A Novel Multiresolution-Statistical Texture Analysis Architecture: Radiomics-Aided Diagnosis of PDAC Based on Plain CT Images

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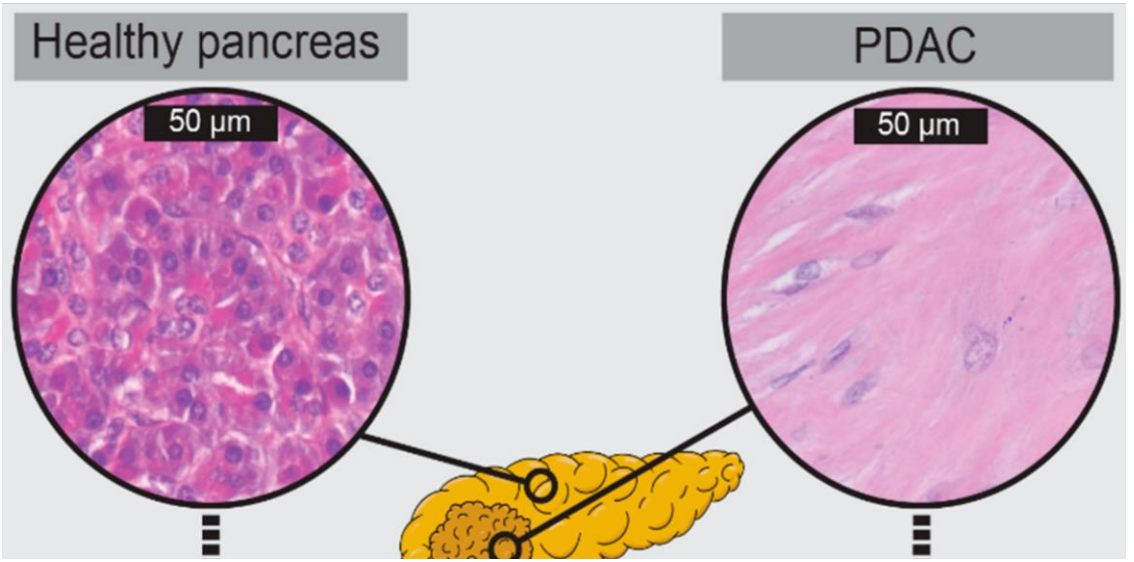
Outline

- Introduction to the problem
- Methodology
- Results
- Implementation details and results

INTRODUCTION

Problem Statement

- PDAC – Pancreatic ductal adenocarcinoma – Type of tumor
- CT imaging is a frequently used non-invasive examination method for PDAC
  - Plain CT
  - Contrast enhanced CT
- Limitations:
  - Subjective judgement
  - No access contrast enhancement
  - Allergic reactions or renal toxicity caused by contrast agent



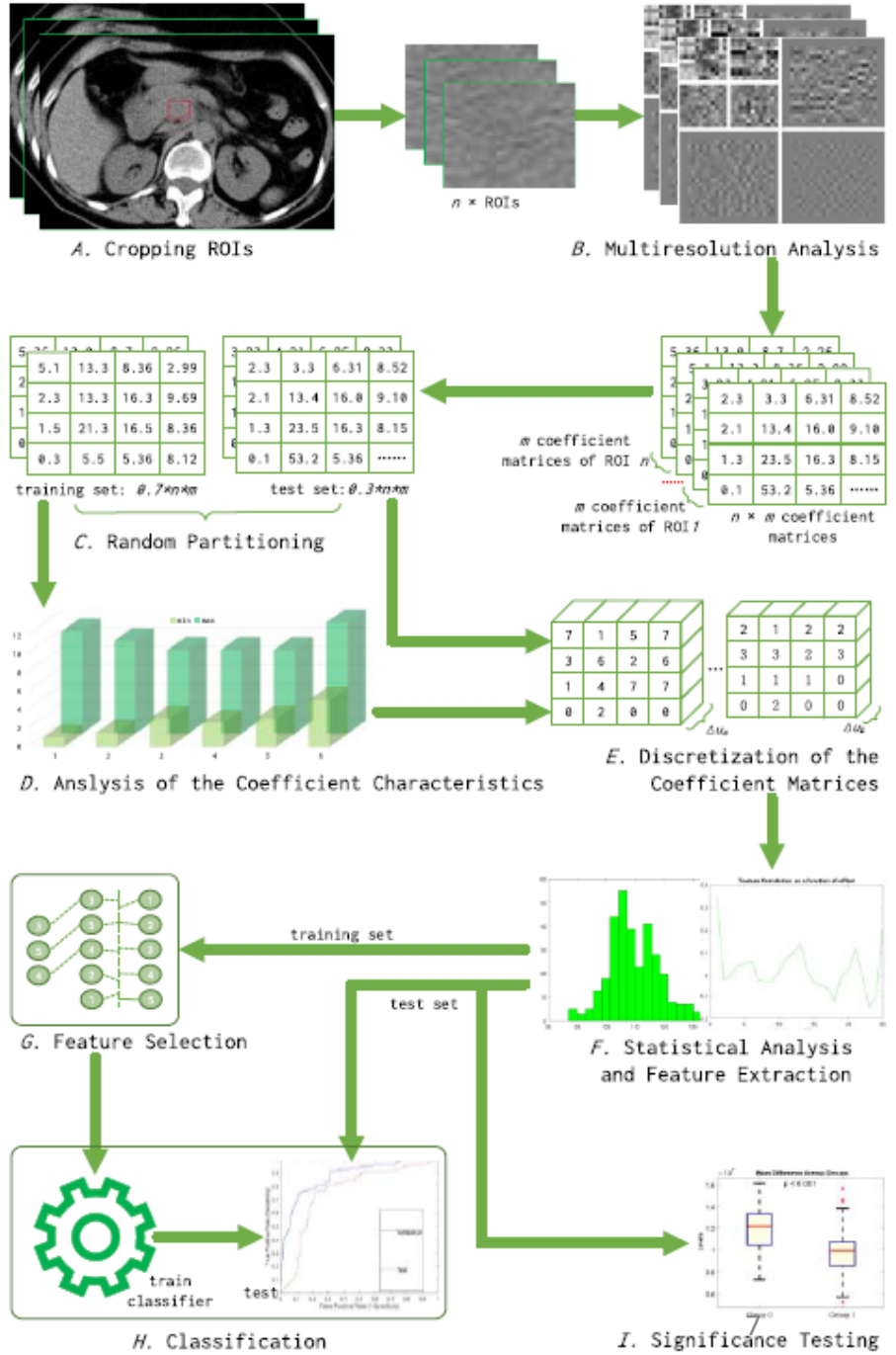
Related Works

- Quantitative features of radiomics, such as texture can provide interpretability
- Radiomics + AI plays important role in early diagnosis of PDAC based on plain CT
- Radiomics features used in previous works
    - LoG (Laplacian of Gaussian) + Histogram features
    - GLCM (Gray-level co-occurrence matrix)
    - GLCM + GLRLM (Gray-level run-length matrix) + ACM (Angle co-occurrence matrix)
    - Histogram features + GLCM + Wavelet transform features

METHODOLOGY

Overview

- ✓Cropping ROIs
- ✓Multiresolution Analysis :
  - ✓Wavelet transform
  - ✓Wavelet packet transform
  - ✓Contourlet transform
- ✓Random Partitioning
- ✓Analysis of Coefficient Characteristics
- ✓Discretization of the coefficient matrices
- ✓Statistical Analysis and Feature extraction
- ✓Feature selection
- ✓Classification and Significance testing



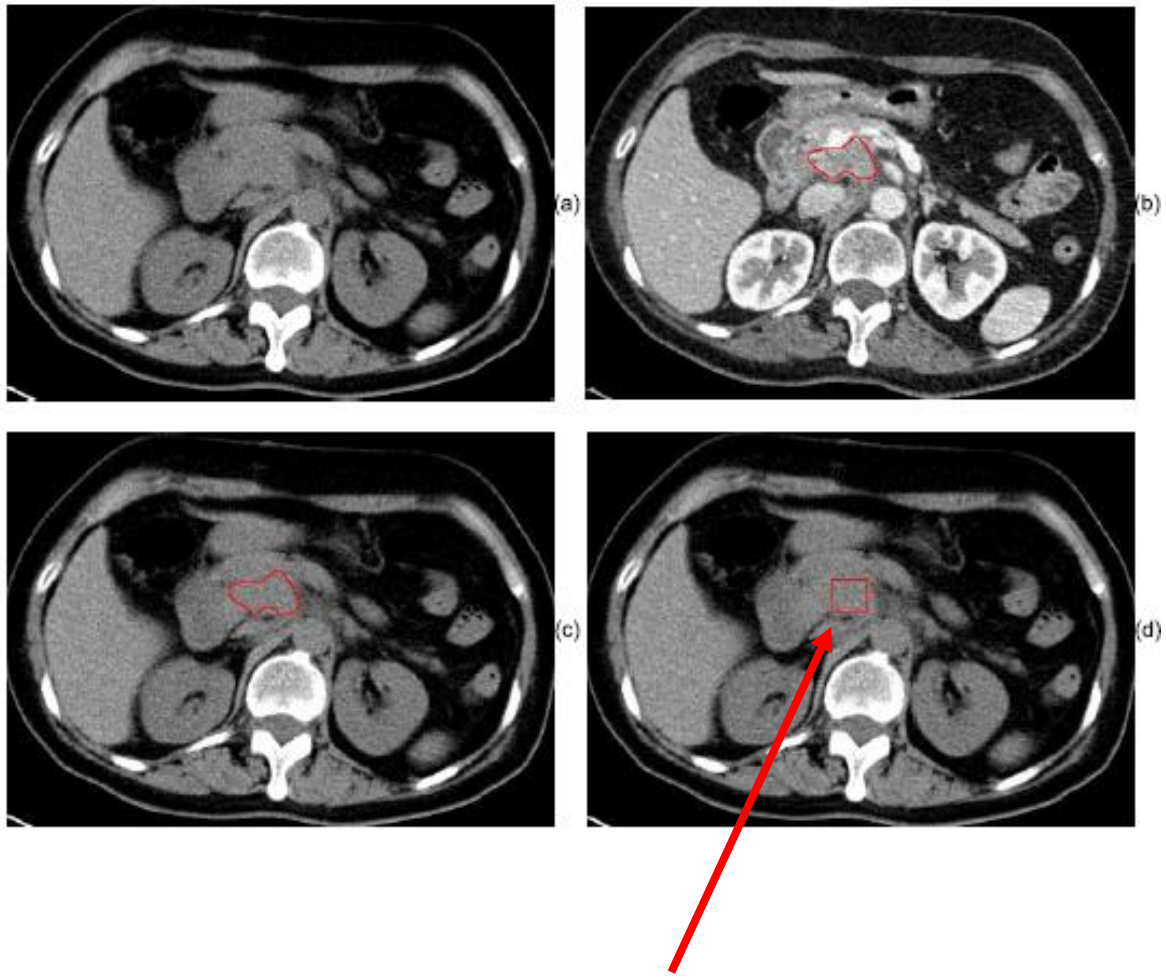
Dataset

- Subjects
  - 153 PDAC
    - 92 male; 61 female
    - Age : 30-84 (59.1y)
  - 159 HP
    - 104 male; 55 female
    - Age : 40 – 57 (45.9y)
- Random partition
  - Train set : Test set = 7:3

- Dataset
  - Plain CT slices (2 or 5mm thickness)
  - Window level : 40-50 HU
  - Window width : 300-350 HU
  - Enhanced CT slices may used as reference

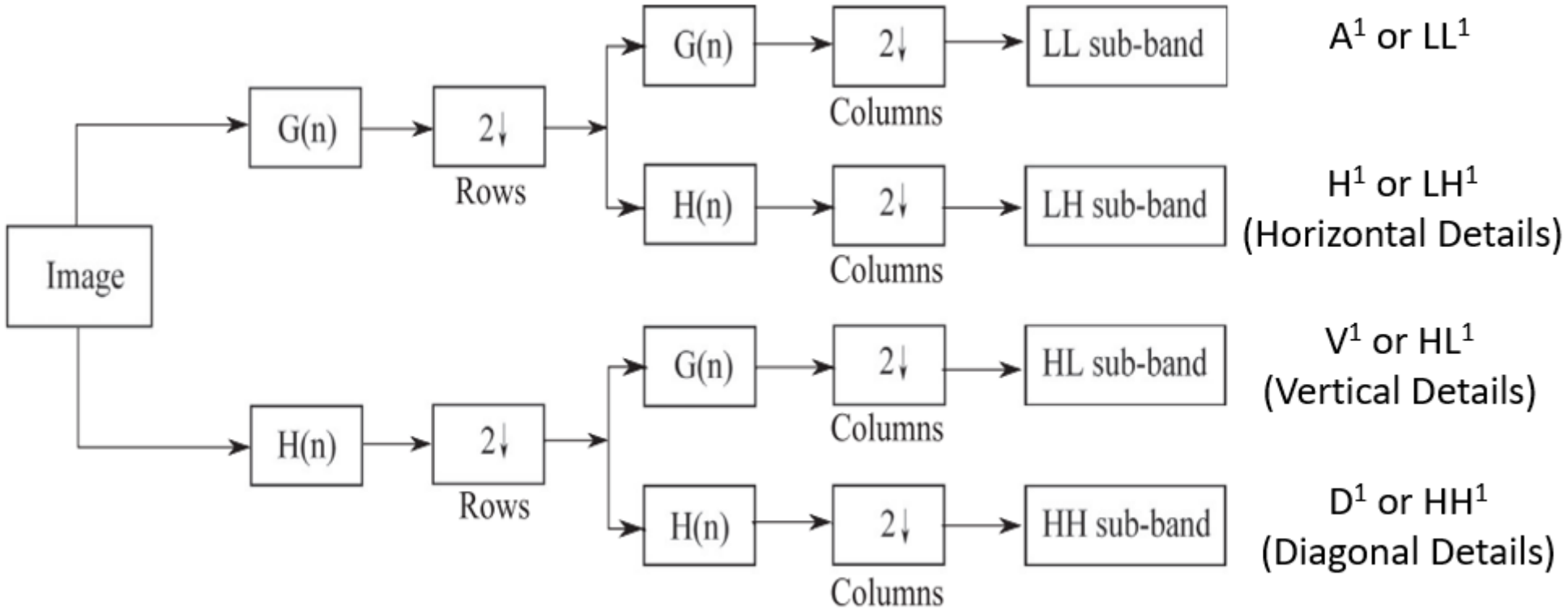
Cropping ROIs

- Cropping strategy
  - PDAC – Slice with largest cross-sectional area of tumor
  - HP – Slice with largest cross-sectional area of HP.
- Annotation
  - By 3 senior radiologists (>6y experience)



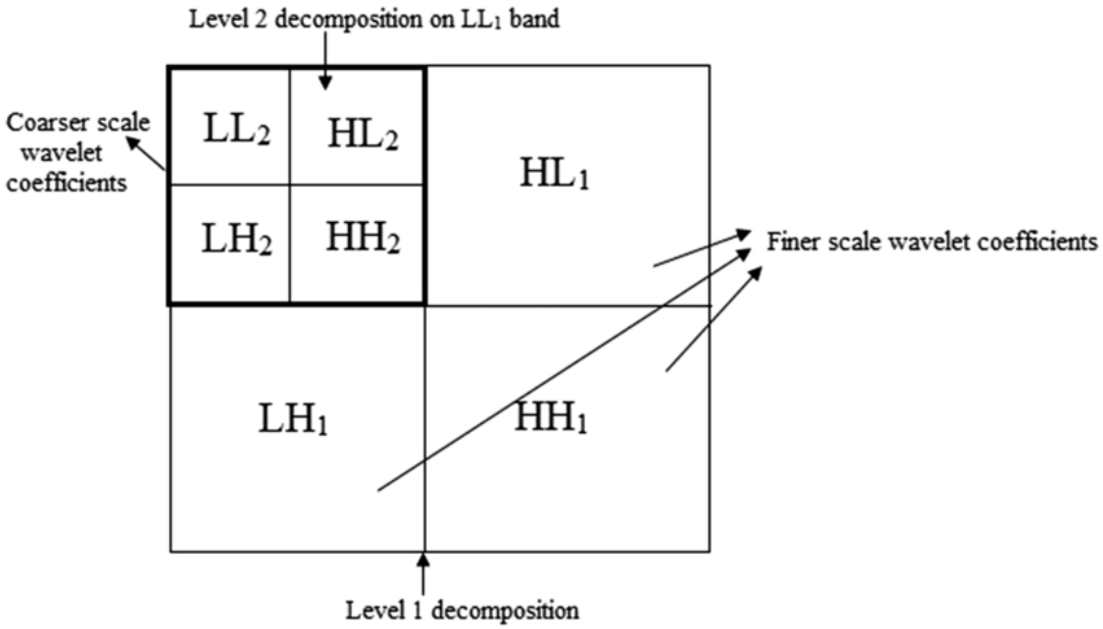
Multiresolution Analysis

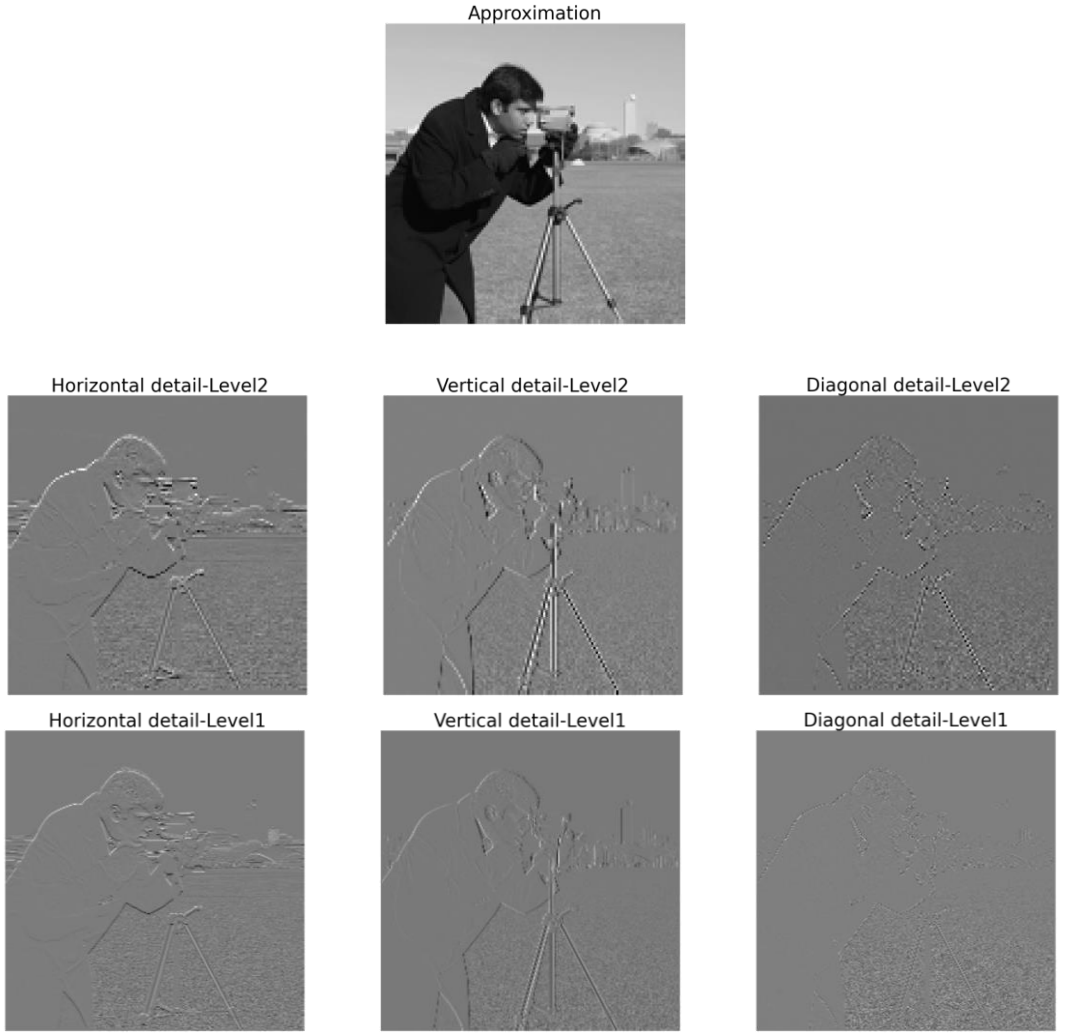
Decompose an ROI into multiple sub-band components.



Multiresolution Analysis

- Wavelet Name : db3
- 2 level decomposition





Analysis of Coefficient Characteristics

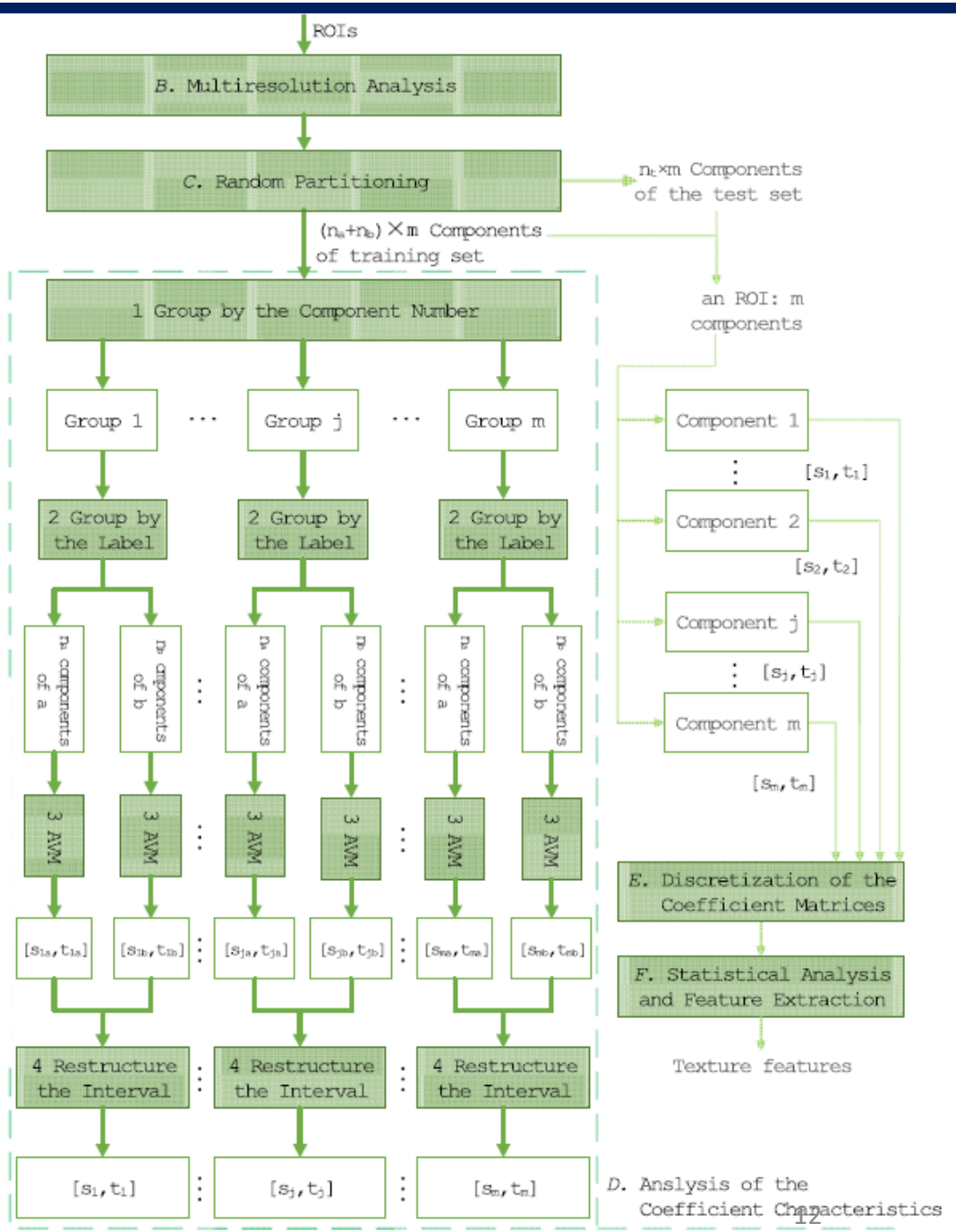
- Group by component number
- Group by label
- Find averages of min and max
- Structure the interval

$$x_{ji} = \min\left(C_{ji} = \begin{bmatrix} c_{11} & \cdots & c_{1l} \\ c_{21} & \ddots & \vdots \\ \cdots & \cdots & c_{kl} \end{bmatrix}\right) \qquad s_{ja} = \frac{\sum_{i=1}^{n_a} x_{ji}}{n_a}, \quad s_{jb} = \frac{\sum_{i=1}^{n_b} x_{ji}}{n_b}$$

$$y_{ji} = \max\left(C_{ji} = \begin{bmatrix} c_{11} & \cdots & c_{1l} \\ c_{21} & \ddots & \vdots \\ \cdots & \cdots & c_{kl} \end{bmatrix}\right) \qquad t_{ja} = \frac{\sum_{i=1}^{n_a} y_{ji}}{n_a}, \quad t_{jb} = \frac{\sum_{i=1}^{n_b} y_{ji}}{n_b}$$

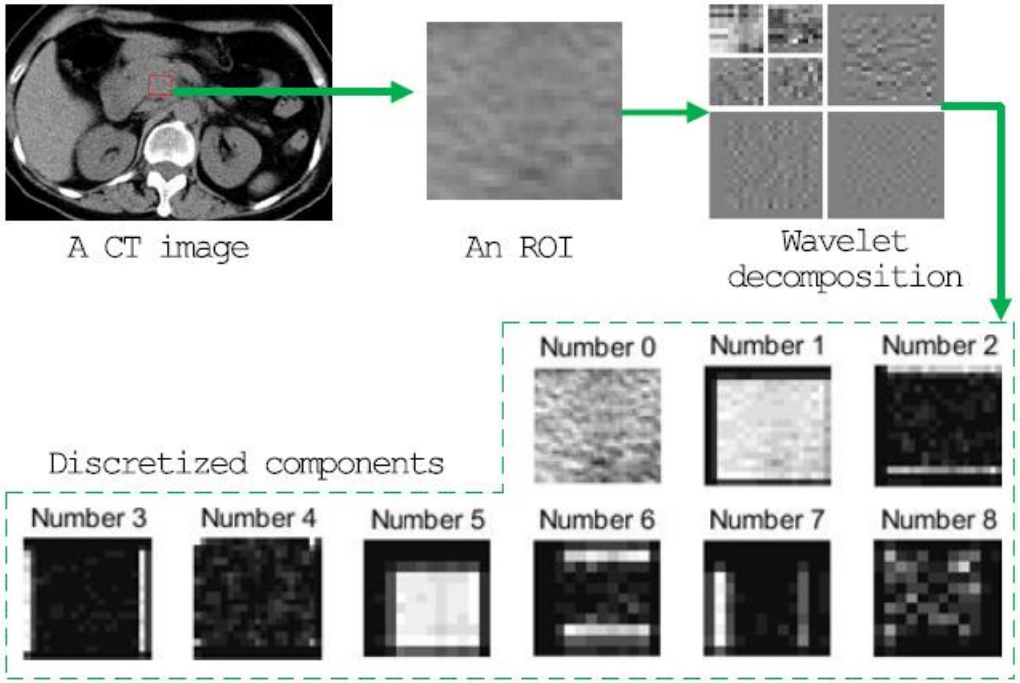
$$s_j = \min\left(s_{ja}, s_{jb}\right)$$

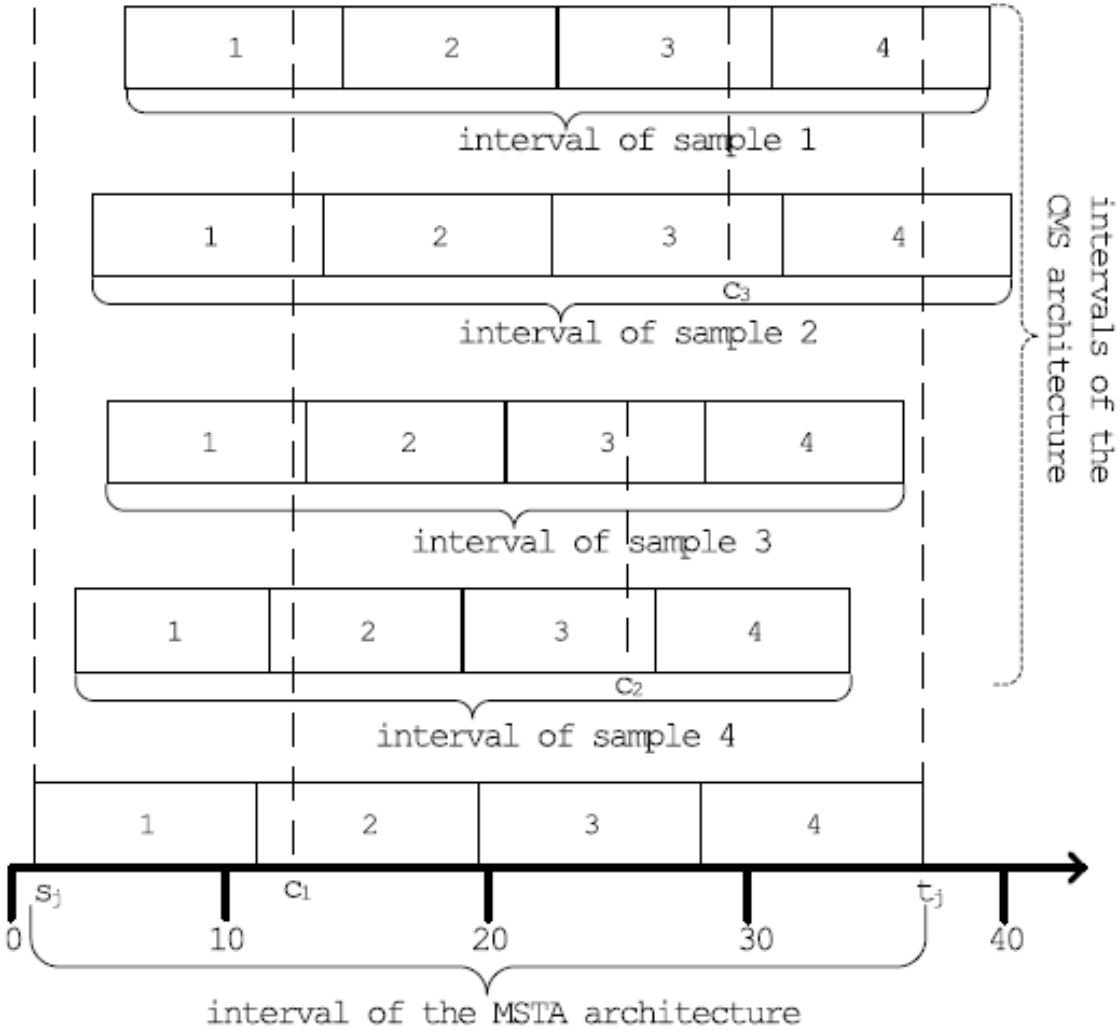
$$t_j = \max\left(t_{ja}, t_{jb}\right)$$



Discretization of the coefficient matrices

- Number of bins = 8/16/24





Statistical Analysis and Feature extraction

Coefficient statistics (3)	Histograms (7)	Gray-level cooccurrence matrix (5)	Gray level run-length matrix (11)
Mean	Mean	Contrast	Short-run emphasis
Variance	Standard deviation	Correlation	Long-run emphasis
Average Energy	Smoothness	Energy	Gray-level non-uniformity
	Cubic moment	Homogeneity	Run-length non-uniformity
	Uniformity	Entropy	Run percentage
	Entropy		Low gray-level run emphasis
	Fourth moment		High gray-level run emphasis
			Short run low gray-level emphasis
			Short run high gray-level emphasis
			Long run low gray-level emphasis
			Long run high gray-level emphasis

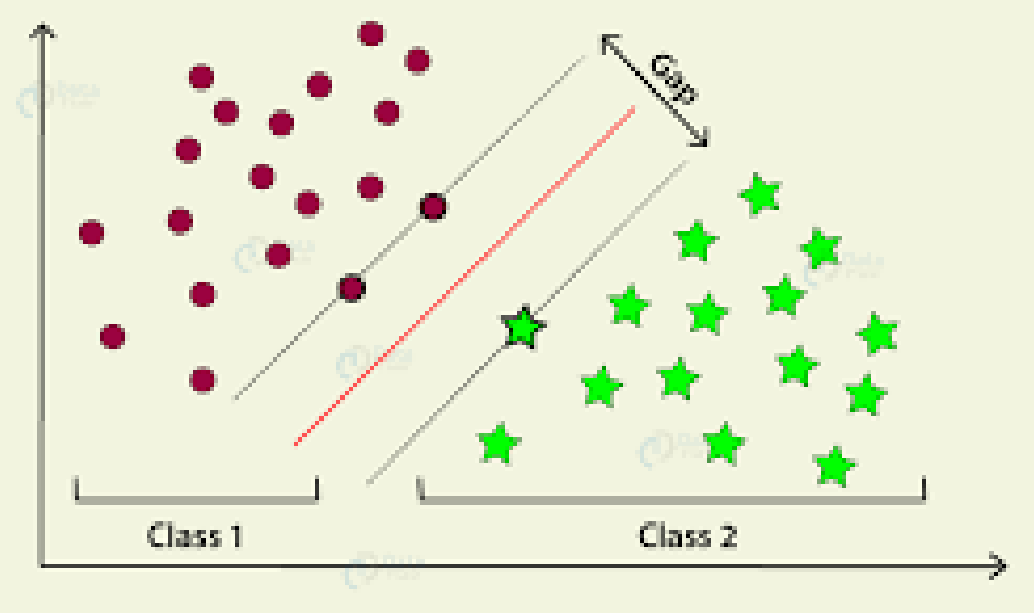
https://github.com/giakou4/pyfeats/blob/main/Features.pdf

Feature selection

- ILFS (Infinite Latent Feature Selection) algorithm proposed by G.Roffo et al.
- Ranking of all the features based on trainset and selected the first k features.
  - K < 20 (empirically limited)

Classification and Significance testing

- Experimented with multiple ML methods and selected SVM (with linear kernel).
  - Small sample size
  - Widely used in radiomics studies
  - Interpretability
  - Generalization
- 10-fold cross validation
- Mann-Whitney U tests
  - Non-parametric test



Experimental Setup

- Evaluation metrics:
  - Accuracy
  - ROC curve – Receiver operating characteristics curve
  - AUC – area under curve
  - Sensitivity
  - Specificity

RESULTS

Classification - Results

- On validation set – 10 cross validation

TABLE III

VALIDATION RESULTS OF THE CLASSIFICATIONS (AVERAGE PERFORMANCE): ACC (%), ACCURACY; SEN (%), SENSITIVITY; SPE (%), SPECIFICITY

No.	Method	ACC	SEN	SPE	AUC	No.	Method	ACC	SEN	SPE	AUC
1	GLS	73.85±12.79	79.44±12.79	68.47±19.88	0.809±0.094	6	ACM	68.35±9.34	59.81±17.8	76.58±12.7	0.692±0.094
2	GLH	74.31±8.56	67.29±15.32	81.08±13.4	0.814±0.100	7	LOG	78.44±8.49	73.83±13.24	82.88±11.76	0.841±0.084
3	GLCM	67.43±6.59	57.94±13.55	76.58±7.80	0.719±0.105	8	WT	75.23±9.94	77.57±8.01	72.97±18.04	0.800±0.098
4	GLRLM	77.98±8.50	74.77±13.10	81.08±10.09	0.85±0.069	9	WPT	77.06±9.62	78.5±9.34	75.68±14.33	0.832±0.075
5	GL-M	76.61±8.64	71.03±9.04	81.98±14.90	0.865±0.068	10	CT	77.06±10.37	76.64±7.74	77.48±17.86	0.836±0.096
11	CMS-W-CS	76.61±10.46	75.7±12.54	77.48±13.81	0.799±10.24	16	MSTA-W-CS	76.15±6.82	78.50±8.62	73.87±13.96	0.820±0.098
12	CMS-W-H	75.69±6.08	73.83±11.55	77.48±14.37	0.798±0.118	17	MSTA-W-H	77.06±8.31	79.44±8.17	74.77±17.12	0.821±0.107
13	CMS-W-COM	67.89±9.96	56.07±20.62	79.28±8.69	0.715±0.090	18	MSTA-W-COM	78.44±5.59	71.03±6.43	85.59±7.73	0.822±0.061
14	CMS-W-RLM	77.52±10.51	77.57±14.66	77.48±15.67	0.842±0.071	19	MSTA-W-RLM	77.98±7.70	78.50±14.08	77.48±14.46	0.835±0.077
15	CMS-W-M	76.15±9.28	71.03±19.03	81.08±12.46	0.831±0.072	**20**	**MSTA-W-M**	**80.28±7.05**	**79.44±13.38**	**81.08±10.09**	**0.871±0.060**
21	CMS-WP-CS	76.15±12.16	80.37±9.71	72.07±21.27	0.814±0.085	26	MSTA-WP-CS	78.90±6.43	78.50±7.21	79.28±8.74	0.850±0.079
22	CMS-WP-H	74.77±11.35	77.57±12.86	72.07±17.99	0.803±0.124	27	MSTA-WP-H	79.36±8.61	78.50±10.35	80.18±12.75	0.865±0.069
23	CMS-WP-COM	43.58±10.85	10.28±11.04	75.68±30.66	0.417±0.125	28	MSTA-WP-COM	72.94±9.38	61.68±18.94	83.78±13.46	0.761±0.108
24	CMS-WP-RLM	75.23±8.44	74.77±8.75	75.68±14.97	0.819±0.092	**29**	**MSTA-WP-RLM**	**79.36±8.47**	**77.57±10.04**	**81.08±13.87**	**0.872±0.057**
25	CMS-WP-M	73.39±10.31	73.83±13.55	72.97±15.56	0.795±0.111	**30**	**MSTA-WP-M**	**81.19±7.80**	**76.64±13.33**	**85.59±9.82**	**0.879±0.062**
31	CMS-C-CS	75.69±10.73	71.96±10.26	79.28±15.52	0.786±0.095	36	MSTA-C-CS	77.52±8.82	80.37±9.13	74.77±16.57	0.836±0.077
32	CMS-C-H	75.69±11.55	74.77±18.06	76.58±17.32	0.825±0.100	37	MSTA-C-H	78.44±9.24	79.44±15.21	77.48±16.81	0.844±0.082
33	CMS-C-COM	70.64±8.68	56.07±18.73	84.68±9.69	0.745±0.111	38	MSTA-C-COM	70.18±12.35	54.21±24.59	85.59±6.43	0.731±0.146
34	CMS-C-RLM	77.06±7.88	74.77±8.75	79.28±12.97	0.828±0.077	**39**	**MSTA-C-RLM**	**80.28±8.40**	**80.37±10.96**	**80.18±13.49**	**0.866±0.073**
35	CMS-C-M	75.23±9.36	71.96±14.27	78.38±14.42	0.819±0.077	**40**	**MSTA-C-M**	**77.06±7.89**	**71.03±17.39**	**82.88±9.12**	**0.873±0.068**

Classification - Results

- On test set

TABLE IV

TEST RESULTS OF THE CLASSIFICATIONS: ACC (%), ACCURACY; SEN (%), SENSITIVITY; SPE (%), SPECIFICITY. THE BOLD AND ITALIC TEXTS HIGHLIGHT THE HIGHEST PERFORMANCES OBTAINED FOR AN INDICATOR

No.	Method	ACC	SEN	SPE	AUC	No.	Method	ACC	SEN	SPE	AUC
1	GLS	74.47	73.91	75	0.726	6	ACM	62.77	56.52	68.75	0.671
2	GLH	70.21	63.04	77.08	0.772	7	LOG	70.21	67.39	72.92	0.693
3	GLCM	61.7	47.83	75	0.729	8	WT	71.28	69.57	72.92	0.715
4	GLRLM	72.34	69.57	75	0.767	9	WPT	72.34	71.74	72.92	0.701
5	GL-M	73.4	65.22	***81.25***	0.744	10	CT	69.15	67.39	70.83	0.727
11	CMS-W-CS	71.28	69.57	72.92	0.747	16	MSTA-W-CS	74.47	71.74	77.08	0.743
12	CMS-W-H	73.4	71.74	75	0.749	17	MSTA-W-H	73.4	69.57	77.08	0.746
13	CMS-W-COM	63.83	54.35	72.92	0.726	18	MSTA-W-COM	71.28	65.22	77.08	0.753
14	CMS-W-RLM	72.34	69.57	75	0.743	19	MSTA-W-RLM	***77.66***	78.26	77.08	0.778
15	CMS-W-M	73.4	71.74	75	0.752	**20**	**MSTA-W-M**	***77.66***	**78.26**	**77.08**	***0.792***
21	CMS-WP-CS	73.4	71.74	75	0.738	26	MSTA-WP-CS	72.34	73.91	70.83	0.73
22	CMS-WP-H	73.4	76.09	70.83	0.744	27	MSTA-WP-H	74.47	76.09	72.92	0.747
23	CMS-WP-COM	51.06	0	100	0.5	28	MSTA-WP-COM	68.09	56.52	79.17	0.757
24	CMS-WP-RLM	72.34	69.57	75	0.753	**29**	**MSTA-WP-RLM**	***77.66***	**78.26**	**77.08**	**0.787**
25	CMS-WP-M	75.53	73.91	77.08	0.791	30	MSTA-WP-M	75.53	***80.43***	70.83	0.765
31	CMS-C-CS	61.7	47.83	75	0.647	36	MSTA-C-CS	71.28	71.74	70.83	0.768
32	CMS-C-H	71.28	73.91	68.75	0.781	37	MSTA-C-H	71.28	67.39	75	0.769
33	CMS-C-COM	63.83	54.35	72.92	0.703	38	MSTA-C-COM	65.96	52.17	79.17	0.742
34	CMS-C-RLM	72.34	69.57	75	0.752	**39**	**MSTA-C-RLM**	***77.66***	**78.26**	**77.08**	**0.777**
35	CMS-C-M	69.15	65.22	72.92	0.771	**40**	**MSTA-C-M**	**75.53**	**71.74**	**79.17**	**0.781**

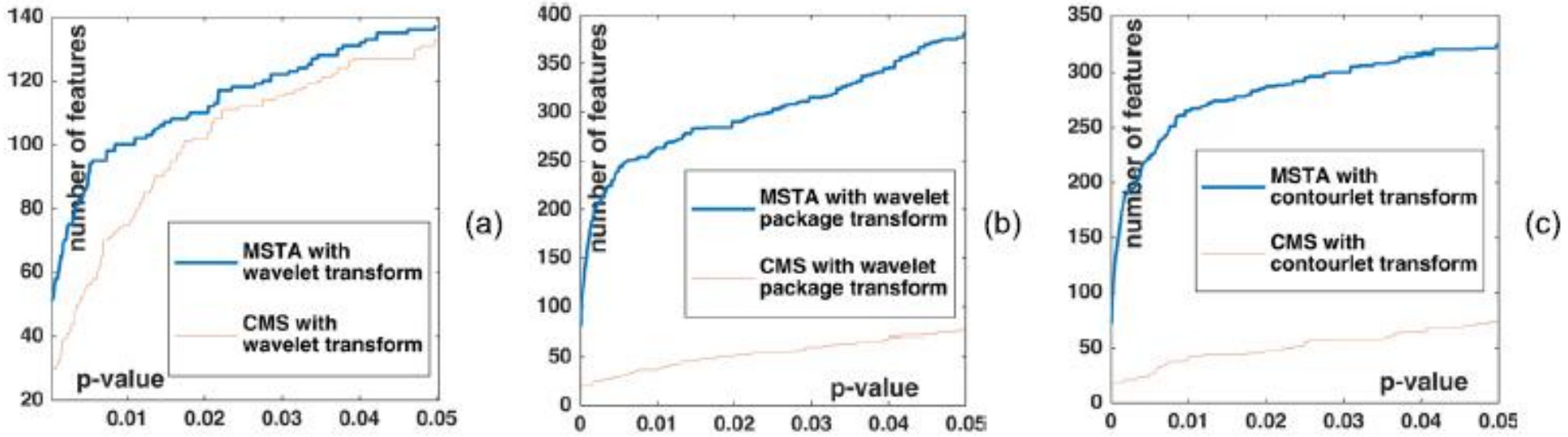
Classification - Results

TEXTURE ANALYSIS	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12	1.13	1.14	1.15	1.16
	1.17	1.18	1.19	1.20	1.21	1.22	1.23	1.24	1.25							
MSTA-W-CS	64.7	64.7	70.2	72.9	68.3	72.0	73.4	71.6	**72.9**	69.7	64.2	61.0	73.4	72.0	67.0	66.1
	71.6	70.2	64.7	64.7	**73.9**	70.2	72.0	65.1	67.9							
MSTA-W-H	70.6	70.6	72.5	70.2	67.4	70.6	**75.7**	72.5	**75.2**	70.6	65.1	55.0	73.4	74.3	62.4	70.2
	75.2	70.2	67.9	69.7	72.9	72.5	74.3	72.0	71.6							
MSTA-W-COM	74.8	74.8	73.4	70.6	Failed	73.4	69.3	69.3	**73.4**	**78.0**	72.9	70.6	75.2	72.9	69.3	70.6
	70.2	72.9	71.1	72.0	76.1	73.9	71.1	67.4	75.2							
MSTA-W-RLM	69.3	70.2	75.7	75.7	70.2	71.6	75.7	73.4	**75.7**	72.0	63.3	72.5	75.2	75.2	70.6	72.0
	71.6	74.3	72.9	73.9	73.9	74.3	**78.4**	74.3	72.5							
MSTA-W-M	75.2	75.2	71.1	75.7	Failed	76.6	77.5	76.6	**79.8**	76.1	68.3	74.3	76.6	76.1	67.4	75.2
	75.2	74.8	75.7	76.1	74.3	78.9	75.7	67.4	74.3							

1.1 fine tree; 1.2 medium tree; 1.3 coarse tree; 1.4 linear discriminant; 1.5 quadratic discriminant; 1.6 logistic regression; 1.7 Gaussian naïve Bayes; 1.8 kernel naïve Bayes; **1.9 linear SVM**; 1.10 quadratic SVM; 1.11 cubic SVM; 1.12 fine Gaussian SVM; 1.13 medium Gaussian SVM; 1.14 coarse Gaussian SVM; 1.15 fine KNN; 1.16 medium KNN; 1.17 coarse KNN; 1.18 cosine KNN; 1.19 cubic KNN: 1.20 weighted KNN; 1.21 ensemble boosted trees; 1.22 ensemble bagged trees; 1.23 ensemble subspace discriminant; 1.24 ensemble subspace KNN; 1.25 ensemble RUSBoosted tree.

Statistical Tests - Results

- Statistical tests were performed based on test set.
- Number of features with statistically significant difference (MSTA vs CMS)



Statistical Tests - Results

- *x :* median for PDAC; *y :* median for HP.
- The alternative hypothesis of a left-tailed test states that $x < y$
- The alternative hypothesis of a right-tailed test states that $x > y$.

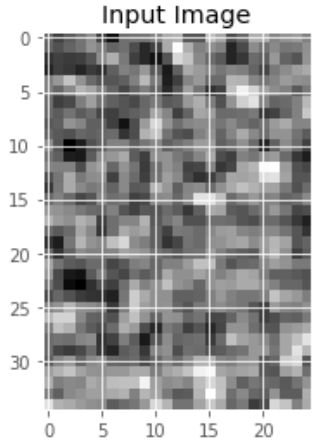
LEFT-TAILED AND RIGHT-TAILED TESTS: DIFFERENCE IN THE TEXTURE FEATURE VALUES FOR PDACS AND HPS; A, H, V, AND D ARE APPROXIMATE, HORIZONTAL, VERTICAL, AND DIAGONAL DIRECTIONS, RESPECTIVELY

No.	Texture analysis method	Component	Feature name	Two-sided p ≤	Left-tailed p ≤	Right-tailed p ≤
f1	MSTA-W-CS	D in 2-level	variance	6.66×10^{-6}	3.33×10^{-6}	
f2	MSTA-W-CS	D in 2-level	average energy	7.16×10^{-6}	3.58×10^{-6}	
f3	MSTA-W-H	A in 1-level	entropy	0.25×10^{-6}	**1.27×10^{-7}**	
f4	MSTA-W-H	A in 1-level	uniformity	1.78×10^{-6}		**8.92×10^{-7}**
f5	MSTA-W-COM	A in 1-level	d=1, homogeneity	1.09×10^{-6}	**5.45×10^{-7}**	
f6	MSTA-W-COM	A in 1-level	d=1, energy	1.78×10^{-6}		**8.99×10^{-7}**
f7	MSTA-W-RLM	D in 2-level	long-run high level emphasis	2.32×10^{-6}	1.16×10^{-6}	
f8	MSTA-W-RLM	D in 2-level	short-run emphasis	1.39×10^{-6}		6.95×10^{-6}

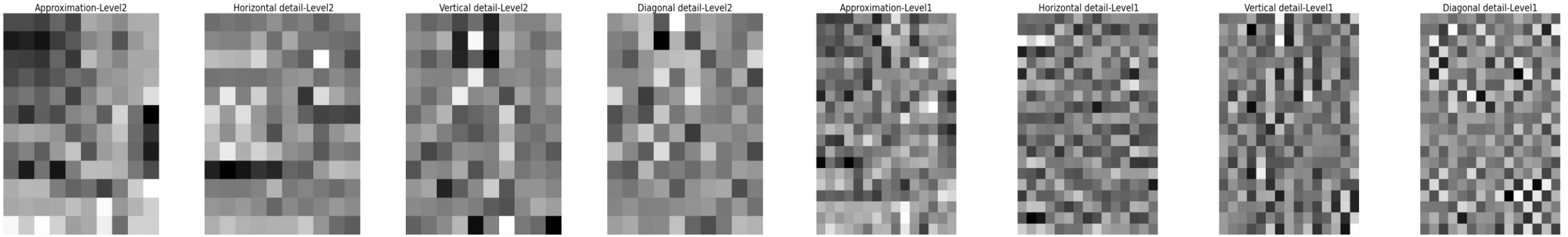
IMPLEMENTATION

https://github.com/Mithunjha/PDAC_Prediction

1. Extraction of ROI



2. Multi resolution analysis : Wavelet decomposition



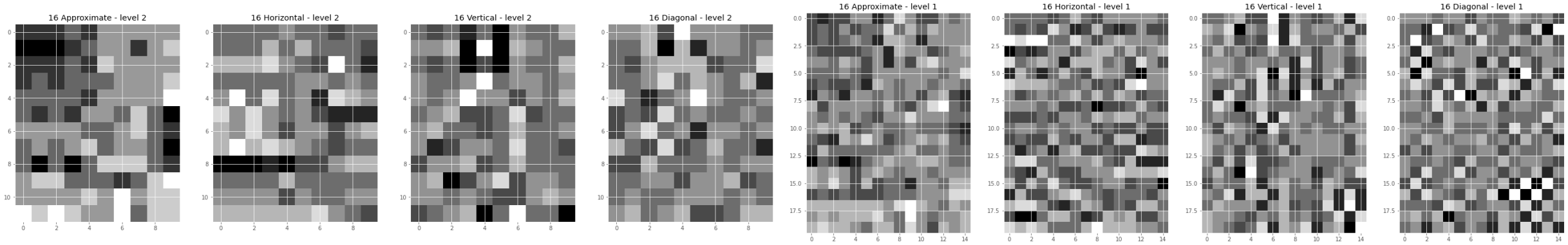
3. Random partitioning

Train set : Test set = 7 : 3

Train data
Class 1 (PDAC) = 107
Class 2 (HP) = 111

Test data
Class 1 (PDAC) = 46
Class 2 (HP) = 48

4. Discretization



5. Feature Extraction

	mean_A2	std_A2	energy_A2	h_mean_A2	h_variance_A2	h_skewness_A2	h_kurtosis_A2	h_entropy_A2
0	1.464286	0.822980	2.821429	1.470028	0.679985	-0.674185	2.356045	1.076812
1	3.805556	1.308507	16.194444	3.820479	1.719129	-0.823211	3.257713	1.591262
2	3.852273	1.702537	17.738636	3.867380	2.910227	-1.092021	3.590984	1.636254

312 x 208

6. Feature selection – based on trainset (218)

	ShortLowGrayLevelEmphasis_A2	LowGrayLevelRunEmphasis_A2	LowGrayLevelRunEmphasis_A1	ShortLowGrayLevelEmphasis_A1
0	3.133088e+14	3.133088e+14	2.049790e+14	2.049790e+14
1	4.367321e+14	4.367321e+14	4.990584e+14	4.990584e+14
2	2.121932e+15	2.121932e+15	2.612274e+15	2.612274e+15
3	8.220777e+14	8.220777e+14	1.021465e+15	1.021465e+15
4	1.055106e-01	1.189265e-01	1.181645e-01	9.655603e-02

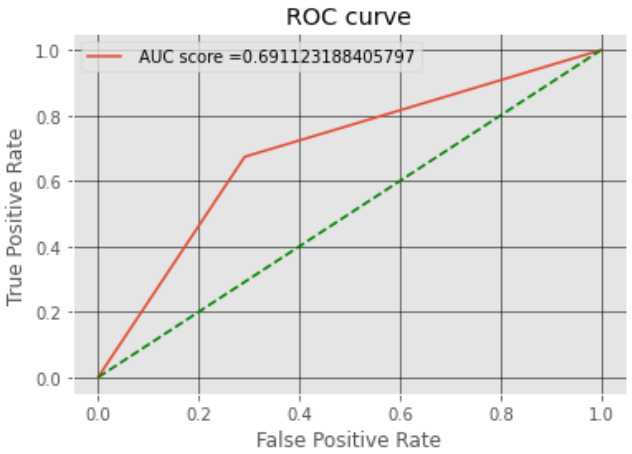
218 x # features

7. Classification and significance testing

Experimented with : Linear SVM, Decision tree, KNN, Poly SVM.
Statistical test : Mann U Whitney test
Results are reported in following slides.

Results

- Selected number of features = 20
- Model = SVM



ROC curve of SVM - Linear

Features	Accuracy	Precision	Sensitivity	Specificity	F1	AUC
ALL	69.15	68.88	67.39	70.83	0.6813	0.6911
CS	72.34	70.83	73.91	70.83	0.7234	0.7237
H	64.89	65.12	60.87	68.75	0.6292	0.6481
COM	68.09	67.39	67.39	68.75	0.6739	0.6807
RLM	70.21	71.43	65.22	75.0	0.6818	0.7011

Results

- Selected number of features = 20
- Feature extraction = ALL

```
Train Accuracy:  0.7752293577981652
Test Accuracy:  0.6914893617021277
Precision:  0.6888888888888889
Sensitivity:  0.6739130434782609
Specificity: 0.7083333333333334
f1:  0.6813186813186812
Area Under Curve (AUC):  0.691123188405797
Classification Report :
              precision    recall  f1-score   support

           0       0.69      0.71      0.70        48
           1       0.69      0.67      0.68        46

    accuracy                           0.69        94
   macro avg       0.69      0.69      0.69        94
weighted avg       0.69      0.69      0.69        94
```

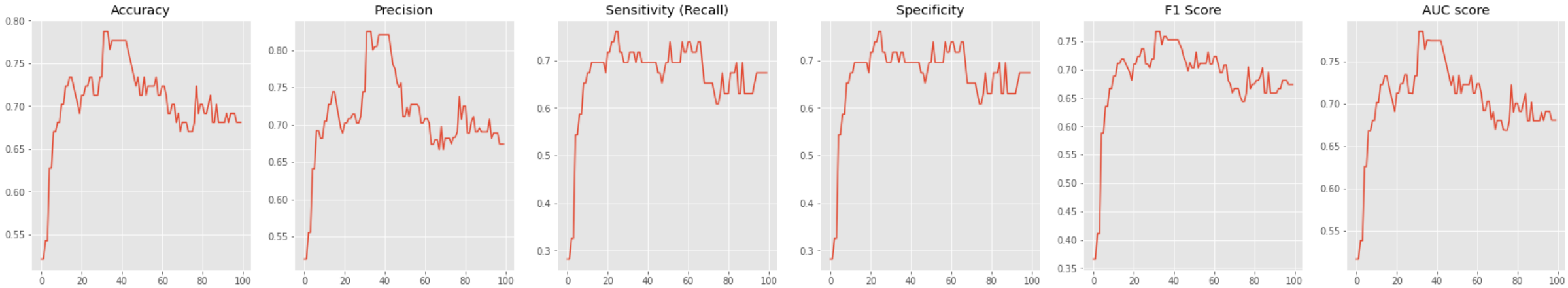
Results of Linear SVM

```
Train Accuracy:  0.8302752293577982
Test Accuracy:  0.7021276595744681
Precision:  0.7142857142857143
Sensitivity:  0.6521739130434783
Specificity: 0.75
f1:  0.6818181818181819
Area Under Curve (AUC):  0.7010869565217391
Classification Report :
              precision    recall  f1-score   support

           0       0.69      0.75      0.72        48
           1       0.71      0.65      0.68        46

    accuracy                           0.70        94
   macro avg       0.70      0.70      0.70        94
weighted avg       0.70      0.70      0.70        94
```

Results of Poly SVM

Models	Accuracy	Precision	Sensitivity	Specificity	F1	AUC
Linear SVM	69.15	68.88	67.39	70.83	0.6813	0.6911
Decision Tree	62.77	61.70	63.04	62.5	0.6237	0.6277
KNN	58.51	57.77	56.52	60.42	0.5714	0.5847
Poly SVM	70.21	71.43	65.22	75	0.6818	0.7011

- Variance of performance metrics along with number of features

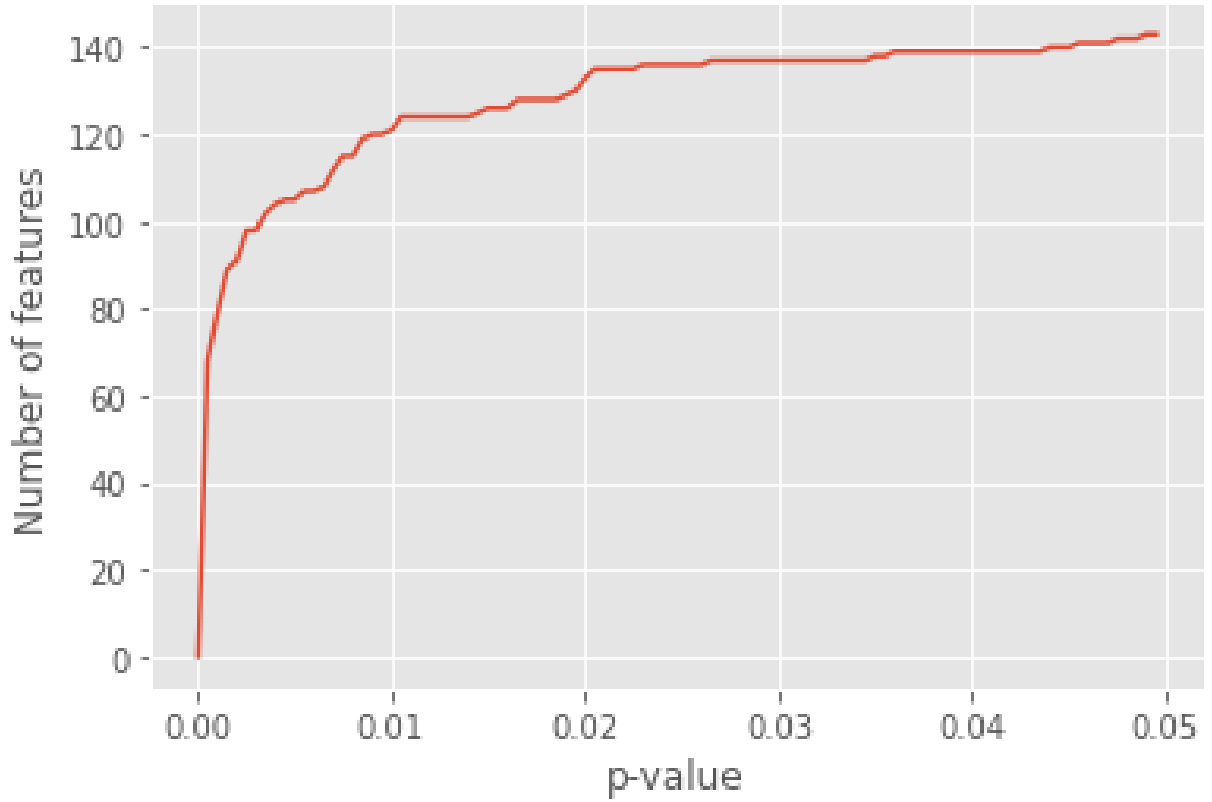


- Selected number of features = 32
- Feature extraction = ALL

Models	Accuracy	Precision	Sensitivity	Specificity	F1	AUC
Linear SVM	78.72	82.5	71.74	71.74	0.7674	0.7858

Statistical Testing

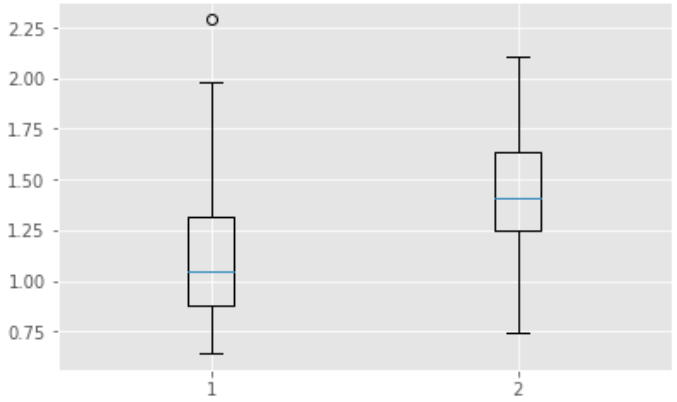
- Number of significant features (for different p-value)



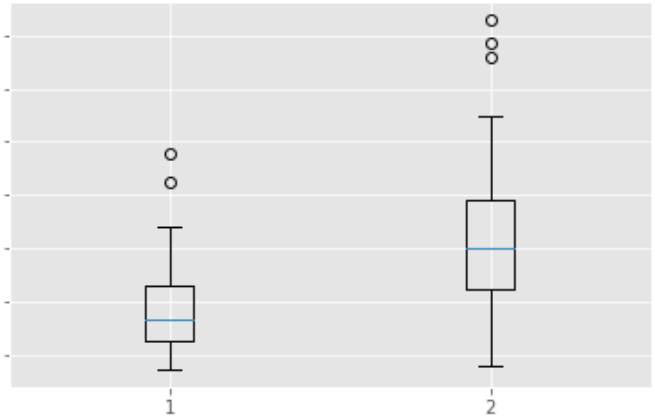
LEFT-TAILED AND RIGHT-TAILED TESTS: DIFFERENCE IN THE TEXTURE FEATURE VALUES FOR PDACs AND HPs;

Feature name	Statistical	Component	Two sided	Less PDAC<HP	Greater PDAC>HP
Std_V2	CS - STD	Vertical – level 2	7.95e-06	3.97e-06	-
Mean_V1	CS – Mean	Vertical – level 1	2.92e-05	-	-
H_entropy_V2	H - Entropy	Vertical – level 2	7.68e-06	3.84e-06	-
H_variance_V2	H - variance	Vertical – level 2	7.96e-06	3.98e-06	-
Contrast_d2_A1	Contrast – Distance 2	Approximate – level 1	1.18e-06	5.88e-07	-
Contrast_d1_A1	Contrast – Distance 1	Approximate – level 1	1.27e-06	6.35e-07	-
LongRunEmphasis_A1	RLM – Long Run Emphasis	Approximate – level 1	1.27e-07	-	6.35e-08
ShortRunEmphasis_A1	RLM – Short Run Emphasis	Approximate – level 1	3.23e-07	1.62e-07	-

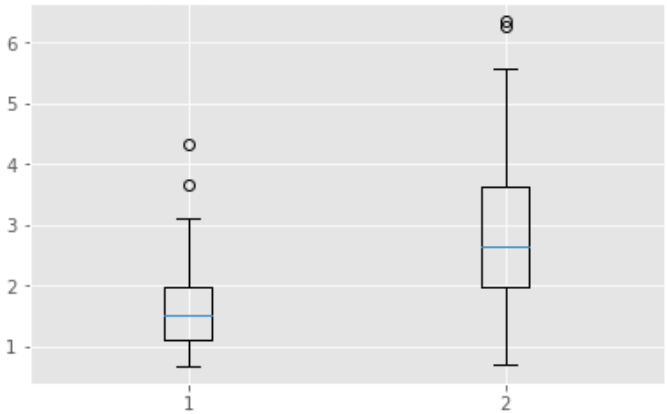
std_V2, p-value: 3.9787e-06, AUC : 0.33



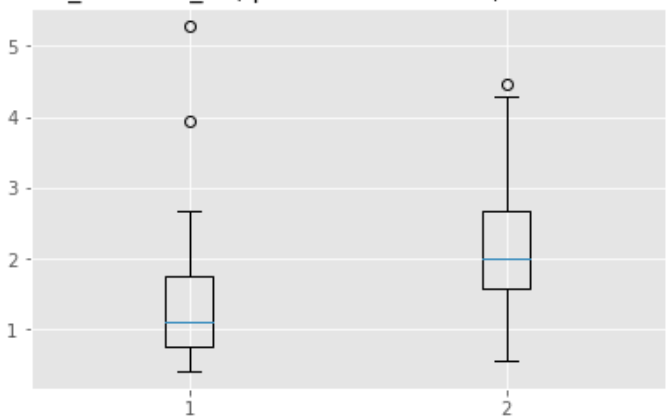
contrast_d2_A1, p-value: 5.881e-07, AUC : 0.44



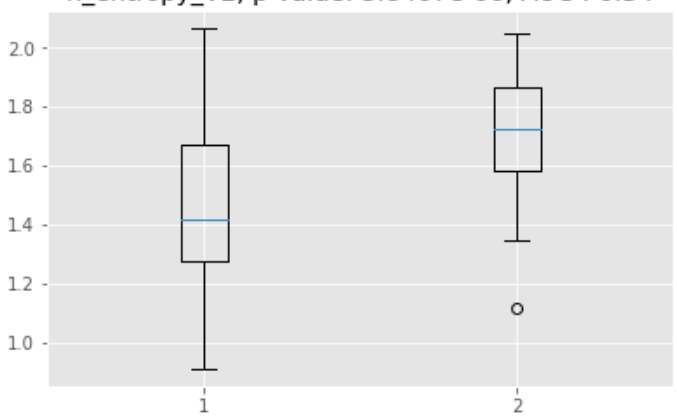
contrast_d1_A1, p-value: 6.347e-07, AUC : 0.21



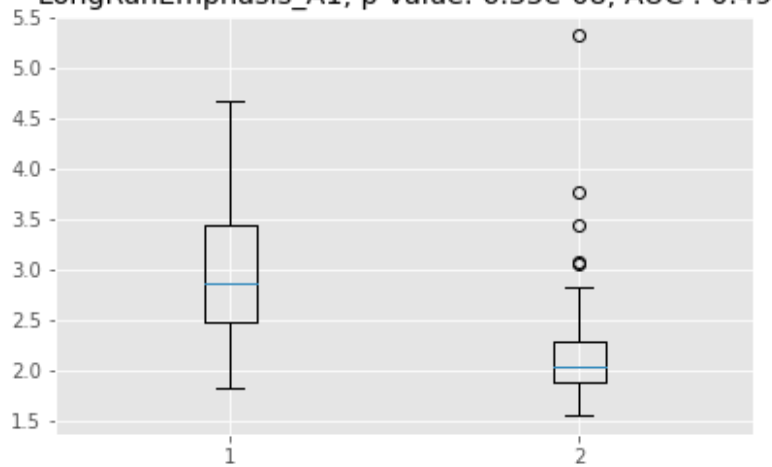
h_variance_V2, p-value: 3.979e-06, AUC : 0.23



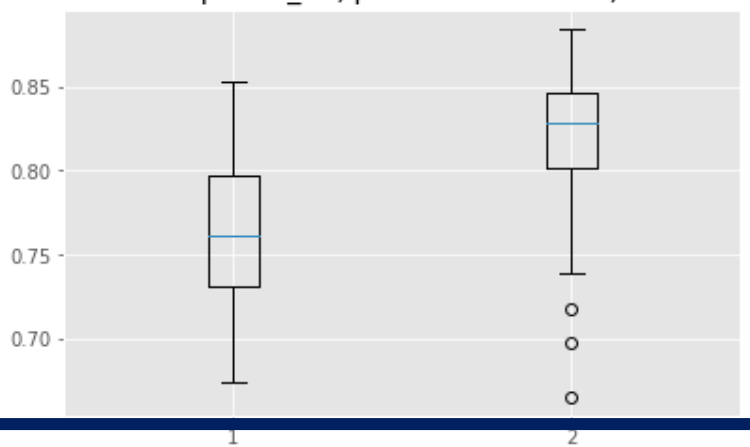
h_entropy_V2, p-value: 3.8407e-06, AUC : 0.34



LongRunEmphasis_A1, p-value: 6.35e-08, AUC : 0.49



ShortRunEmphasis_A1, p-value: 1.617e-07, AUC : 0.19



THANK YOU