Supplementary Materials

Homology-Based Image Processing for Automatic Classification of Histopathological Images of Lung Tissue

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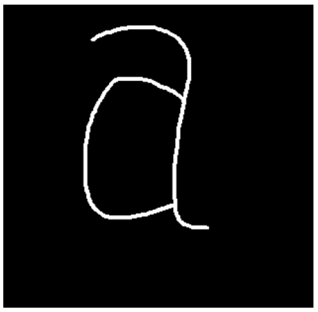
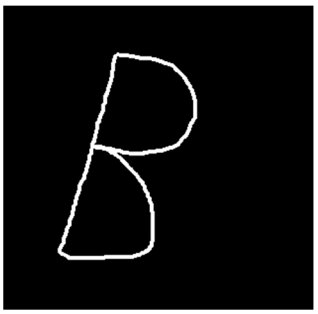
1. A
$b_0 = 2, b_1 = 1$

2. a
$b_0 = 2, b_1 = 1$

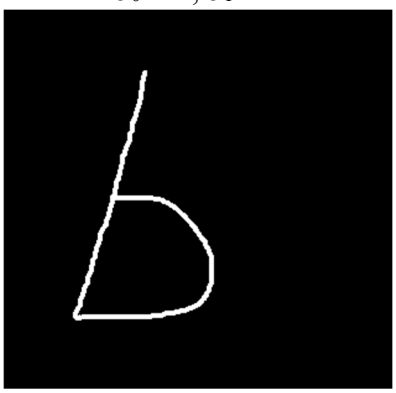


3. B
$b_0 = 3, b_1 = 1$



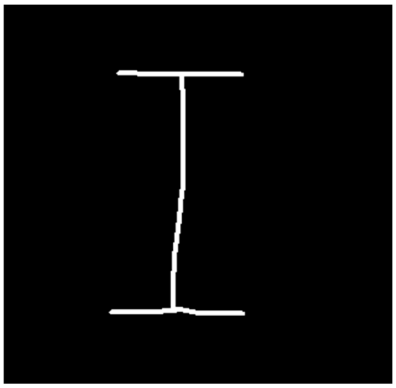
4. b

$b_0 = 2, b_1 = 1$



5. I

$b_0 = 1, b_1 = 1$



6. i

$b_0 = 1, b_1 = 2$

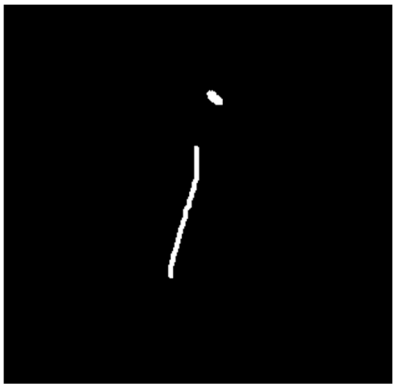


Figure S1. Binarized image of handwritten character and its Betti numbers. Note: Betti numbers of binarized image of handwritten character were calculated. In the images, b_0 corresponds to the number of black regions; b_1 corresponds to the number of white regions.

Table S1. Feature names of texture analysis.

Number	Name of Feature
1	original_firstorder_10Percentile
2	original_firstorder_90Percentile
3	original_firstorder_Energy
4	original_firstorder_Entropy
5	original_firstorder_InterquartileRange
6	original_firstorder_Kurtosis
7	original_firstorder_Maximum
8	original_firstorder_MeanAbsoluteDeviation
9	original_firstorder_Mean
10	original_firstorder_Median
11	original_firstorder_Minimum
12	original_firstorder_Range
13	original_firstorder_RobustMeanAbsoluteDeviation
14	original_firstorder_RootMeanSquared
15	original_firstorder_Skewness
16	original_firstorder_TotalEnergy
17	original_firstorder_Uniformity
18	original_firstorder_Variance
19	original_glcm_Autocorrelation
20	original_glcm_ClusterProminence
21	original_glcm_ClusterShade
22	original_glcm_ClusterTendency
23	original_glcm_Contrast
24	original_glcm_Correlation
25	original_glcm_DifferenceAverage
26	original_glcm_DifferenceEntropy
27	original_glcm_DifferenceVariance
28	original_glcm_Id
29	original_glcm_Idm
30	original_glcm_Idmn
31	original_glcm_Idn
32	original_glcm_Imc1
33	original_glcm_Imc2
34	original_glcm_InverseVariance
35	original_glcm_JointEnergy
36	original_glcm_JointEntropy
37	original_glcm_MCC
38	original_glcm_MaximumProbability
39	original_glcm_SumAverage
40	original_glcm_SumEntropy
41	original_glcm_SumSquares
42	original_glrlm_ShortRunEmphasis
43	original_glrlm_LongRunEmphasis
44	original_glrlm_GrayLevelNonUniformity
45	original_glrlm_GrayLevelNonUniformityNormalized
46	original_glrlm_RunLengthNonUniformity
47	original_glrlm_RunLengthNonUniformityNormalized
48	original_glrlm_RunPercentage
49	original_glrlm_GrayLevelVariance
50	original_glrlm_RunVariance
51	original_glrlm_RunEntropy
52	original_glrlm_LowGrayLevelRunEmphasis
53	original_glrlm_HighGrayLevelRunEmphasis
54	original_glrlm_ShortRunLowGrayLevelEmphasis
55	original_glrlm_ShortRunHighGrayLevelEmphasis
56	original_glrlm_LongRunLowGrayLevelEmphasis

57	original_glrlm_LongRunHighGrayLevelEmphasis
58	original_glszm_SmallAreaEmphasis
59	original_glszm_LargeAreaEmphasis
60	original_glszm_GrayLevelNonUniformity
61	original_glszm_GrayLevelNonUniformityNormalized
62	original_glszm_SizeZoneNonUniformity
63	original_glszm_SizeZoneNonUniformityNormalized
64	original_glszm_ZonePercentage
65	original_glszm_GrayLevelVariance
66	original_glszm_ZoneVariance
67	original_glszm_ZoneEntropy
68	original_glszm_LowGrayLevelZoneEmphasis
69	original_glszm_HighGrayLevelZoneEmphasis
70	original_glszm_SmallAreaLowGrayLevelEmphasis
71	original_glszm_SmallAreaHighGrayLevelEmphasis
72	original_glszm_LargeAreaLowGrayLevelEmphasis
73	original_glszm_LargeAreaHighGrayLevelEmphasis
74	original_gldm_SmallDependenceEmphasis
75	original_gldm_LargeDependenceEmphasis
76	original_gldm_GrayLevelNonUniformity
77	original_gldm_DependenceNonUniformity
78	original_gldm_DependenceNonUniformityNormalized
79	original_gldm_GrayLevelVariance
80	original_gldm_DependenceVariance
81	original_gldm_DependenceEntropy
82	original_gldm_LowGrayLevelEmphasis
83	original_gldm_HighGrayLevelEmphasis
84	original_gldm_SmallDependenceLowGrayLevelEmphasis
85	original_gldm_SmallDependenceHighGrayLevelEmphasis
86	original_gldm_LargeDependenceLowGrayLevelEmphasis
87	original_gldm_LargeDependenceHighGrayLevelEmphasis
88	original_ngtdm_Coarseness
89	original_ngtdm_Contrast
90	original_ngtdm_Busyness
91	original_ngtdm_Complexity
92	original_ngtdm_Strength

Table S2. Validation accuracies of CAD with homology-based image processing in the private dataset.

Normalization	Feature Selection	Image Resolutions				Five-Category Accuracy	Optimal Machine Learning Algorithm
0	0	128 × 128				0.85	1
0	0	256 × 256				0.795	6
0	0	256 × 256	128 × 128			0.835	6
0	0	512 × 512				0.84	7
0	0	512 × 512	128 × 128			0.84	7
0	0	512 × 512	256 × 256			0.84	7
0	0	512 × 512	256 × 256	128 × 128		0.86	7
0	0	1024 × 1024				0.645	5
0	0	1024 × 1024	128 × 128			0.695	6
0	0	1024 × 1024	256 × 256			0.735	6
0	0	1024 × 1024	256 × 256	128 × 128		0.765	7
0	0	1024 × 1024	512 × 512			0.73	6
0	0	1024 × 1024	512 × 512	128 × 128		0.755	7
0	0	1024 × 1024	512 × 512	256 × 256		0.76	6
0	0	1024 × 1024	512 × 512	256 × 256	128 × 128	0.77	7
0	1	128 × 128				0.81	1
0	1	256 × 256				0.9	6
0	1	256 × 256	128 × 128			0.845	6
0	1	512 × 512				0.8	7
0	1	512 × 512	128 × 128			0.865	7
0	1	512 × 512	256 × 256			0.84	6
0	1	512 × 512	256 × 256	128 × 128		0.835	7
0	1	1024 × 1024				0.685	6
0	1	1024 × 1024	128 × 128			0.795	6
0	1	1024 × 1024	256 × 256			0.795	6
0	1	1024 × 1024	256 × 256	128 × 128		0.81	6
0	1	1024 × 1024	512 × 512			0.785	6
0	1	1024 × 1024	512 × 512	128 × 128		0.805	6
0	1	1024 × 1024	512 × 512	256 × 256		0.805	6
0	1	1024 × 1024	512 × 512	256 × 256	128 × 128	0.815	6
1	0	128 × 128				0.77	6
1	0	256 × 256				0.795	6
1	0	256 × 256	128 × 128			0.84	6
1	0	512 × 512				0.84	7
1	0	512 × 512	128 × 128			0.84	7
1	0	512 × 512	256 × 256			0.84	7
1	0	512 × 512	256 × 256	128 × 128		0.86	7
1	0	1024 × 1024				0.66	1
1	0	1024 × 1024	128 × 128			0.705	1
1	0	1024 × 1024	256 × 256			0.76	3
1	0	1024 × 1024	256 × 256	128 × 128		0.765	7
1	0	1024 × 1024	512 × 512			0.73	6
1	0	1024 × 1024	512 × 512	128 × 128		0.755	7
1	0	1024 × 1024	512 × 512	256 × 256		0.76	0
1	0	1024 × 1024	512 × 512	256 × 256	128 × 128	0.775	0
1	1	128 × 128				0.82	6
1	1	256 × 256				0.865	6
1	1	256 × 256	128 × 128			0.88	6
1	1	512 × 512				0.825	7
1	1	512 × 512	128 × 128			0.88	7
1	1	512 × 512	256 × 256			0.885	5
1	1	512 × 512	256 × 256	128 × 128		0.835	7
1	1	1024 × 1024				0.665	6
1	1	1024 × 1024	128 × 128			0.855	6
1	1	1024 × 1024	256 × 256			0.83	6
1	1	1024 × 1024	256 × 256	128 × 128		0.8	6
1	1	1024 × 1024	512 × 512			0.765	6
1	1	1024 × 1024	512 × 512	128 × 128		0.85	6
1	1	1024 × 1024	512 × 512	256 × 256		0.86	6
1	1	1024 × 1024	512 × 512	256 × 256	128 × 128	0.86	6

Table S3. Validation accuracies of CAD with texture analysis in the private dataset.

Normalization	Feature Selection	Image Resolutions				Five-Category Accuracy	Optimal Machine Learning Algorithm
0	0	128 × 128				0.77	5
0	0	256 × 256				0.715	6
0	0	256 × 256	128 × 128			0.72	7
0	0	512 × 512				0.705	5
0	0	512 × 512	128 × 128			0.695	6
0	0	512 × 512	256 × 256			0.715	5
0	0	512 × 512	256 × 256	128 × 128		0.71	5
0	0	1024 × 1024				0.72	6
0	0	1024 × 1024	128 × 128			0.815	5
0	0	1024 × 1024	256 × 256			0.655	6
0	0	1024 × 1024	256 × 256	128 × 128		0.74	5
0	0	1024 × 1024	512 × 512			0.65	5
0	0	1024 × 1024	512 × 512	128 × 128		0.725	6
0	0	1024 × 1024	512 × 512	256 × 256		0.69	6
0	0	1024 × 1024	512 × 512	256 × 256	128 × 128	0.665	5
0	1	128 × 128				0.73	5
0	1	256 × 256				0.81	2
0	1	256 × 256	128 × 128			0.75	6
0	1	512 × 512				0.835	2
0	1	512 × 512	128 × 128			0.725	6
0	1	512 × 512	256 × 256			0.85	2
0	1	512 × 512	256 × 256	128 × 128		0.725	6
0	1	1024 × 1024				0.865	1
0	1	1024 × 1024	128 × 128			0.755	6
0	1	1024 × 1024	256 × 256			0.745	6
0	1	1024 × 1024	256 × 256	128 × 128		0.735	6
0	1	1024 × 1024	512 × 512			0.71	6
0	1	1024 × 1024	512 × 512	128 × 128		0.7	6
0	1	1024 × 1024	512 × 512	256 × 256		0.73	5
0	1	1024 × 1024	512 × 512	256 × 256	128 × 128	0.74	6
1	0	128 × 128				0.83	3
1	0	256 × 256				0.77	3
1	0	256 × 256	128 × 128			0.78	4
1	0	512 × 512				0.8	0
1	0	512 × 512	128 × 128			0.815	4
1	0	512 × 512	256 × 256			0.77	3
1	0	512 × 512	256 × 256	128 × 128		0.8	4
1	0	1024 × 1024				0.77	4
1	0	1024 × 1024	128 × 128			0.815	5
1	0	1024 × 1024	256 × 256			0.815	2
1	0	1024 × 1024	256 × 256	128 × 128		0.81	4
1	0	1024 × 1024	512 × 512			0.805	1
1	0	1024 × 1024	512 × 512	128 × 128		0.82	3
1	0	1024 × 1024	512 × 512	256 × 256		0.835	3
1	0	1024 × 1024	512 × 512	256 × 256	128 × 128	0.825	4
1	1	128 × 128				0.825	0
1	1	256 × 256				0.81	6
1	1	256 × 256	128 × 128			0.83	4
1	1	512 × 512				0.8	4
1	1	512 × 512	128 × 128			0.8	0
1	1	512 × 512	256 × 256			0.795	4
1	1	512 × 512	256 × 256	128 × 128		0.8	4
1	1	1024 × 1024				0.72	2
1	1	1024 × 1024	128 × 128			0.82	4
1	1	1024 × 1024	256 × 256			0.82	4
1	1	1024 × 1024	256 × 256	128 × 128		0.82	4
1	1	1024 × 1024	512 × 512			0.79	4
1	1	1024 × 1024	512 × 512	128 × 128		0.8	4
1	1	1024 × 1024	512 × 512	256 × 256		0.82	3
1	1	1024 × 1024	512 × 512	256 × 256	128 × 128	0.815	4

Table S4. Validation accuracies of CAD with homology-based image processing in the public dataset.

Normalization	Feature Selection	Image Resolutions				Three-Category Accuracy	Optimal Machine Learning Algorithm
0	0	96 × 96				0.9810	7
0	0	192 × 192				0.9907	7
0	0	192 × 192	96 × 96			0.9913	7
0	0	384 × 384				0.9923	7
0	0	384 × 384	96 × 96			0.9923	7
0	0	384 × 384	192 × 192			0.9917	7
0	0	384 × 384	192 × 192	96 × 96		0.9927	7
0	0	768 × 768				0.9897	7
0	0	768 × 768	96 × 96			0.9910	7
0	0	768 × 768	192 × 192			0.9900	7
0	0	768 × 768	192 × 192	96 × 96		0.9913	7
0	0	768 × 768	384 × 384			0.9927	7
0	0	768 × 768	384 × 384	96 × 96		0.9907	7
0	0	768 × 768	384 × 384	192 × 192		0.9900	7
0	0	768 × 768	384 × 384	192 × 192	96 × 96	0.9927	7
0	1	96 × 96				0.9250	7
0	1	192 × 192				0.9633	7
0	1	192 × 192	96 × 96			0.9740	7
0	1	384 × 384				0.9710	7
0	1	384 × 384	96 × 96			0.9827	7
0	1	384 × 384	192 × 192			0.9740	7
0	1	384 × 384	192 × 192	96 × 96		0.9807	7
0	1	768 × 768				0.9687	7
0	1	768 × 768	96 × 96			0.9793	7
0	1	768 × 768	192 × 192			0.9783	7
0	1	768 × 768	192 × 192	96 × 96		0.9810	7
0	1	768 × 768	384 × 384			0.9773	7
0	1	768 × 768	384 × 384	96 × 96		0.9833	7
0	1	768 × 768	384 × 384	192 × 192		0.9820	7
0	1	768 × 768	384 × 384	192 × 192	96 × 96	0.9847	7
1	0	96 × 96				0.9810	7
1	0	192 × 192				0.9907	7
1	0	192 × 192	96 × 96			0.9913	7
1	0	384 × 384				0.9923	7
1	0	384 × 384	96 × 96			0.9923	7
1	0	384 × 384	192 × 192			0.9917	7
1	0	384 × 384	192 × 192	96 × 96		0.9927	7
1	0	768 × 768				0.9897	7
1	0	768 × 768	96 × 96			0.9910	7
1	0	768 × 768	192 × 192			0.9903	2
1	0	768 × 768	192 × 192	96 × 96		0.9913	7
1	0	768 × 768	384 × 384			0.9927	7
1	0	768 × 768	384 × 384	96 × 96		0.9907	7
1	0	768 × 768	384 × 384	192 × 192		0.9927	2
1	0	768 × 768	384 × 384	192 × 192	96 × 96	0.9927	7
1	1	96 × 96				0.9307	7
1	1	192 × 192				0.9647	7
1	1	192 × 192	96 × 96			0.9700	7
1	1	384 × 384				0.9700	7
1	1	384 × 384	96 × 96			0.9813	7
1	1	384 × 384	192 × 192			0.9750	7
1	1	384 × 384	192 × 192	96 × 96		0.9813	7
1	1	768 × 768				0.9697	7
1	1	768 × 768	96 × 96			0.9810	7
1	1	768 × 768	192 × 192			0.9787	7
1	1	768 × 768	192 × 192	96 × 96		0.9810	7
1	1	768 × 768	384 × 384			0.9747	7
1	1	768 × 768	384 × 384	96 × 96		0.9850	7
1	1	768 × 768	384 × 384	192 × 192		0.9823	7
1	1	768 × 768	384 × 384	192 × 192	96 × 96	0.9850	7

Table S5. Validation accuracies of CAD with texture analysis in the public dataset.

Normalization	Feature Selection	Image Resolutions				Three-Category Accuracy	Optimal Machine Learning Algorithm
0	0	96 × 96				0.9867	7
0	0	192 × 192				0.9873	7
0	0	192 × 192	96 × 96			0.9893	7
0	0	384 × 384				0.9873	7
0	0	384 × 384	96 × 96			0.9897	7
0	0	384 × 384	192 × 192			0.9877	7
0	0	384 × 384	192 × 192	96 × 96		0.9907	7
0	0	768 × 768				0.9873	7
0	0	768 × 768	96 × 96			0.9913	7
0	0	768 × 768	192 × 192			0.9880	7
0	0	768 × 768	192 × 192	96 × 96		0.9890	7
0	0	768 × 768	384 × 384			0.9897	7
0	0	768 × 768	384 × 384	96 × 96		0.9890	7
0	0	768 × 768	384 × 384	192 × 192		0.9877	7
0	0	768 × 768	384 × 384	192 × 192	96 × 96	0.9923	7
0	1	96 × 96				0.9707	7
0	1	192 × 192				0.9767	7
0	1	192 × 192	96 × 96			0.9787	7
0	1	384 × 384				0.9653	7
0	1	384 × 384	96 × 96			0.9763	7
0	1	384 × 384	192 × 192			0.9757	7
0	1	384 × 384	192 × 192	96 × 96		0.9803	7
0	1	768 × 768				0.9650	7
0	1	768 × 768	96 × 96			0.9783	7
0	1	768 × 768	192 × 192			0.9773	7
0	1	768 × 768	192 × 192	96 × 96		0.9803	7
0	1	768 × 768	384 × 384			0.9633	7
0	1	768 × 768	384 × 384	96 × 96		0.9780	7
0	1	768 × 768	384 × 384	192 × 192		0.9777	7
0	1	768 × 768	384 × 384	192 × 192	96 × 96	0.9827	7
1	0	96 × 96				0.9867	7
1	0	192 × 192				0.9873	7
1	0	192 × 192	96 × 96			0.9893	7
1	0	384 × 384				0.9873	7
1	0	384 × 384	96 × 96			0.9897	7
1	0	384 × 384	192 × 192			0.9877	7
1	0	384 × 384	192 × 192	96 × 96		0.9917	7
1	0	768 × 768				0.9873	7
1	0	768 × 768	96 × 96			0.9907	7
1	0	768 × 768	192 × 192			0.9883	7
1	0	768 × 768	192 × 192	96 × 96		0.9890	7
1	0	768 × 768	384 × 384			0.9893	7
1	0	768 × 768	384 × 384	96 × 96		0.9893	7
1	0	768 × 768	384 × 384	192 × 192		0.9880	7
1	0	768 × 768	384 × 384	192 × 192	96 × 96	0.9923	7
1	1	96 × 96				0.9707	7
1	1	192 × 192				0.9767	7
1	1	192 × 192	96 × 96			0.9777	7
1	1	384 × 384				0.9653	7
1	1	384 × 384	96 × 96			0.9767	7
1	1	384 × 384	192 × 192			0.9757	7
1	1	384 × 384	192 × 192	96 × 96		0.9803	7
1	1	768 × 768				0.9643	7
1	1	768 × 768	96 × 96			0.9767	7
1	1	768 × 768	192 × 192			0.9773	7
1	1	768 × 768	192 × 192	96 × 96		0.9810	7
1	1	768 × 768	384 × 384			0.9633	7
1	1	768 × 768	384 × 384	96 × 96		0.9777	7
1	1	768 × 768	384 × 384	192 × 192		0.9777	7
1	1	768 × 768	384 × 384	192 × 192	96 × 96	0.9820	7