Confidence Calibration for Deep Renal Biopsy Immunofluorescence Image Classification

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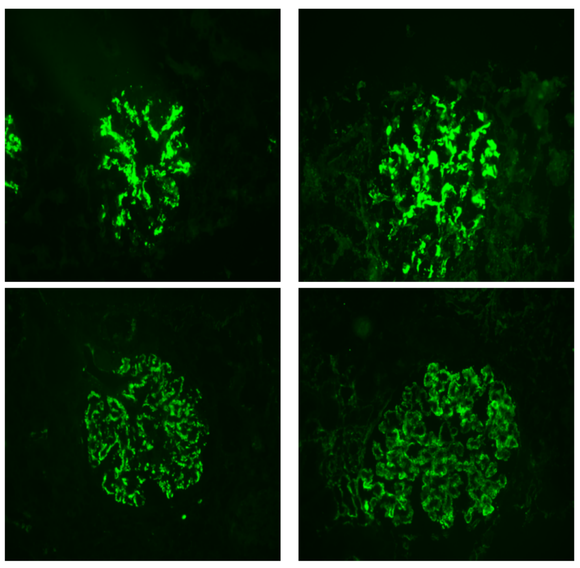
Immunofluorescence in Renal Biopsy

- Immunofluorescence is a powerful technique for light microscopy that makes use of fluorescent-labeled antibodies
- Pattern of antibody deposits require strong expertise to be analyzed



This work focuses on using Convolutional Neural Networks (CNNs) for the automatic identification of two deposit patterns:

I. Mesangial – *Top Row*
II. Parietal – *Bottom Row*

Deep Learning in Medical Imaging

- Convolutional Neural Networks have been widely employed in several Medical Imaging tasks such as image classification, detection, segmentation, and others
- Neural Networks are often seen as **black boxes**: this does not suit our task

Inter-rater agreement (Cohen's Kappa) between expert practitioners is very low

	GT	P1	P2
P3	0.50	0.70	0.34
P2	0.50	0.50	
P1	0.80		

(a) Mesangial

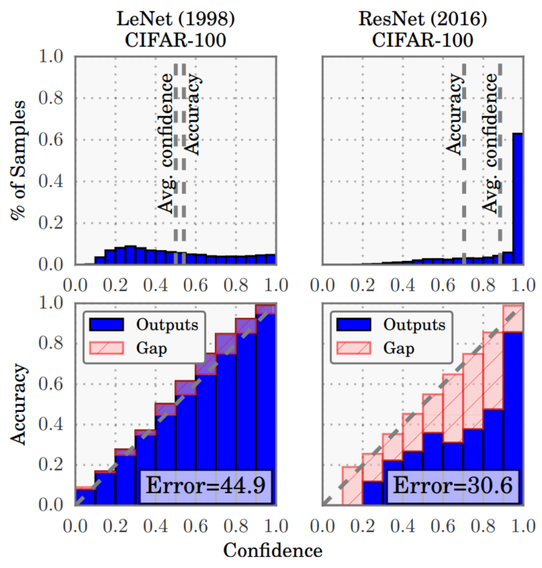
	GT	P1	P2
P3	0.40	0.60	0.60
P2	0.40	0.42	
P1	0.60		

(b) Parietal

- Binary predictions are thus an extremely underwhelming tool for immunofluorescence image analysis

The Proposed Method

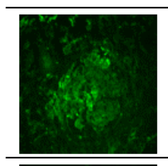
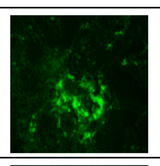
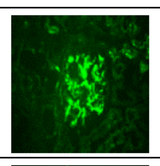
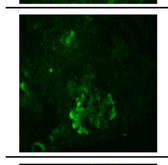
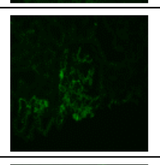
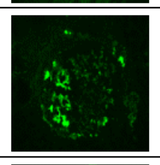
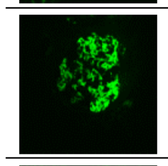
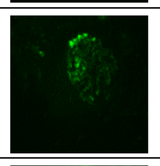
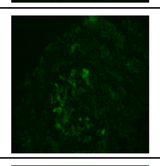
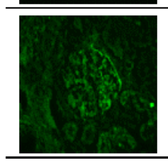
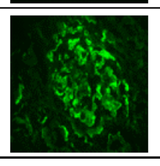
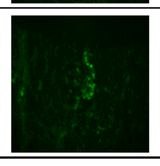
- **Dataset**:
  - 11k images
  - 3k exhibit parietal pattern
  - 2k exhibit mesangial pattern
  - 1k exhibit both patterns
- Two mutually non-exclusive classification tasks
- One residual blocks neural network per task
- We want to obtain reliable outputs; we thus apply model recalibration[1] and aim to obtain:
  - calibrated probabilities – low Expected Calibration Error (ECE)
  - good discriminative power – high accuracy



[1] C. Guo, G. Pleiss, Y. Sun, and K. Q. Weinberger, "On Calibration of Modern Neural Networks," in Proceedings of the 34th International Conference on Machine Learning-Volume 70, 2017, pp. 1321–1330.

Qualitative Results

Expert practitioners provided likelihood scores of the mesangial pattern

GT: yes Pred: no	*Calib* Uncalib	GT: no Pred: yes	*Calib* Uncalib	GT: yes Pred: yes	*Calib* Uncalib *Human*
	*0.830* 0.992		*0.781* 0.980		*0.965* 0.999 *1.000*
	*0.771* 0.977		*0.774* 0.964		*0.771* 0.977 *0.400*
	*0.571* 0.707		*0.572* 0.711		*0.658* 0.883 *0.600*
	*0.562* 0.684		*0.560* 0.679		*0.558* 0.673 *0.400*

Quantitative Results

TABLE I
PERFORMANCE FOR MESANGIAL PATTERN CLASSIFICATION.

		Uncalibrated						PS						TS
Model	**Drop**	**Acc**	**Prec**	**Rec**	**F1-S**	**AUC**	**ECE**	**Acc**	**Prec**	**Rec**	**F1-S**	**AUC**	**ECE**	**ECE**
DenseNet-121	0	81.00	76.70	70.90	73.70	79.00	13.19	77.50	81.00	52.30	63.50	72.50	4.96	2.31
DenseNet-121	0.5	82.20	76.50	75.70	76.10	80.90	4.19	78.80	86.90	51.2	64.40	73.30	5.27	3.00
ResNet-101	0	82.10	75.40	77.60	76.50	81.20	8.86	80.00	85.40	56.30	67.80	75.30	3.08	2.67
ResNet-101	0.5	82.10	79.20	70.90	74.80	79.90	12.64	78.80	85.00	52.80	65.10	76.30	3.77	3.06
ResNet-18	0	81.30	78.30	69.30	73.50	78.90	1.62	79.40	85.70	54.10	66.30	74.30	4.40	1.41
ResNet-18	0.5	81.90	76.40	74.90	75.60	80.50	3.35	78.50	83.60	53.10	64.90	73.40	6.33	2.96
ResNet-50	0	81.60	72.70	81.60	76.90	81.60	7.59	79.70	85.20	55.50	67.20	74.90	4.71	2.19
ResNet-50	0.5	81.70	77.30	72.50	74.80	79.90	3.62	79.60	85.90	55.20	67.20	74.90	3.83	2.58
ResNet-152	0	81.60	75.50	75.50	75.50	80.40	10.40	79.80	85.30	55.70	67.40	75.00	4.45	3.00
ResNet-152	0.5	82.10	73.80	81.10	77.30	81.90	2.22	80.00	86.90	54.90	67.30	75.00	4.53	2.29
EfficientNet-b3	0.3	78.40	72.50	68.30	70.30	76.40	12.54	77.60	82.10	51.50	63.30	72.40	4.94	3.13
EfficientNet-b4	0.4	79.60	75.20	68.00	71.40	77.30	14.54	78.40	85.00	51.50	64.10	73.00	4.78	4.00
EfficientNet-b5	0.4	79.40	75.50	66.70	70.80	76.90	13.16	76.70	81.40	49.10	61.20	71.20	7.02	5.70

- **Eight Convolutional Neural Network architectures:**
  - DenseNet-121
  - ResNet-18
  - ResNet-50
  - ResNet-101
  - ResNet-152
  - EfficientNet-b3
  - EfficientNet-b4
  - EfficientNet-b5
- **Two dropout probabilities**:
  - 0
  - 0.5
- **Two re-calibration techniques:**
  - Platt Scaling (PS)
  - Temperature Scaling (TS)

- Good classification accuracy on both tasks with every CNN
- Minor boost in accuracy with dropout probability set to 0.5
- Good balance between recall and precision
- Temperature Scaling outperforms Platt Scaling
- **Calibrated probabilities are closer to human-assigned likelihood scores *w.r.t.* uncalibrated outputs**

TABLE II
PERFORMANCE FOR PARIETAL PATTERN CLASSIFICATION.

		Uncalibrated						PS						TS
Model	**Drop**	**Acc**	**Prec**	**Rec**	**F1-S**	**AUC**	**ECE**	**Acc**	**Prec**	**Rec**	**F1-S**	**AUC**	**ECE**	**ECE**
DenseNet-121	0	76.80	79.90	64.70	71.50	75.70	15.42	76.40	83.40	59.30	69.30	74.80	6.97	5.73
DenseNet-121	0.5	80.30	78.70	77.10	77.90	80.00	13.25	77.20	85.60	59.30	70.10	75.60	4.20	3.21
ResNet-101	0	77.30	75.40	73.60	74.50	77.0	17.31	76.00	83.40	58.20	68.60	74.40	4.57	3.88
ResNet-101	0.5	75.90	82.60	58.90	68.70	74.40	18.93	75.20	84.50	54.70	66.40	73.20	5.04	3.77
ResNet-18	0	75.60	76.50	66.00	70.90	74.70	15.04	75.60	82.60	58.00	68.10	74.00	4.85	4.36
ResNet-18	0.5	78.20	79.00	70.20	74.30	77.50	11.37	76.10	83.10	58.90	68.90	74.50	5.36	4.19
ResNet-50	0	76.80	82.10	62.00	70.60	75.50	17.38	75.20	86.10	53.80	66.20	73.30	5.34	3.66
ResNet-50	0.5	76.90	82.10	62.20	70.80	75.60	16.78	75.80	84.30	56.00	67.30	73.70	5.55	4.52
ResNet-152	0	77.60	81.20	65.30	72.40	76.50	18.59	76.00	84.30	57.30	68.20	74.30	4.23	4.06
ResNet-152	0.5	76.00	80.00	62.20	70.00	74.70	19.00	74.70	82.40	56.00	66.70	73.10	5.53	4.53
EfficientNet-b3	0.3	78.20	74.90	77.60	76.20	78.10	8.52	74.40	83.20	54.00	65.50	72.50	5.80	2.35
EfficientNet-b4	0.4	77.50	77.80	70.00	73.70	76.80	12.37	74.30	82.90	54.00	65.40	72.50	6.36	3.69
EfficientNet-b5	0.4	77.50	77.50	70.40	73.80	76.90	14.62	75.10	82.70	56.40	67.10	73.40	5.77	3.85