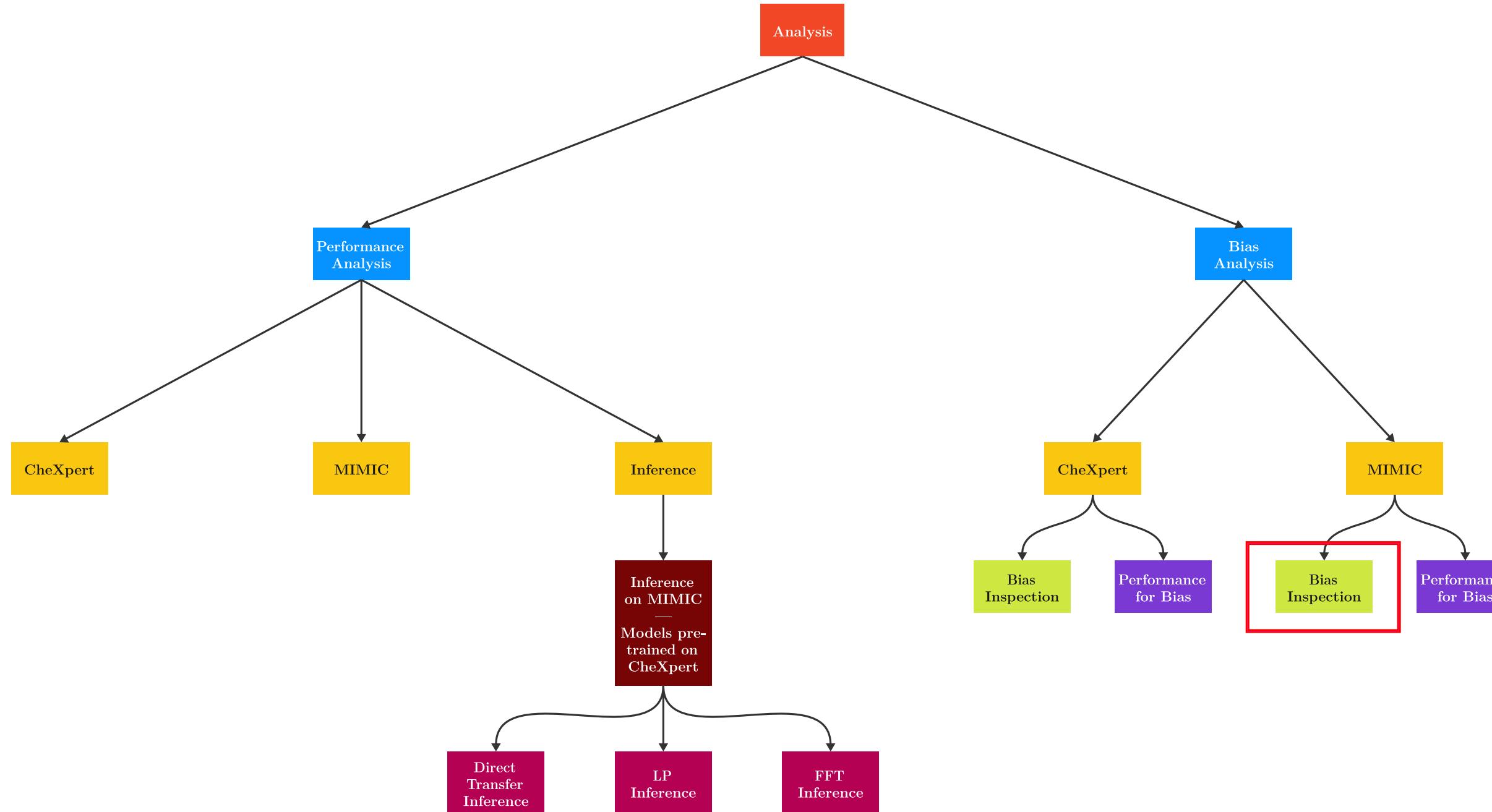
Model Name	Mode	Normalised ExpVar		%	%	%	%	%	%
CXR-FMKD-Direct-FFT (MSE)	PCA Mode 1	47%	FALSE	0%	47%	46%	46%	46%	
			TRUE	0%	0%	1%	1%	1%	
			TRUE+	47%	0%	0%	0%	0%	
CXR-FMKD-Direct-FFT (MSE)	PCA Mode 2	24%	FALSE	0%	23%	0%	0%	21%	
			TRUE	0%	1%	0%	0%	2%	
			TRUE+	24%	0%	24%	24%	0%	
CXR-FMKD-Direct-FFT (MSE)	PCA Mode 3	17%	FALSE	0%	17%	14%	15%	17%	
			TRUE	0%	0%	3%	2%	1%	
			TRUE+	17%	0%	0%	0%	0%	
CXR-FMKD-Direct-FFT (MSE)	PCA Mode 4	12%	FALSE	0%	10%	11%	12%	11%	
			TRUE	0%	1%	0%	0%	1%	
			TRUE+	12%	0%	0%	0%	0%	

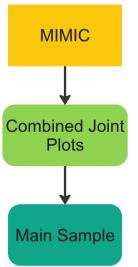
- 0 means no bias (i.e. all p-values are greater than 0.05)
 - 100 means biased (i.e., on average, p-values $0.001 < p < 0.05$)
 - 150 means “significantly” biased (i.e., all p-values $p < 0.001$)
- Race Attribute Sex Attribute Average
- | | | | | | | | |
|--------|-------------|-----|-------------|-------------|-------------|-------------|-------------|
| SCORES | FALSE (0) | 0 | | 80% | 95% | 88% | FALSE |
| | TRUE (100) | 100 | | 4% | 5% | 4% | TRUE |
| | TRUE+ (150) | 150 | | 16% | 0% | 8% | TRUE+ |
| | | | 27.75791432 | 40.72569778 | 39.39579653 | 5.299769378 | 16.52884185 |
| | | | | | 5.299769378 | | |



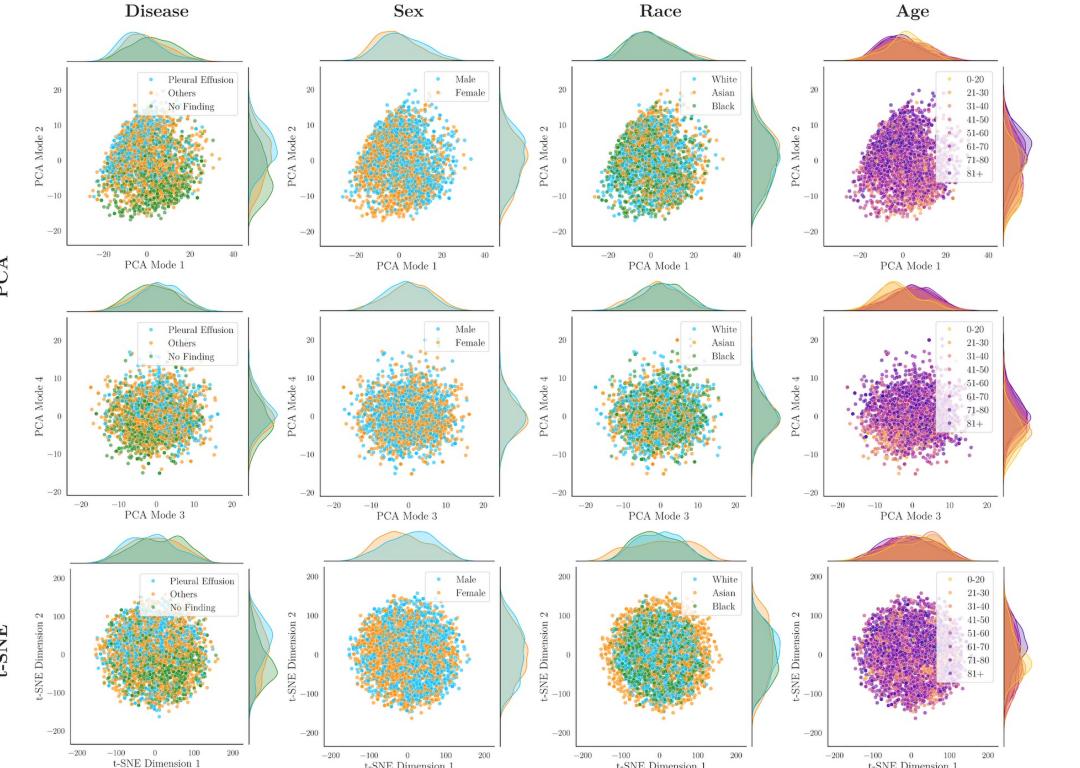
Model Shortname (CheXpert)	Statistical Test Applied	Race (Formatted Bias Scores)	Race (Combined Bias Score)	Sex (Formatted Bias Scores)	Sex (Combined Bias Score)	Attributes Average (Formatted Bias Scores)	Attributes Average (Combined Bias Score)
CXR-FM-LP	ks	FALSE : 46.81% TRUE : 22.44% TRUE+ : 30.75%	68.56391922	FALSE : 0.04% TRUE : 1.41% TRUE+ : 98.55%	149.2369366	FALSE : 23.42% TRUE : 11.93% TRUE+ : 64.65%	108.9004279
CXR-Model-FFT	ks	FALSE : 74.43% TRUE : 7.74% TRUE+ : 17.83%	34.47856891	FALSE : 82.46% TRUE : 12.63% TRUE+ : 4.91%	19.99515537	FALSE : 78.45% TRUE : 10.19% TRUE+ : 11.37%	27.23686214
CXR-FMKD-Direct-FFT (MSE)	ks	FALSE : 80.31% TRUE : 3.57% TRUE+ : 16.13%	27.75791432	FALSE : 94.82% TRUE : 4.95% TRUE+ : 0.23%	5.299769378	FALSE : 87.56% TRUE : 4.26% TRUE+ : 8.18%	16.52884185
CXR-FMKD-Direct-FFT (CS)	ks	FALSE : 65.09% TRUE : 10.86% TRUE+ : 24.05%	46.93630242	FALSE : 61.84% TRUE : 13.07% TRUE+ : 25.09%	50.7002099	FALSE : 63.47% TRUE : 11.97% TRUE+ : 24.57%	48.81825616
CXR-FMKD-Direct-FFT (MSE-CS 0.6-0.4)	ks	FALSE : 75.98% TRUE : 7.40% TRUE+ : 16.61%	32.32277636	FALSE : 75.99% TRUE : 18.45% TRUE+ : 5.56%	26.792117	FALSE : 75.99% TRUE : 12.92% TRUE+ : 11.09%	29.55744668

MIMIC

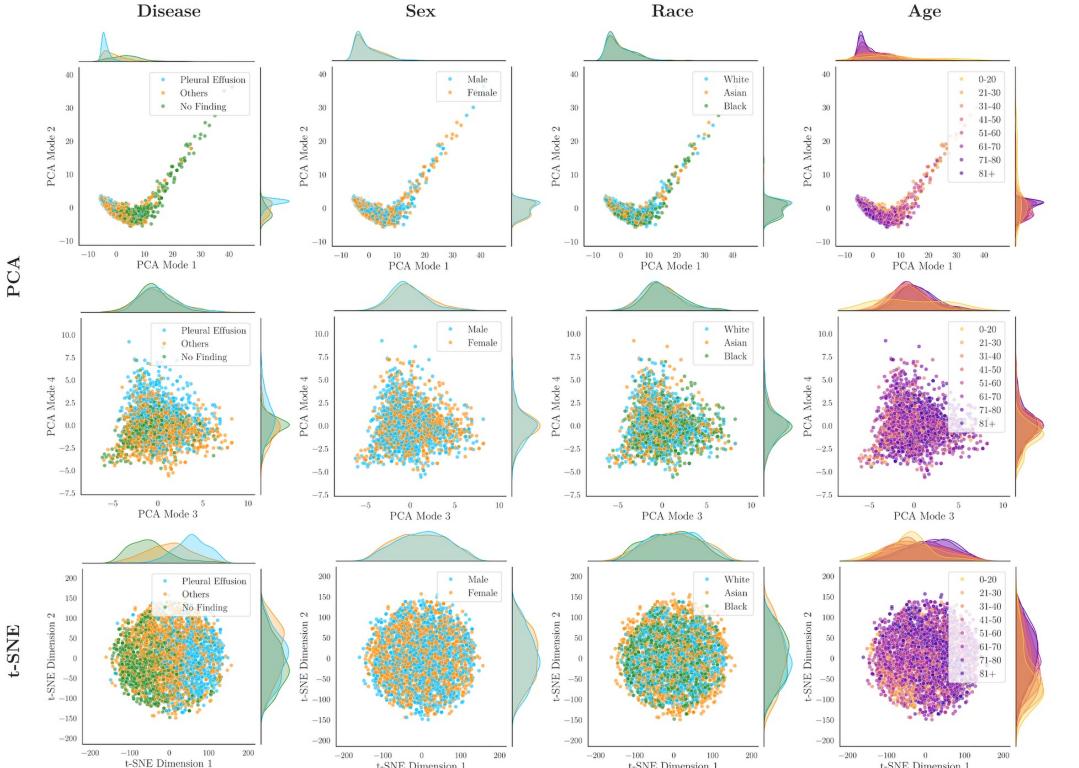




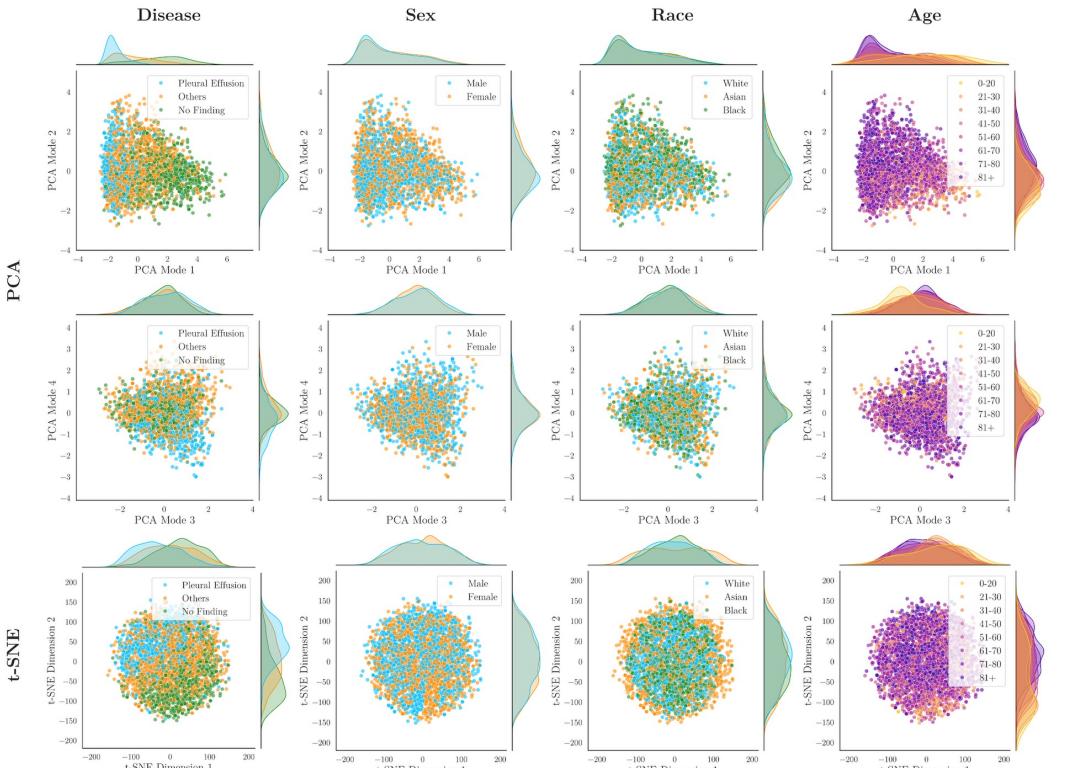
CXR-FM-LP
PCA and t-SNE Joint Plots | MIMIC



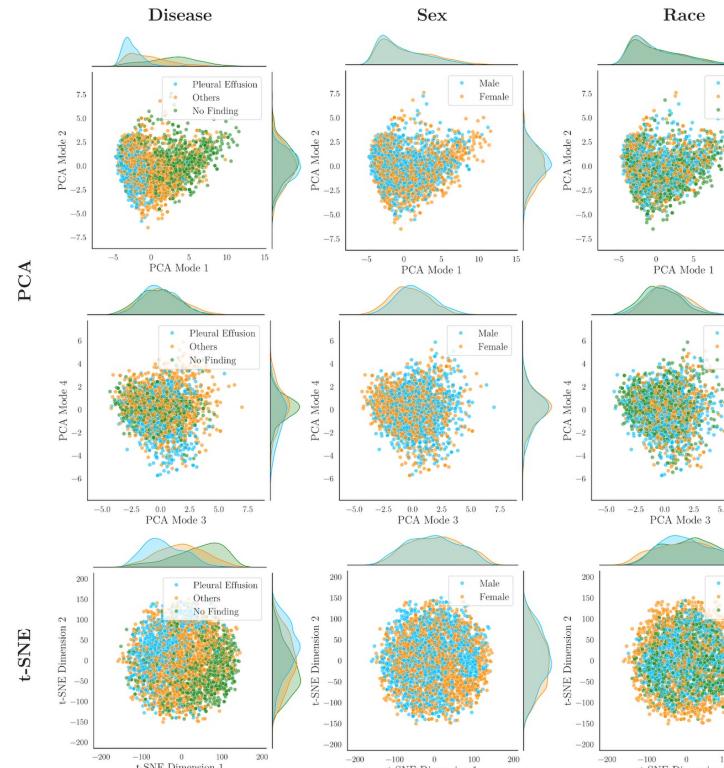
CXR-Model-FFT
PCA and t-SNE Joint Plots | MIMIC



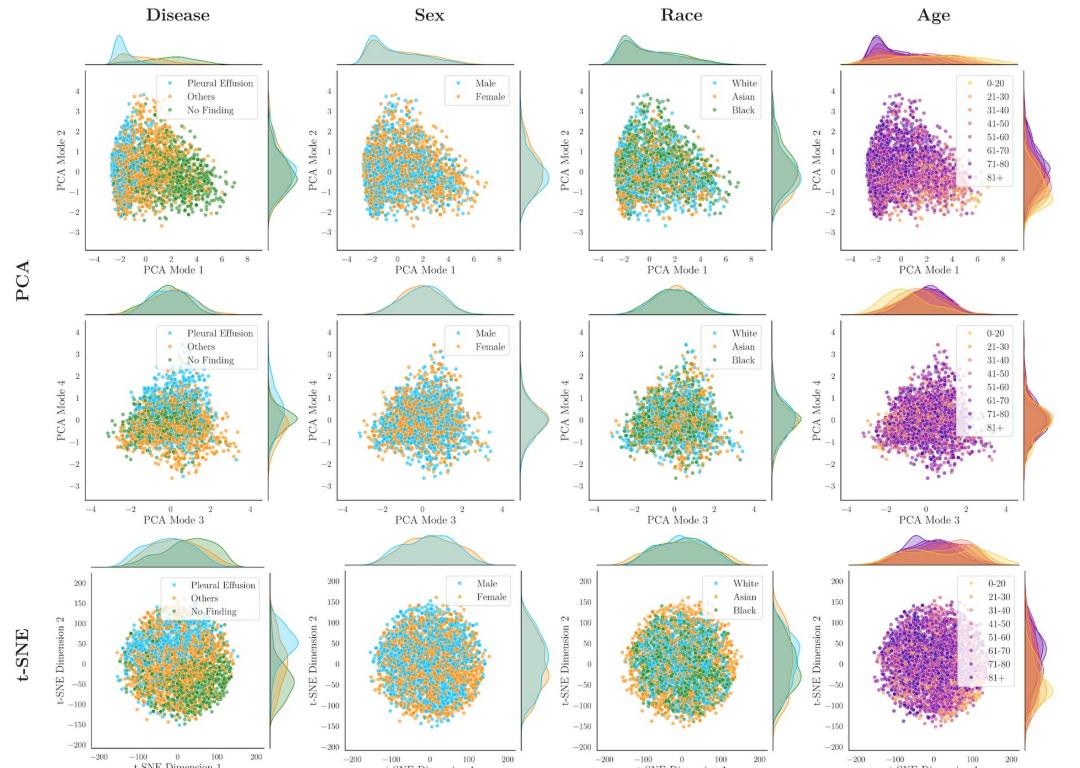
CXR-FMKD-Direct-FFT (MSE)
PCA and t-SNE Joint Plots | MIMIC

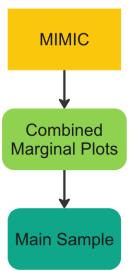


CXR-FMKD-Direct-FFT (CS)
PCA and t-SNE Joint Plots | MIMIC

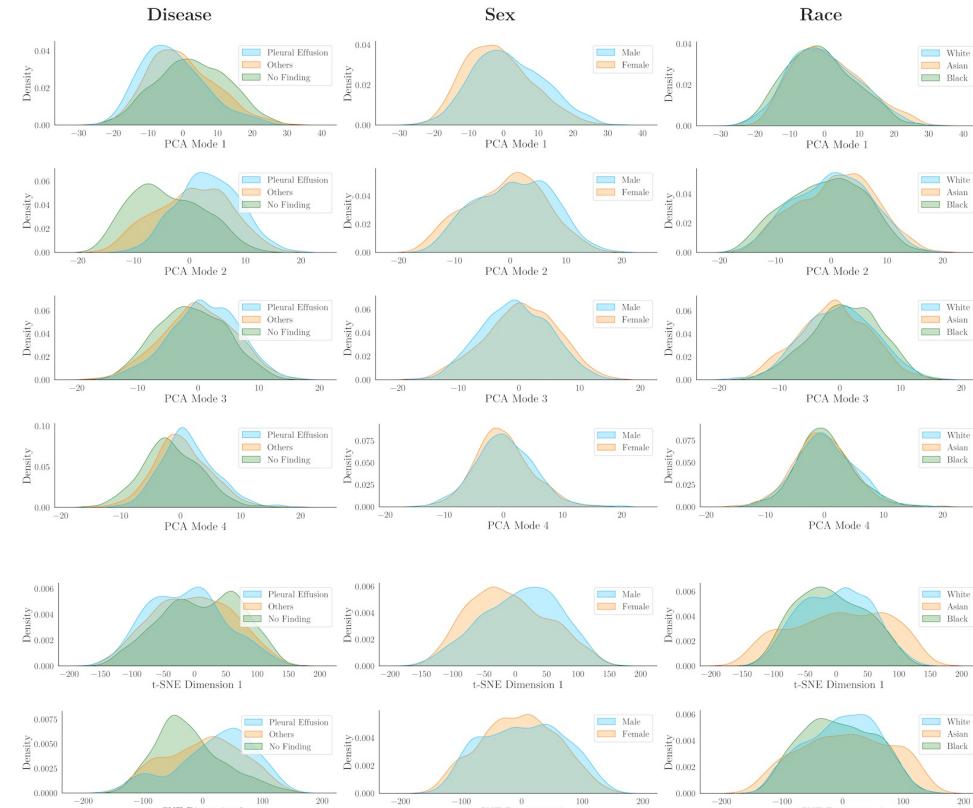


CXR-FMKD-Direct-FFT (MSE-CS | 0.9-0.1)
PCA and t-SNE Joint Plots | MIMIC

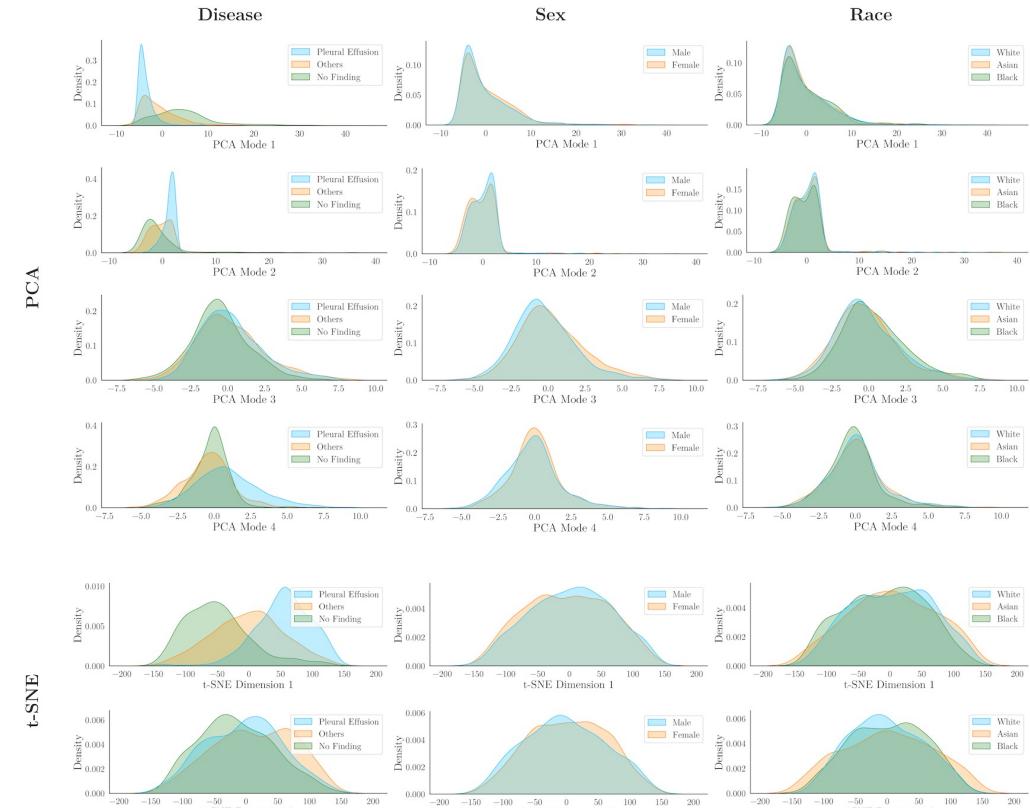




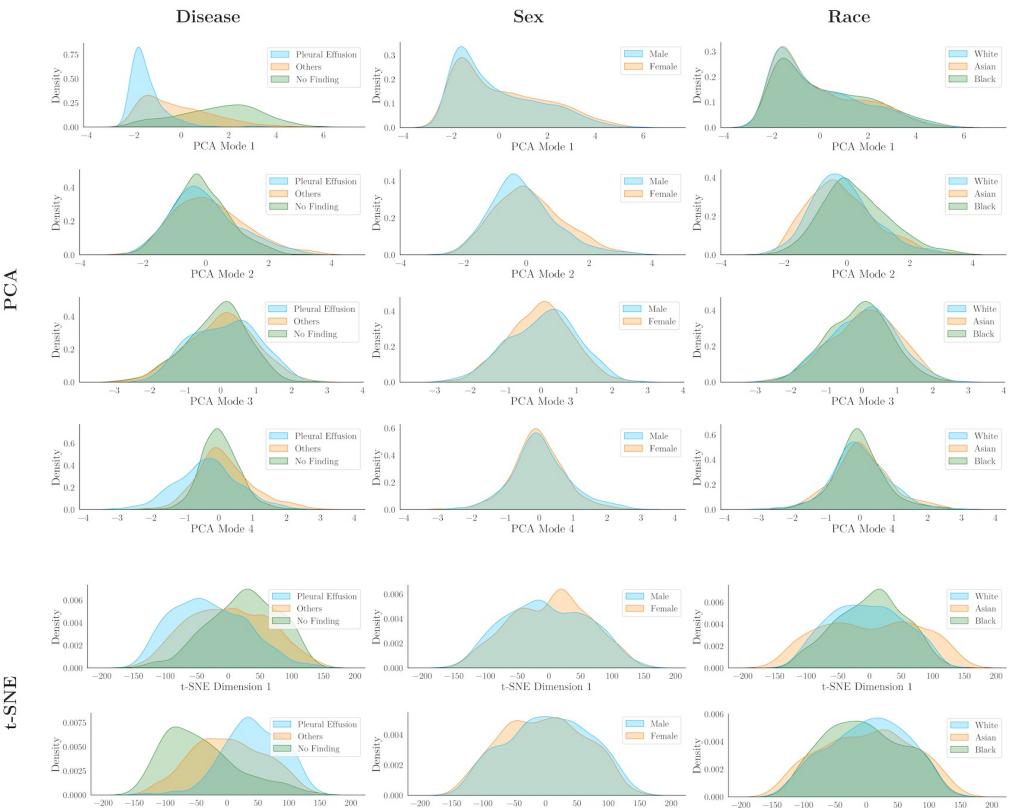
CXR-FM-LP
PCA and t-SNE Marginal Plots | MIMIC



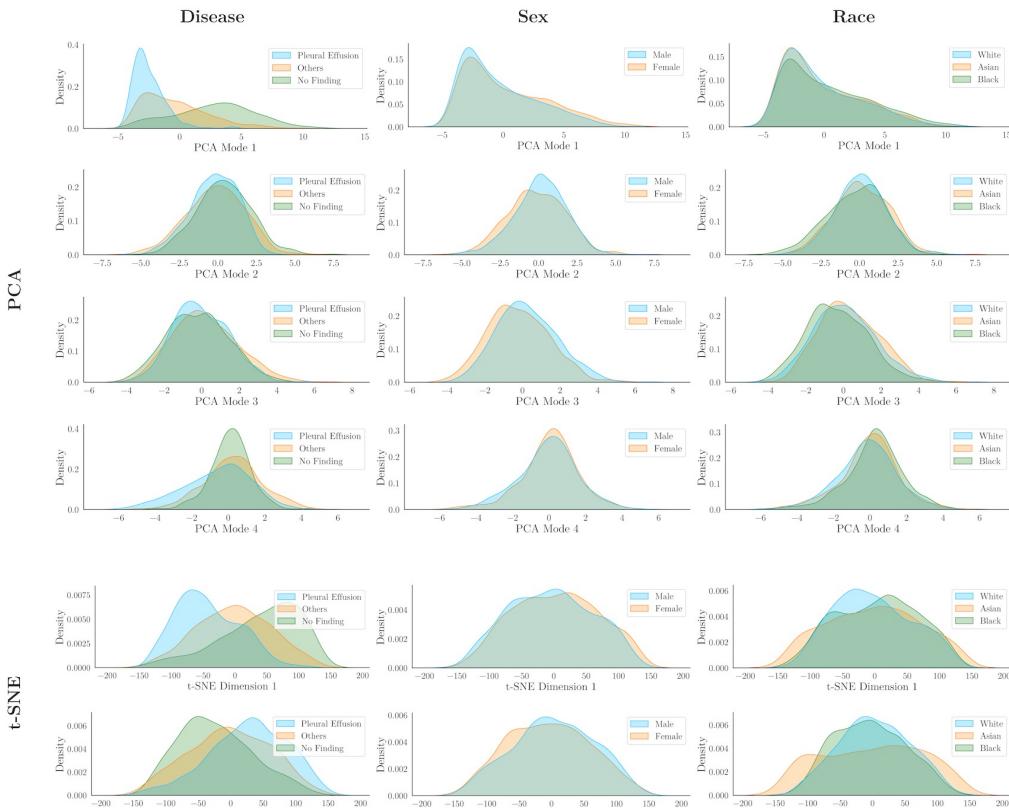
CXR-Model-FFT
PCA and t-SNE Marginal Plots | MIMIC



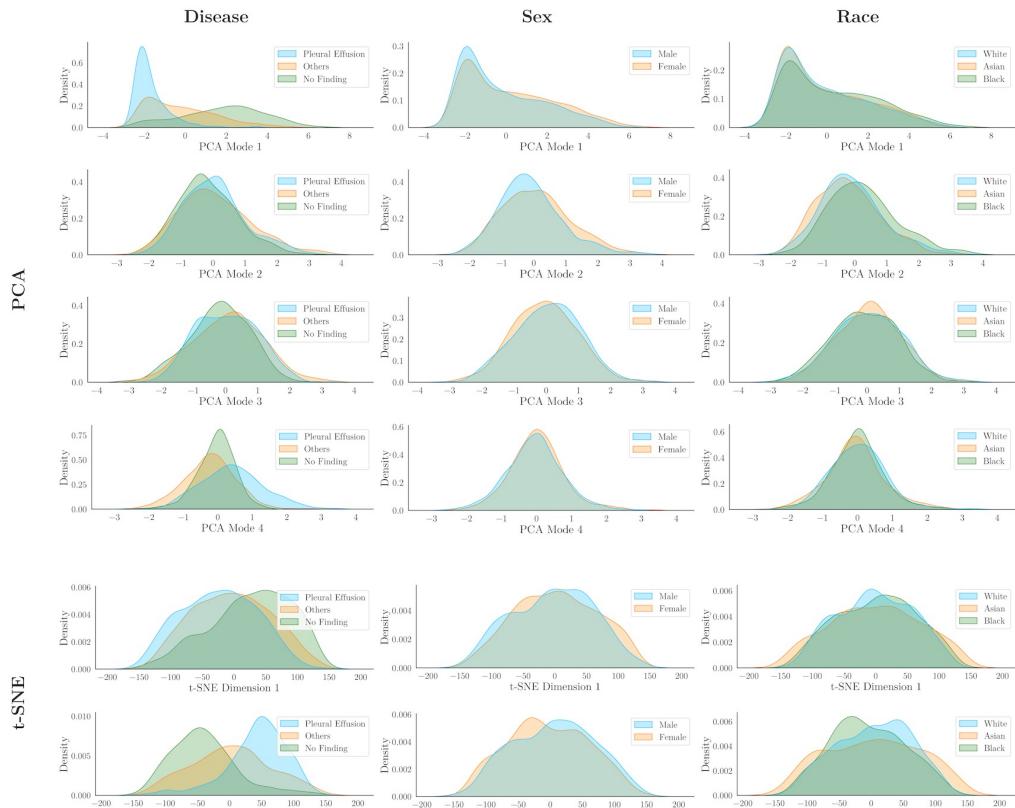
CXR-FMKD-Direct-FFT (MSE)
PCA and t-SNE Marginal Plots | MIMIC

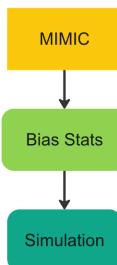


CXR-FMKD-Direct-FFT (CS)
PCA and t-SNE Marginal Plots | MIMIC



CXR-FMKD-Direct-FFT (MSE-CS | 0.9-0.1)
PCA and t-SNE Marginal Plots | MIMIC





Model Shortname (MIMIC)	Statistical Test Applied	Race (Formatted Bias Scores)	Race (Combined Bias Score)	Sex (Formatted Bias Scores)	Sex (Combined Bias Score)	Attributes Average (Formatted Bias Scores)	Attributes Average (Combined Bias Score)
CXR-FM-LP	ks	FALSE : 61.74% TRUE : 24.42% TRUE+ : 13.85%	45.18728818	FALSE : 19.17% TRUE : 10.99% TRUE+ : 69.84%	115.7516234	FALSE : 40.45% TRUE : 17.70% TRUE+ : 41.84%	80.4694558
CXR-Model-FFT	ks	FALSE : 74.74% TRUE : 17.46% TRUE+ : 7.80%	29.16190515	FALSE : 19.13% TRUE : 48.28% TRUE+ : 32.59%	97.1639754	FALSE : 46.93% TRUE : 32.87% TRUE+ : 20.19%	63.16294028
CXR-FMKD-Direct-FFT (MSE)	ks	FALSE : 64.69% TRUE : 18.52% TRUE+ : 16.79%	43.70650114	FALSE : 22.71% TRUE : 42.42% TRUE+ : 34.87%	94.72453432	FALSE : 43.70% TRUE : 30.47% TRUE+ : 25.83%	69.21551773
CXR-FMKD-Direct-FFT (CS)	ks	FALSE : 63.22% TRUE : 20.70% TRUE+ : 16.09%	44.82629753	FALSE : 20.73% TRUE : 12.67% TRUE+ : 66.60%	112.5714074	FALSE : 41.97% TRUE : 16.68% TRUE+ : 41.34%	78.69885245
CXR-FMKD-Direct-FFT (MSE-CS 0.9-0.1)	ks	FALSE : 55.37% TRUE : 22.43% TRUE+ : 22.20%	55.72425435	FALSE : 16.73% TRUE : 19.83% TRUE+ : 63.43%	114.9845132	FALSE : 36.05% TRUE : 21.13% TRUE+ : 42.82%	85.35438377

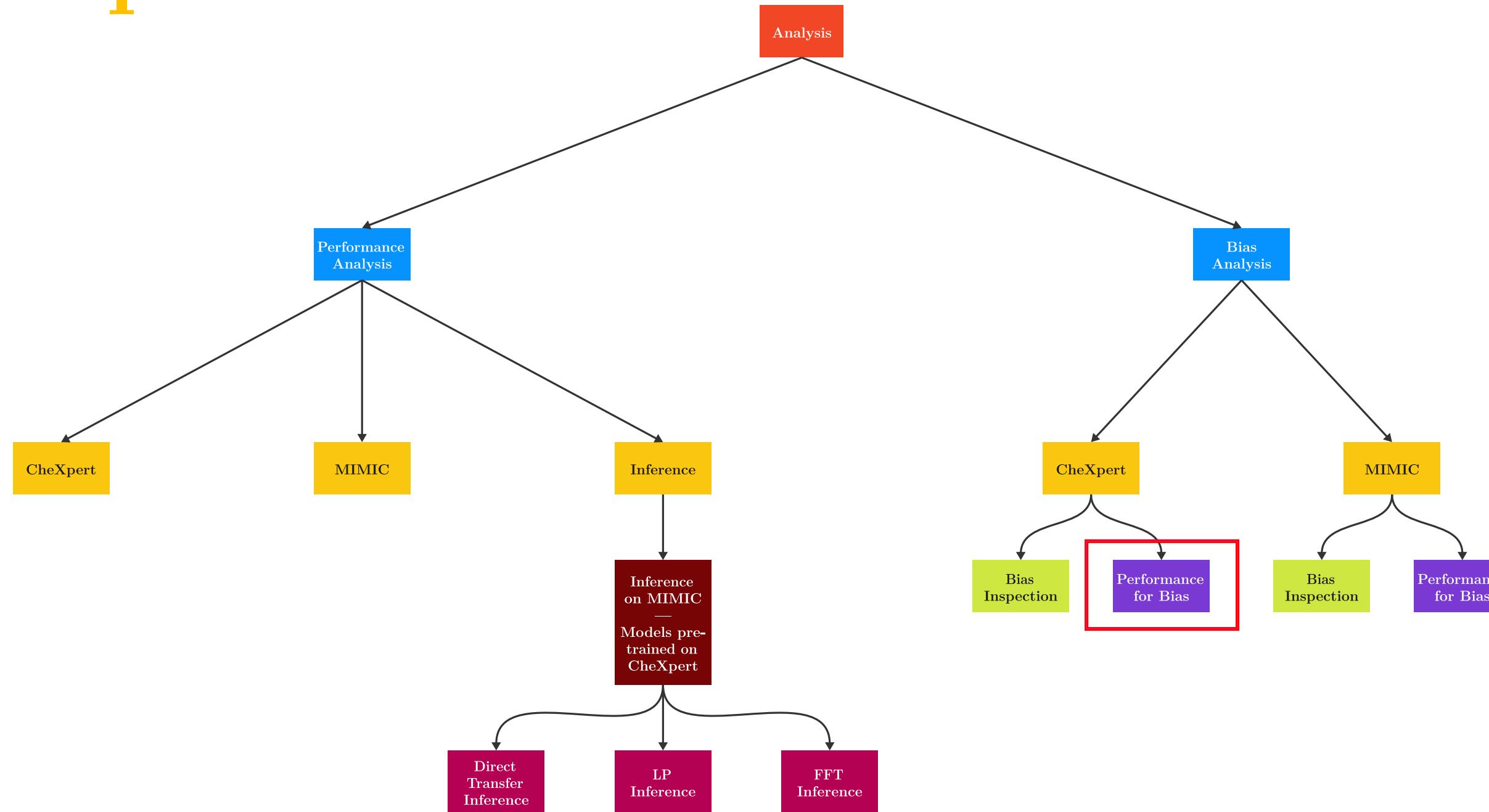
CheXpert

Model Shortname (CheXpert)	Statistical Test Applied	Race (Formatted Bias Scores)	Race (Combined Bias Score)	Sex (Formatted Bias Scores)	Sex (Combined Bias Score)	Attributes Average (Formatted Bias Scores)	Attributes Average (Combined Bias Score)
CXR-FM-LP	ks	FALSE : 46.81% TRUE : 22.44% TRUE+ : 30.75%	68.56391922	FALSE : 0.04% TRUE : 1.41% TRUE+ : 98.55%	149.2369366	FALSE : 23.42% TRUE : 11.93% TRUE+ : 64.65%	108.9004279
CXR-Model-FFT	ks	FALSE : 74.43% TRUE : 7.74% TRUE+ : 17.83%	34.47856891	FALSE : 82.46% TRUE : 12.63% TRUE+ : 4.91%	19.99515537	FALSE : 78.45% TRUE : 10.19% TRUE+ : 11.37%	27.23686214
CXR-FMKD-Direct-FFT (MSE)	ks	FALSE : 80.31% TRUE : 3.57% TRUE+ : 16.13%	27.75791432	FALSE : 94.82% TRUE : 4.95% TRUE+ : 0.23%	5.299769378	FALSE : 87.56% TRUE : 4.26% TRUE+ : 8.18%	16.52884185
CXR-FMKD-Direct-FFT (CS)	ks	FALSE : 65.09% TRUE : 10.86% TRUE+ : 24.05%	46.93630242	FALSE : 61.84% TRUE : 13.07% TRUE+ : 25.09%	50.7002099	FALSE : 63.47% TRUE : 11.97% TRUE+ : 24.57%	48.81825616
CXR-FMKD-Direct-FFT (MSE-CS 0.6-0.4)	ks	FALSE : 75.98% TRUE : 7.40% TRUE+ : 16.61%	32.32277636	FALSE : 75.99% TRUE : 18.45% TRUE+ : 5.56%	26.792117	FALSE : 75.99% TRUE : 12.92% TRUE+ : 11.09%	29.55744668

MIMIC

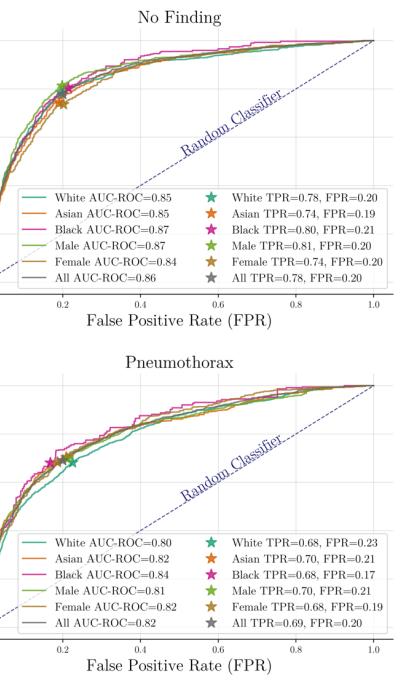
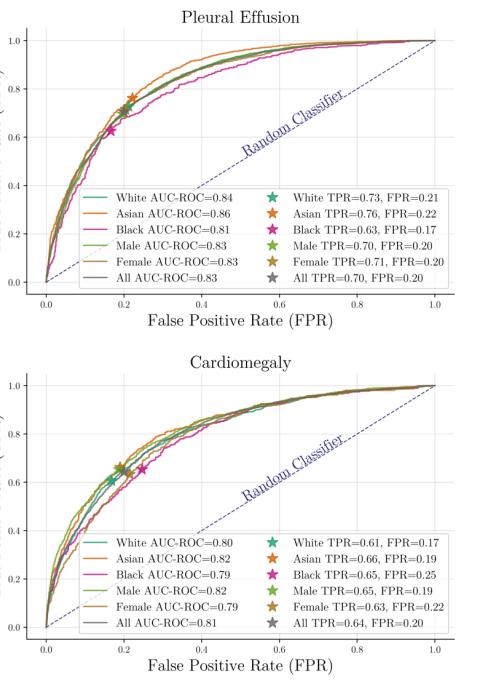
Model Shortname (MIMIC)	Statistical Test Applied	Race (Formatted Bias Scores)	Race (Combined Bias Score)	Sex (Formatted Bias Scores)	Sex (Combined Bias Score)	Attributes Average (Formatted Bias Scores)	Attributes Average (Combined Bias Score)
CXR-FM-LP	ks	FALSE : 61.74% TRUE : 24.42% TRUE+ : 13.85%	45.18728818	FALSE : 19.17% TRUE : 10.99% TRUE+ : 69.84%	115.7516234	FALSE : 40.45% TRUE : 17.70% TRUE+ : 41.84%	80.4694558
CXR-Model-FFT	ks	FALSE : 74.74% TRUE : 17.46% TRUE+ : 7.80%	29.16190515	FALSE : 19.13% TRUE : 48.28% TRUE+ : 32.59%	97.1639754	FALSE : 46.93% TRUE : 32.87% TRUE+ : 20.19%	63.16294028
CXR-FMKD-Direct-FFT (MSE)	ks	FALSE : 64.69% TRUE : 18.52% TRUE+ : 16.79%	43.70650114	FALSE : 22.71% TRUE : 42.42% TRUE+ : 34.87%	94.72453432	FALSE : 43.70% TRUE : 30.47% TRUE+ : 25.83%	69.21551773
CXR-FMKD-Direct-FFT (CS)	ks	FALSE : 63.22% TRUE : 20.70% TRUE+ : 16.09%	44.82629753	FALSE : 20.73% TRUE : 12.67% TRUE+ : 66.60%	112.5714074	FALSE : 41.97% TRUE : 16.68% TRUE+ : 41.34%	78.69885245
CXR-FMKD-Direct-FFT (MSE-CS 0.9-0.1)	ks	FALSE : 55.37% TRUE : 22.43% TRUE+ : 22.20%	55.72425435	FALSE : 16.73% TRUE : 19.83% TRUE+ : 63.43%	114.9845132	FALSE : 36.05% TRUE : 21.13% TRUE+ : 42.82%	85.35438377

CheXpert

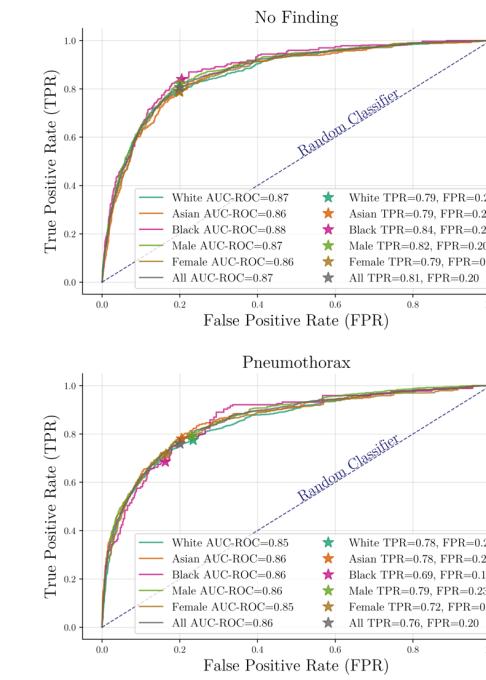
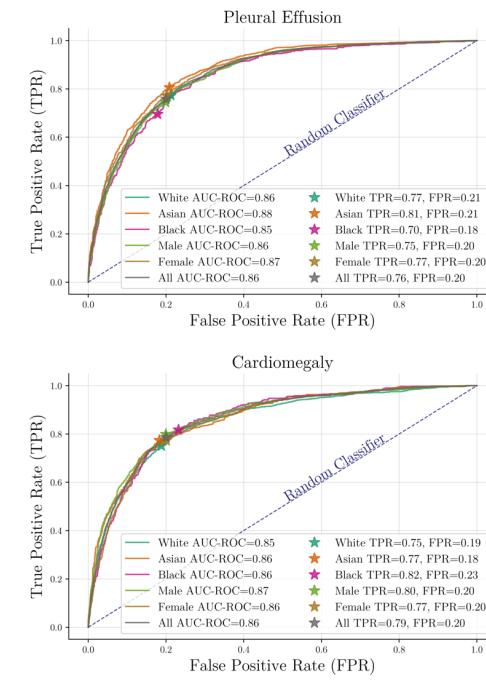


ROC Curves

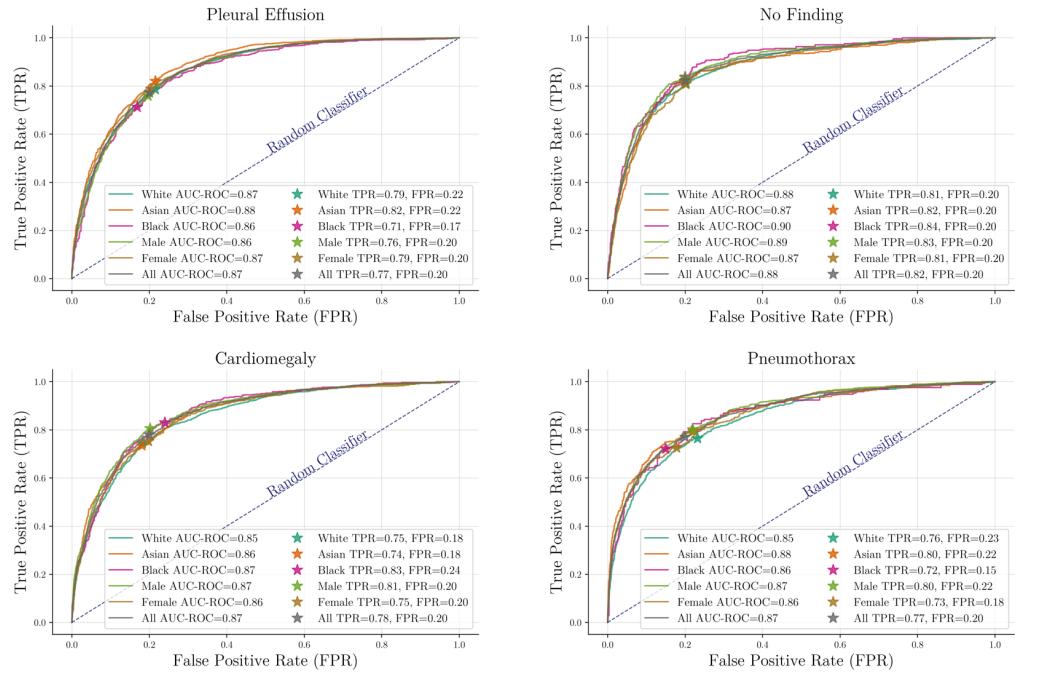
CXR-FM-LP
ROC Curve | CheXpert



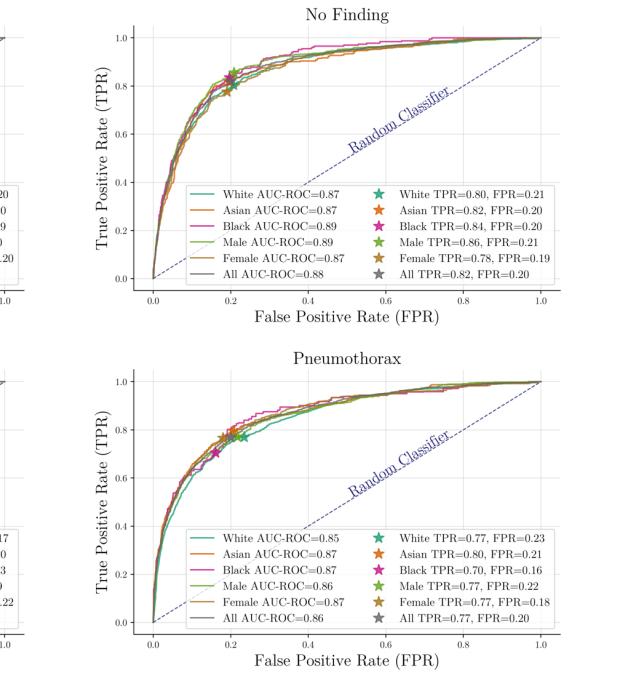
CXR-Model-FFT
ROC Curve | CheXpert



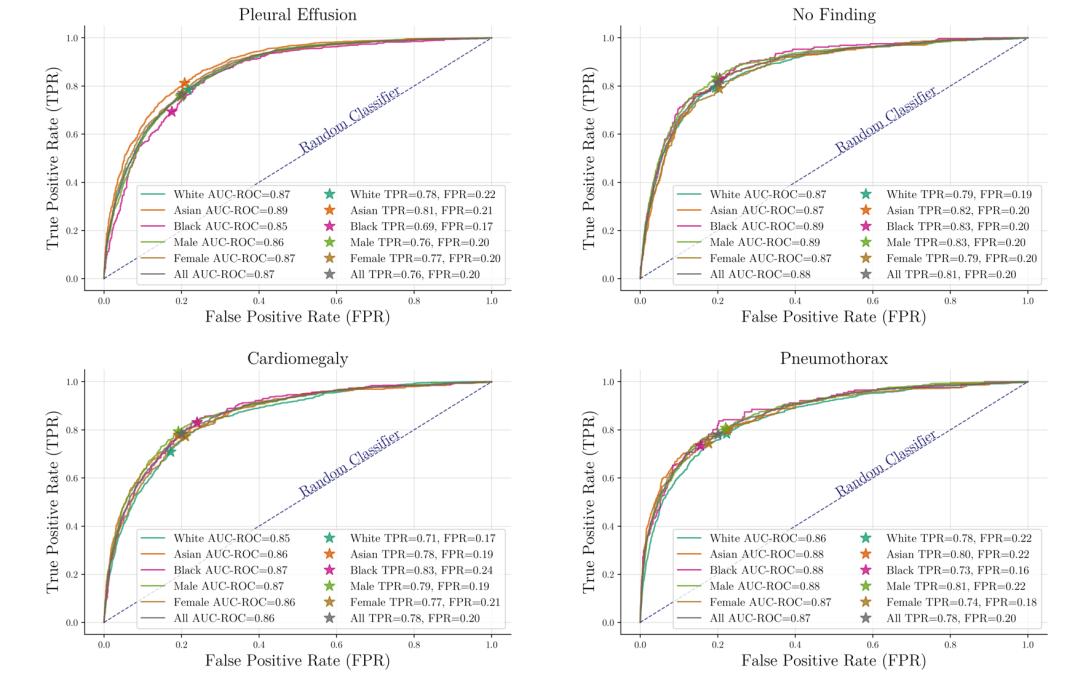
CXR-FMKD-Direct-FFT (MSE)
ROC Curve | CheXpert



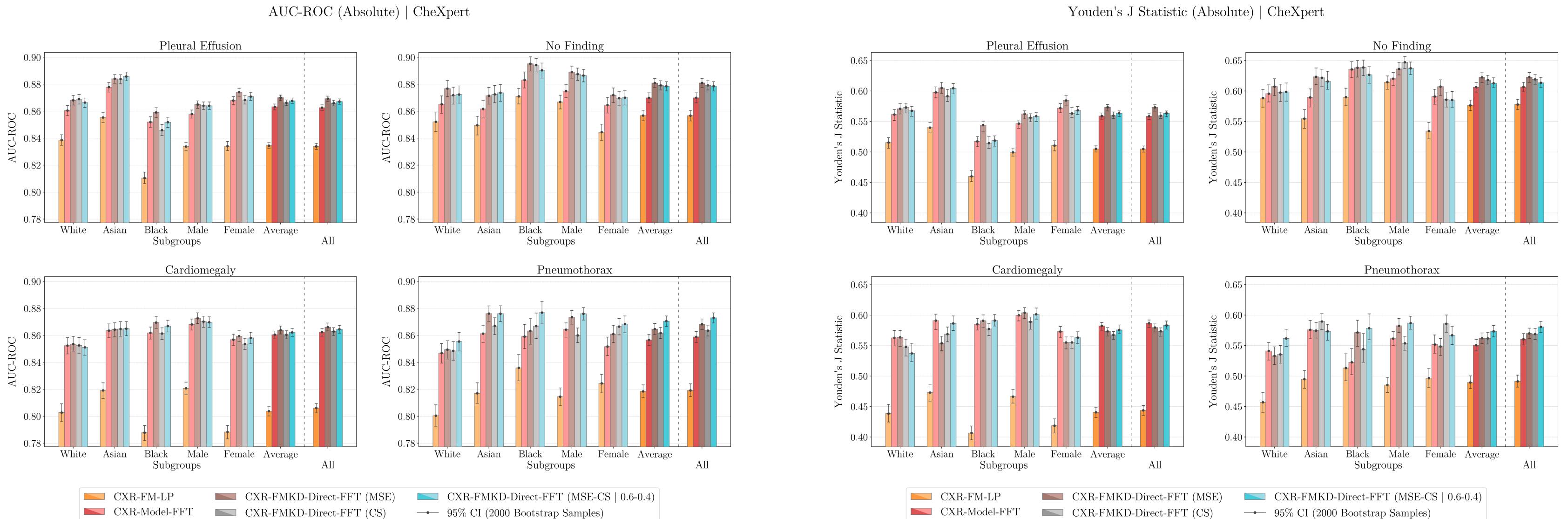
CXR-FMKD-Direct-FFT (CS)
ROC Curve | CheXpert



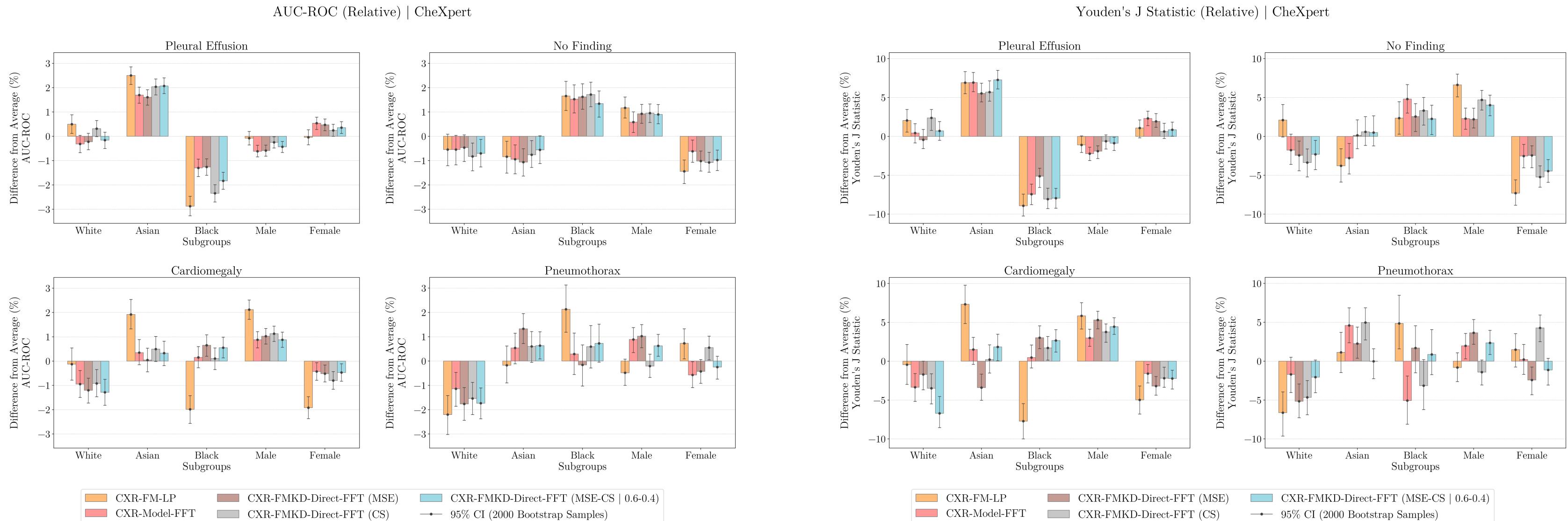
CXR-FMKD-Direct-FFT (MSE-CS | 0.6-0.4)
ROC Curve | CheXpert



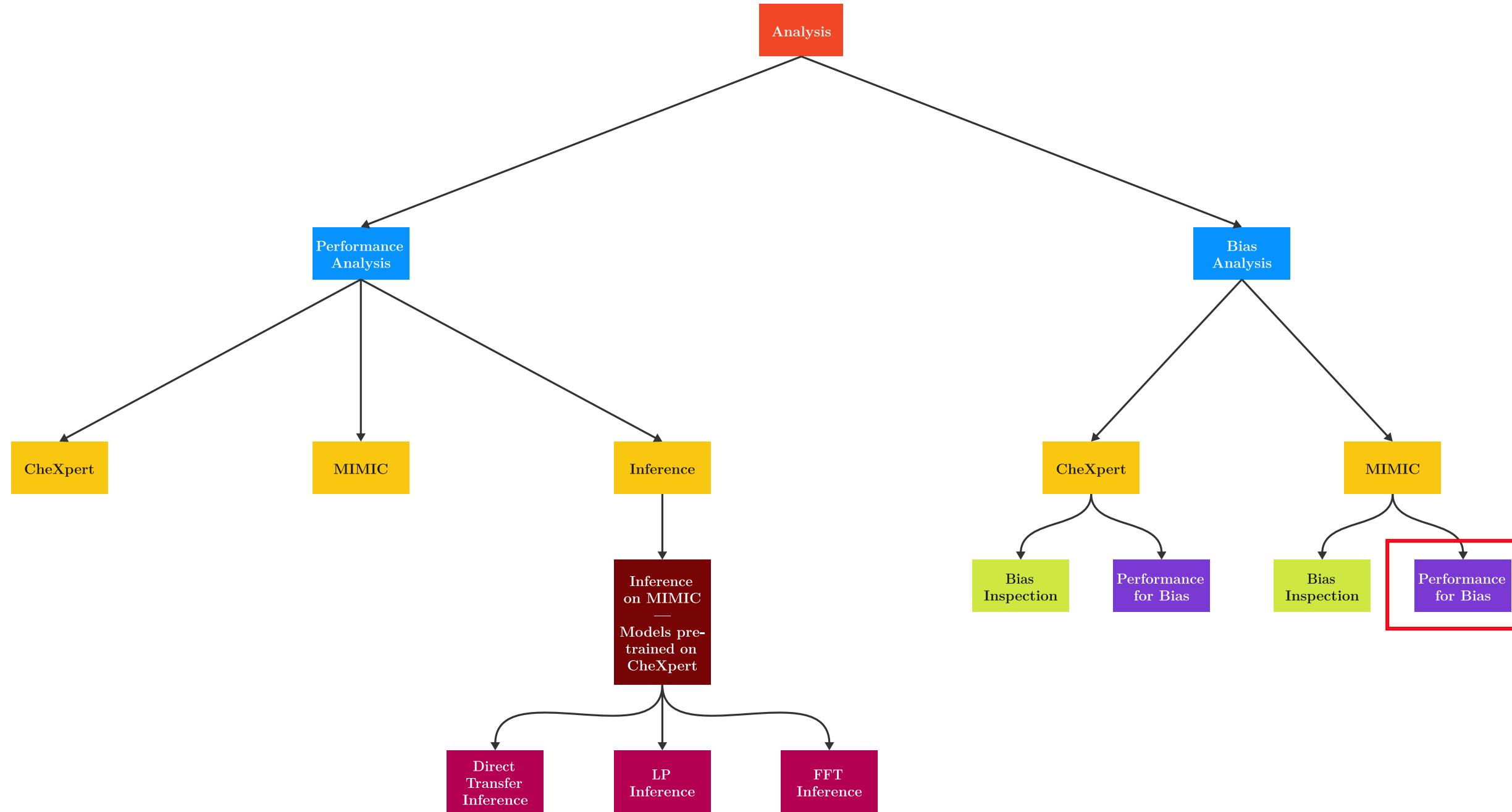
Absolute Performance



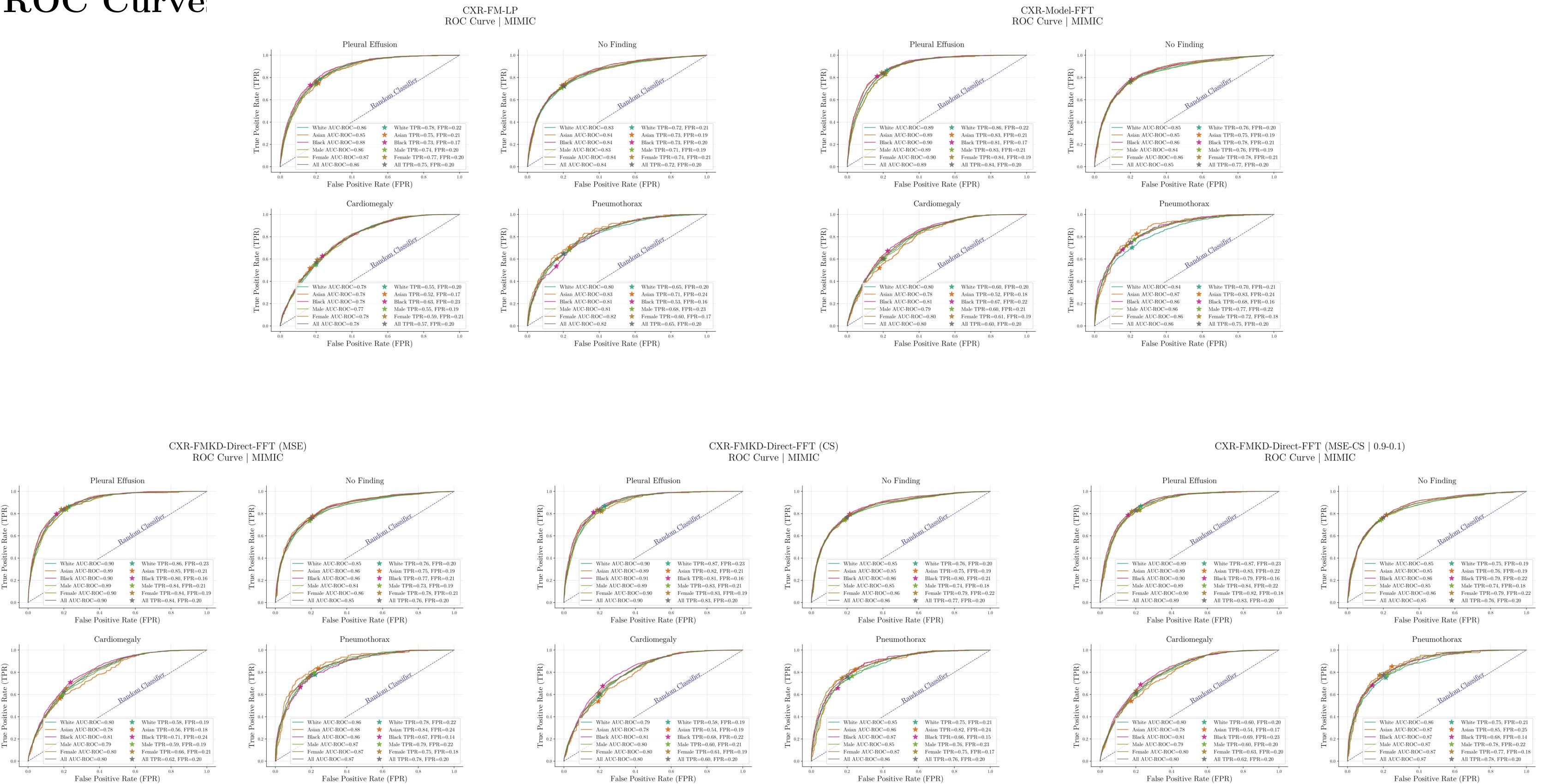
Relative Performance



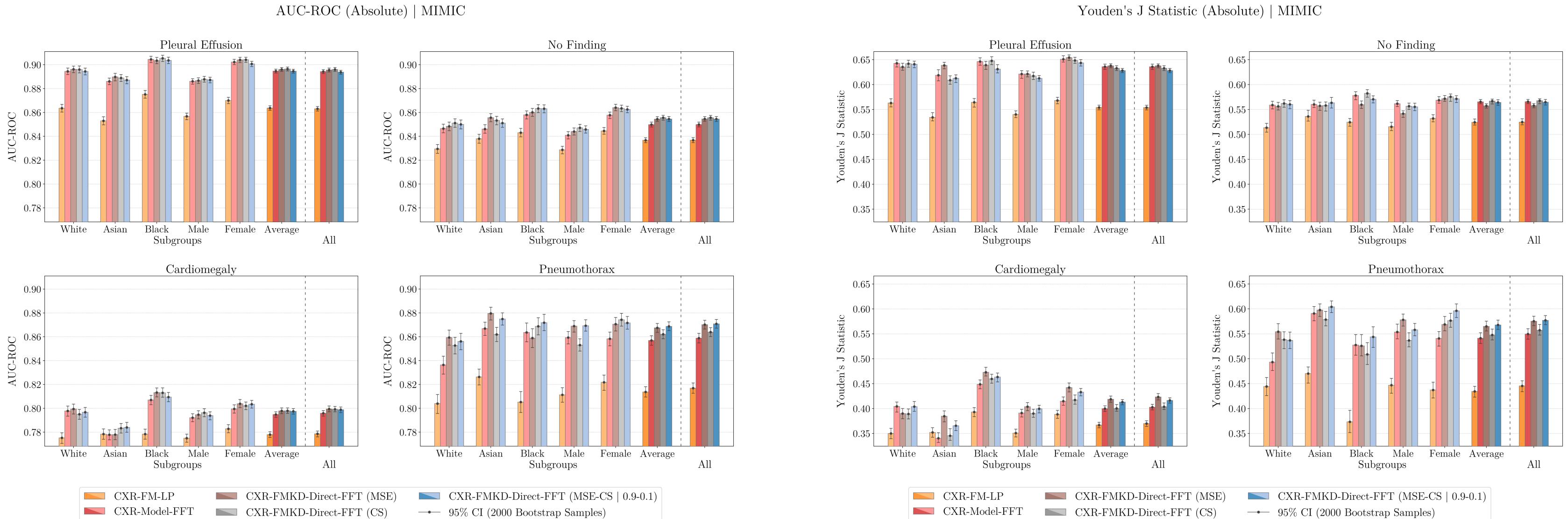
MIMIC



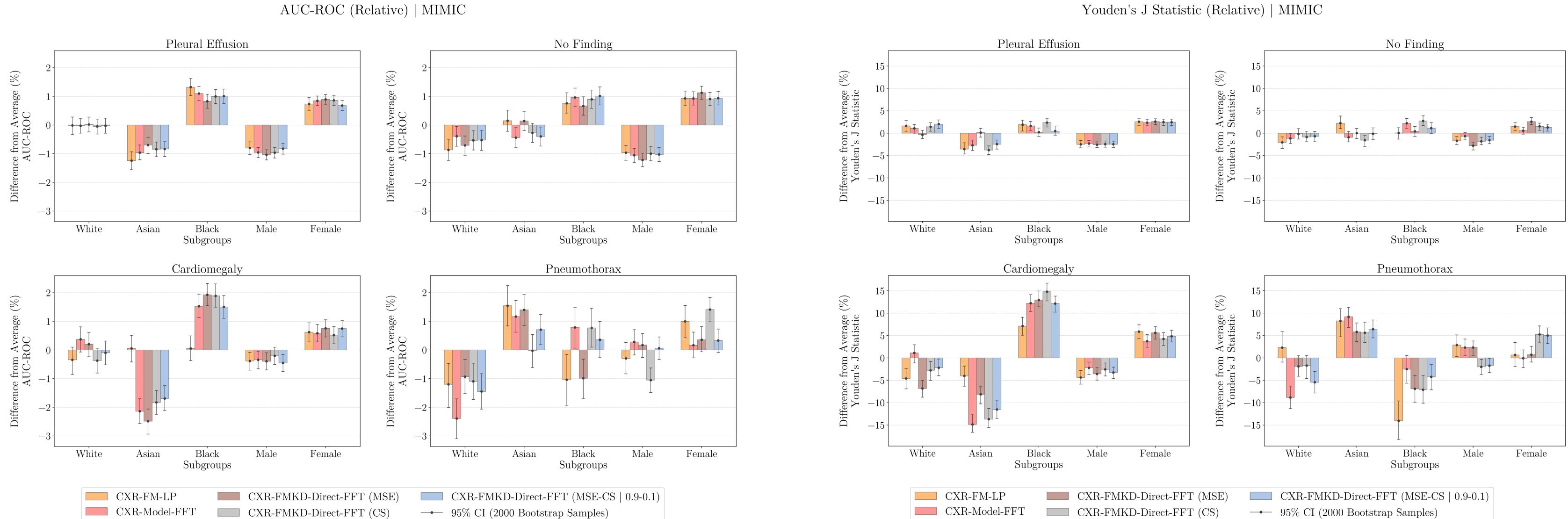
ROC Curve



Absolute Performance



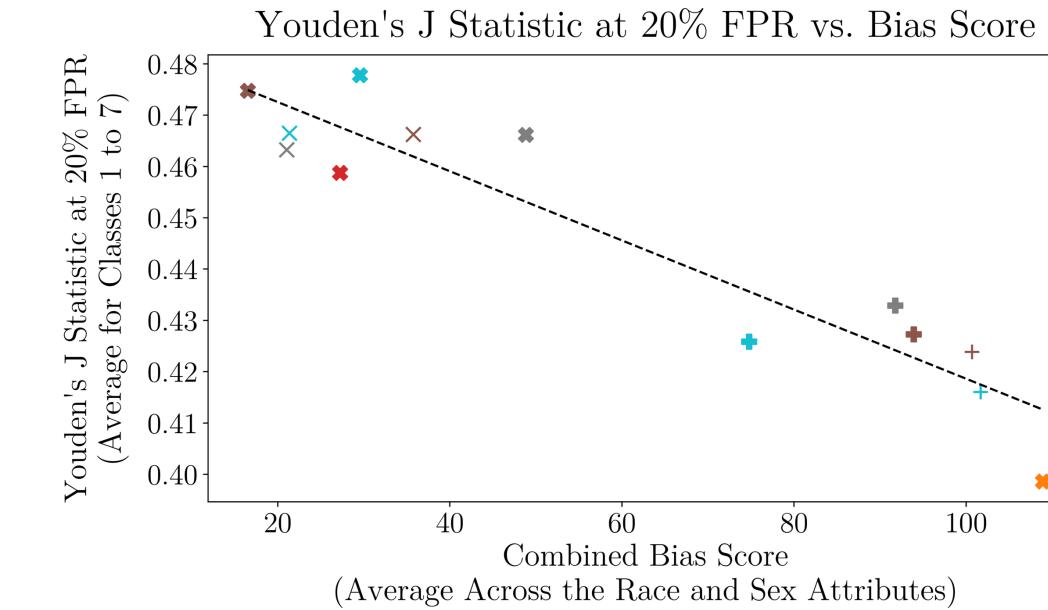
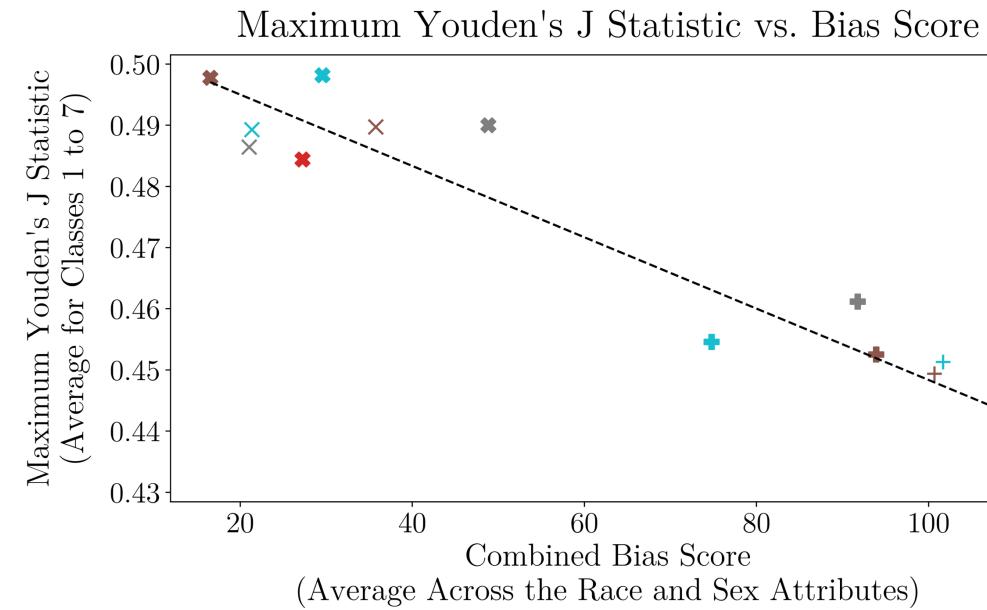
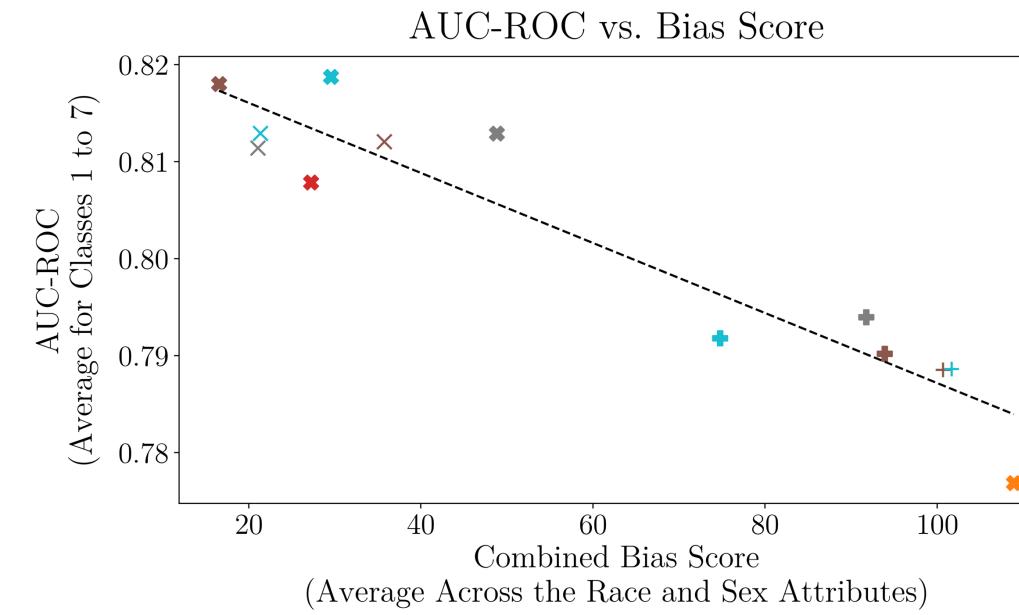
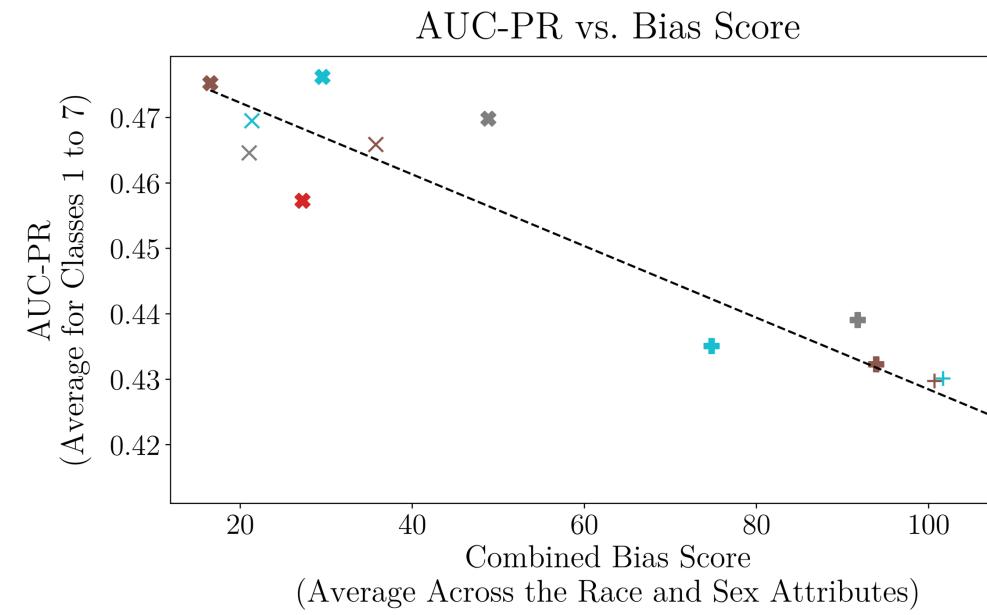
Relative Performance



PERFORMANCE VS. BIAS

CheXpert

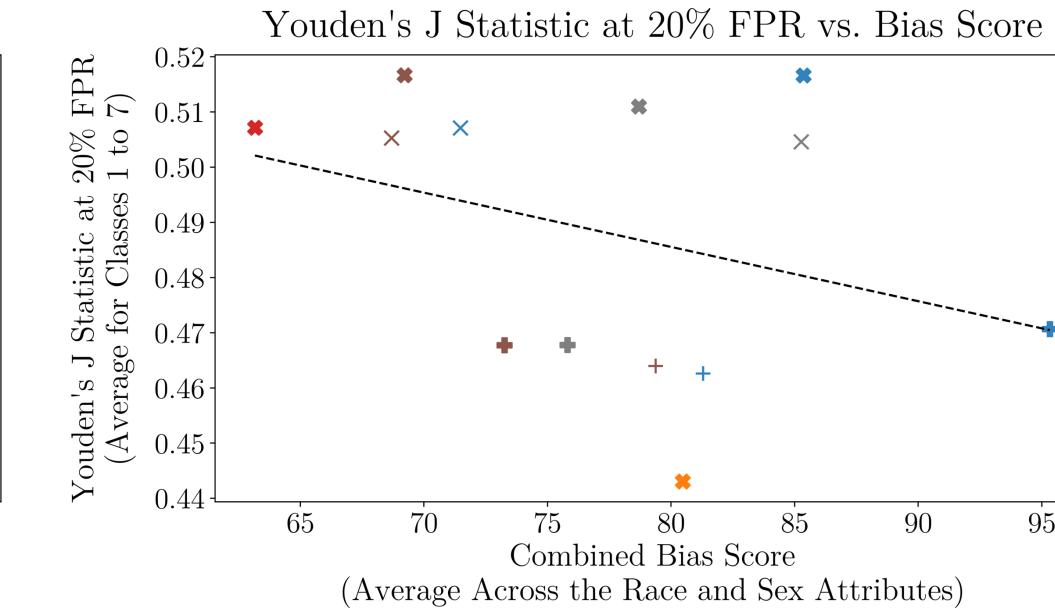
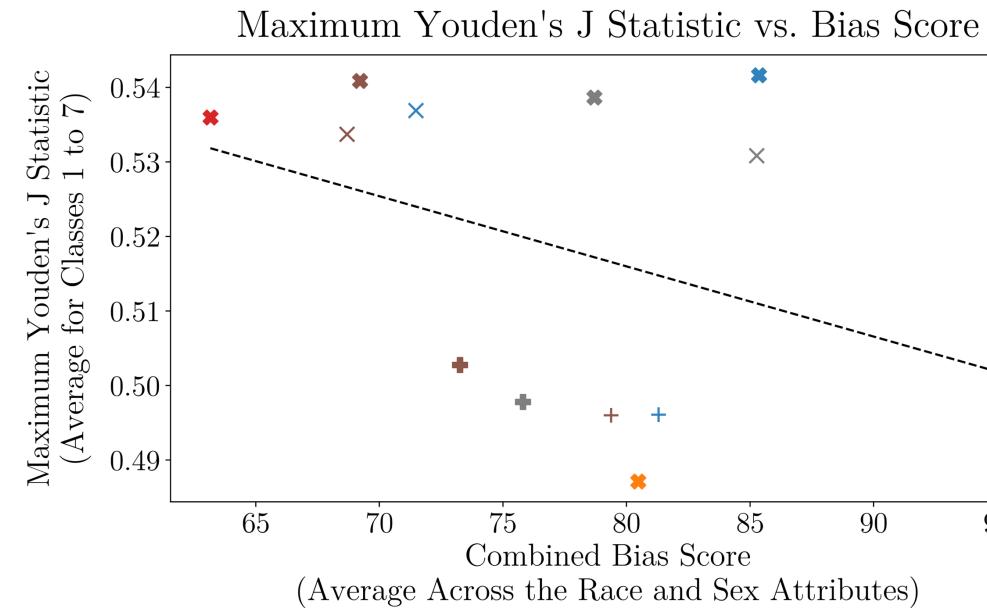
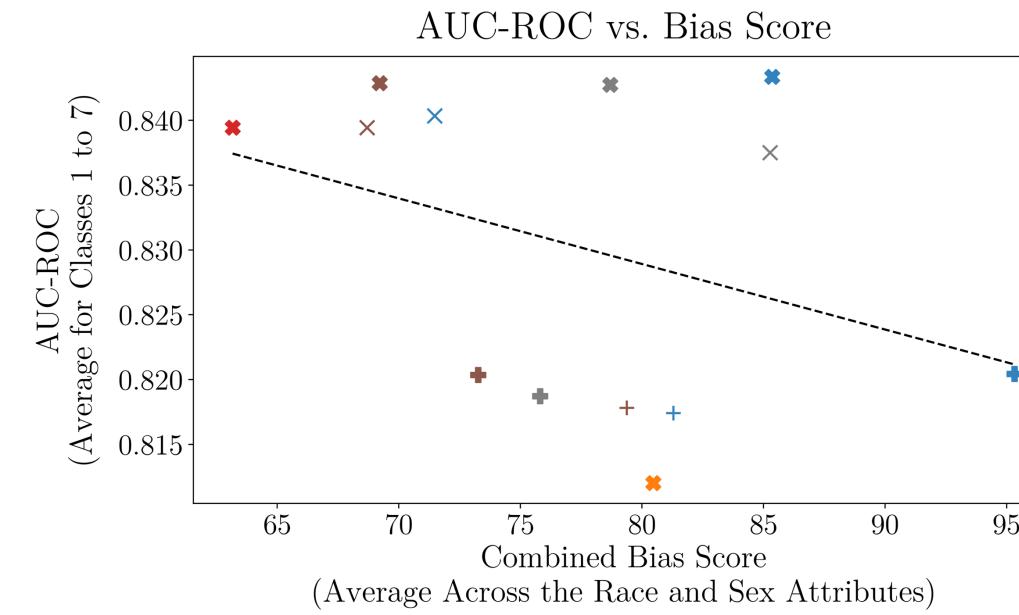
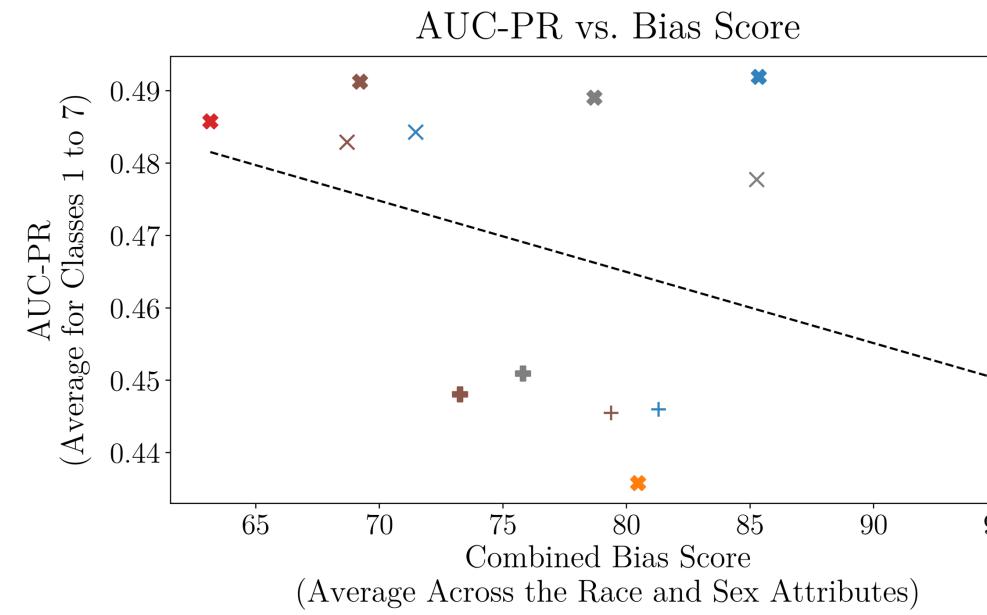
Performance vs. Bias Plots | CheXpert



- 1. CXR-FM-LP
- 2. CXR-Model-FFT
- 3. CXR-FMKD-LP (MSE)
- 4. CXR-FMKD-FFT (MSE)
- 5. CXR-FMKD-Direct-LP (MSE)
- 6. CXR-FMKD-Direct-FFT (MSE)
- 7. CXR-FMKD-FFT (CS)
- 8. CXR-FMKD-Direct-LP (CS)
- 9. CXR-FMKD-Direct-FFT (CS)
- 10. CXR-FMKD-LP (MSE-CS | 0.6-0.4)
- 11. CXR-FMKD-FFT (MSE-CS | 0.6-0.4)
- 12. CXR-FMKD-Direct-LP (MSE-CS | 0.6-0.4)
- 13. CXR-FMKD-Direct-FFT (MSE-CS | 0.6-0.4)
- 14. Line of Best Fit

MIMIC

Performance vs. Bias Plots | MIMIC



- | | | |
|-----------------------------|------------------------------------|--|
| 1. CXR-FM-LP | 6. CXR-FMKD-Direct-FFT (MSE) | 11. CXR-FMKD-FFT (MSE-CS 0.9-0.1) |
| 2. CXR-Model-FFT | 7. CXR-FMKD-FFT (CS) | 12. CXR-FMKD-Direct-LP (MSE-CS 0.9-0.1) |
| 3. CXR-FMKD-LP (MSE) | 8. CXR-FMKD-Direct-LP (CS) | 13. CXR-FMKD-Direct-FFT (MSE-CS 0.9-0.1) |
| 4. CXR-FMKD-FFT (MSE) | 9. CXR-FMKD-Direct-FFT (CS) | 14. Line of Best Fit |
| 5. CXR-FMKD-Direct-LP (MSE) | 10. CXR-FMKD-LP (MSE-CS 0.9-0.1) | |

END