(considerably) **Red**ucing **Anno**tation Need in Self-Explanatory Models for Lung Nodule Diagnosis

(cRedAnno)

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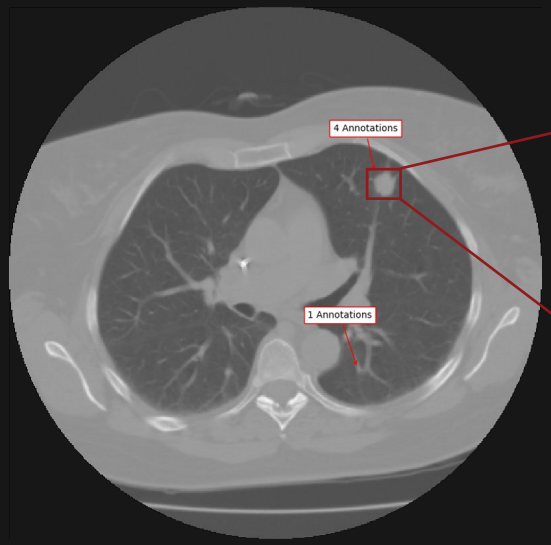
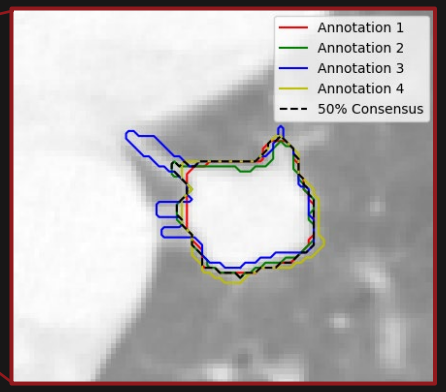
Background:
Lung nodule diagnosis



CT scan

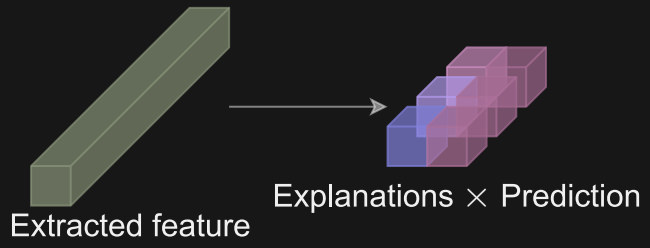


Nodule detection

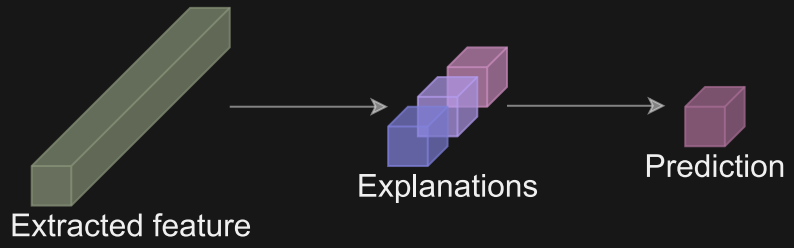
Nodule attributes	Subtlety	Obvious
	InternalStructure	Soft Tissue
	Calcification	Non-central
	Sphericity	Ovoid
	Margin	Sharp
	Lobulation	Nearly No Lobulation
	Spiculation	Medium Spiculation
	Texture	Solid
	Malignancy	Moderately Suspicious

Annotation info

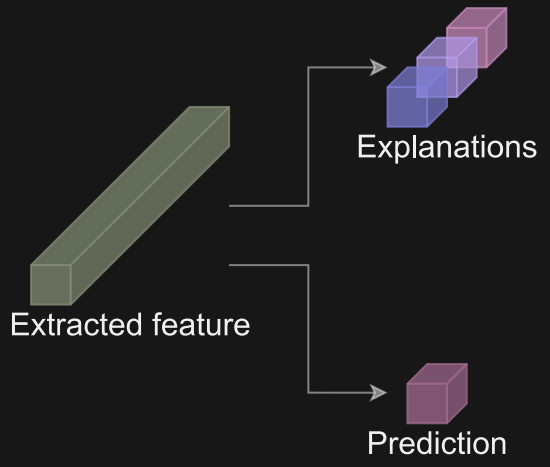
Related work:
Feature-based self-explanatory models



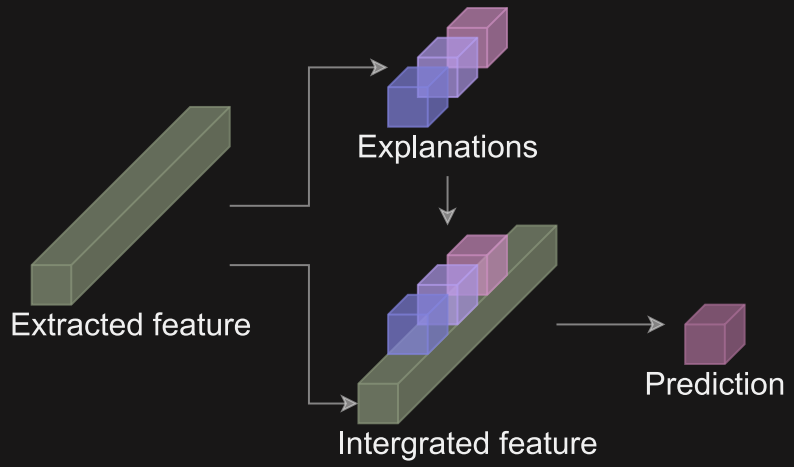
Teaching Explanation Networks



Concept Bottleneck Networks

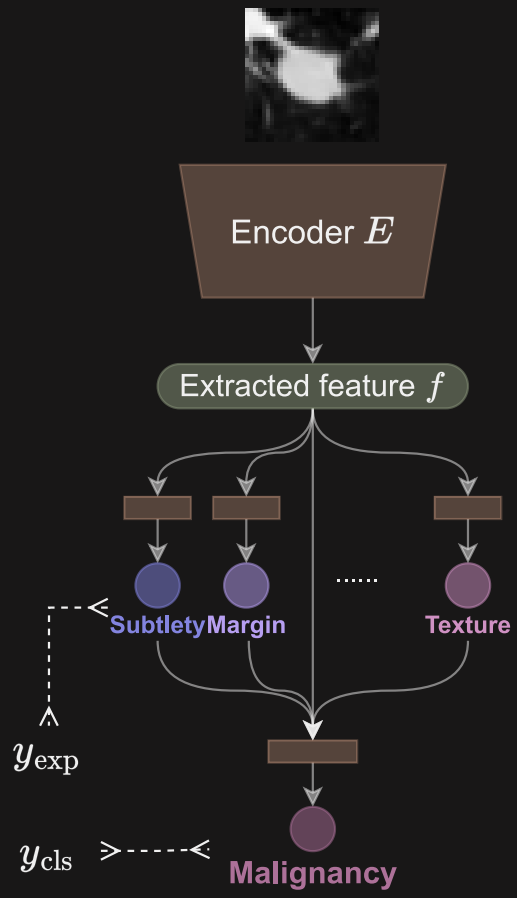


Multitask Learning Networks

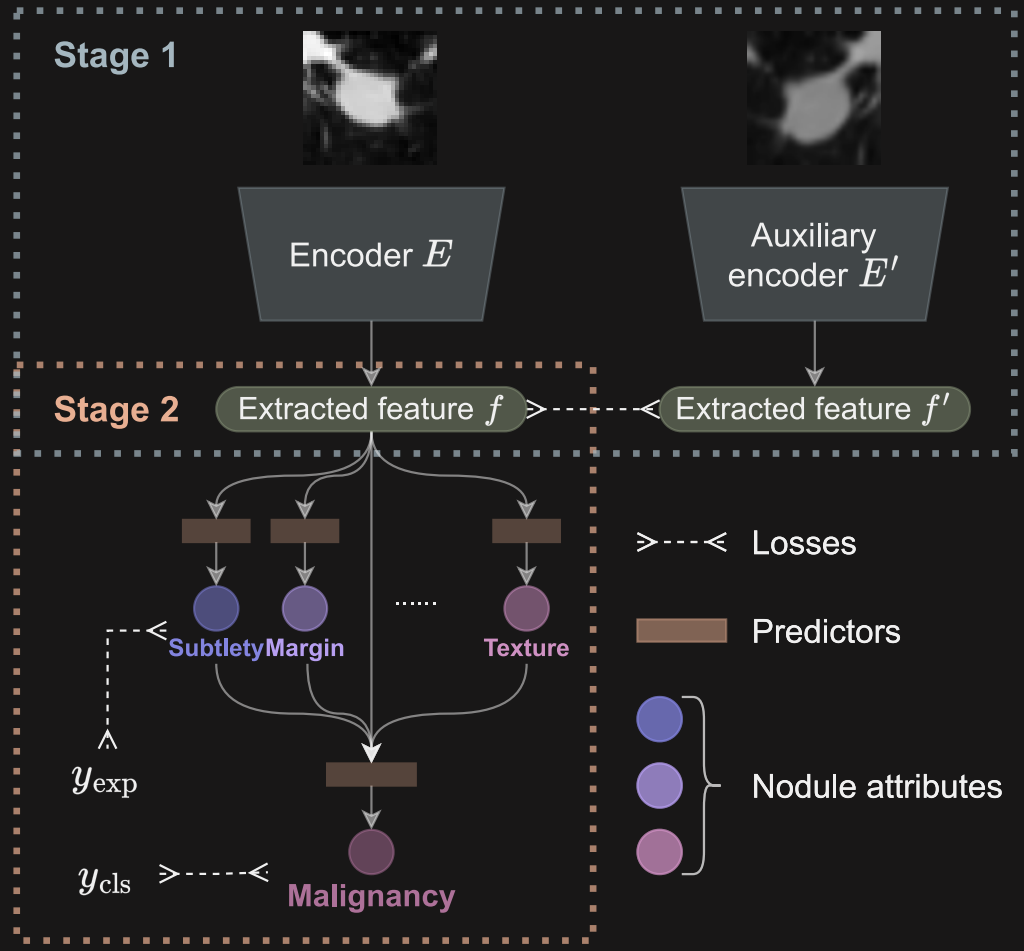


Hierarchical Networks

Method



Previous methods



cRedAnno

Results: Predicting nodule attributes and malignancy

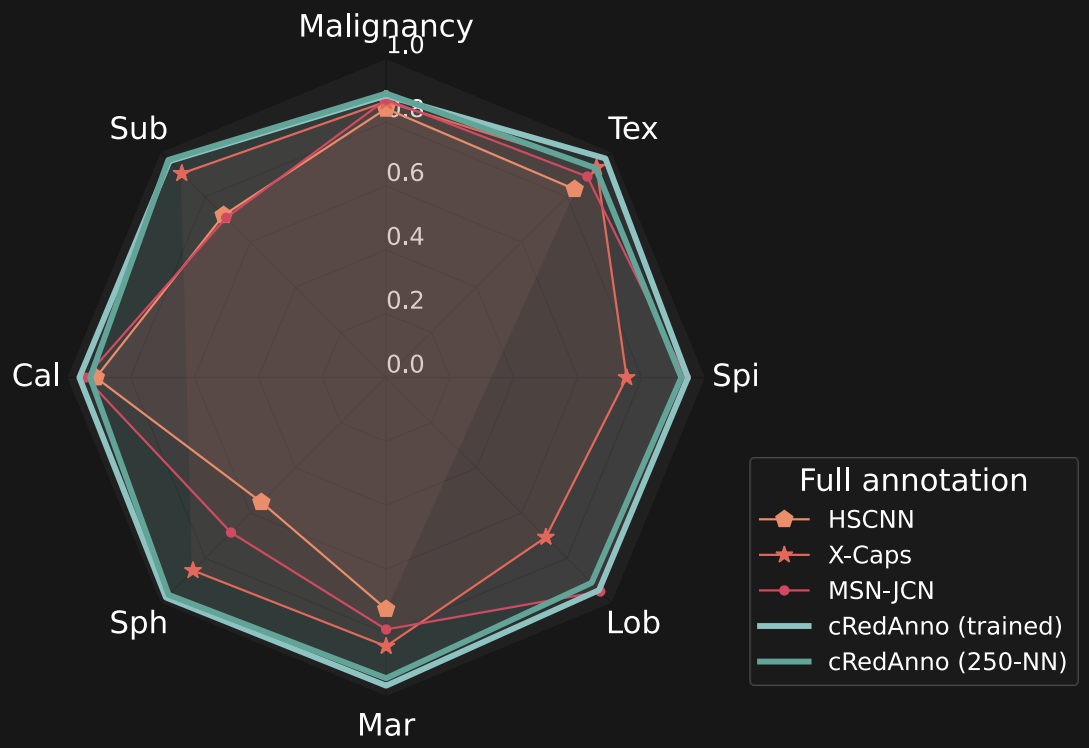
	Nodule attributes							Malignancy	#nodules	Additional information
	Sub	Cal	Sph	Mar	Lob	Spi	Tex			
Full annotation										
HSCNN[1]	71.90	90.80	55.20	72.50	-	-	83.40	84.20	4252	3D volume data
X-Caps[2]	90.39	-	85.44	84.14	70.69	75.23	93.10	86.39	1149	**None**
MSN-JCN[3]	70.77	94.07	68.63	78.88	**94.75**	93.75	89.00	87.07	2616	segmentation mask + diameter + OTSU + SLIC
MTMR[4]	-	-	-	-	-	-	-	**93.50**	1422	all 2D slices in 3D volumes
cRedAnno (50-NN)	94.93	92.72	95.58	93.76	91.29	92.72	94.67	87.52		
cRedAnno* (250-NN)	**96.36**	92.59	96.23	94.15	90.90	92.33	92.72	88.95	**730**	
cRedAnno* (trained)	95.84	**95.97**	**97.40**	**96.49**	94.15	**94.41**	**97.01**	88.30		
Partial annotation										
WeakSup[5] (1:5)	43.10	63.90	42.40	58.50	40.60	38.70	51.20	82.40	2558	multi-scale 3D volume data, all malignancy annotations, 1/(1+N) attribute annotations
WeakSup[5] (1:3)	66.80	91.50	66.40	79.60	74.30	81.40	82.20	**89.10**		
cRedAnno (10%, 50-NN)	94.93	92.07	**96.75**	**94.28**	**92.59**	91.16	**94.15**	87.13		
cRedAnno* (10%, 150-NN)	**95.32**	89.47	97.01	93.89	91.81	90.51	92.85	88.17	**730**	**None**
cRedAnno* (1%, trained)	91.81	**93.37**	96.49	90.77	89.73	**92.33**	93.76	86.09		

#nodules	0	1	sum
train	276	242	**518**
val	108	104	**212**
sum	**384**	**346**	**730**

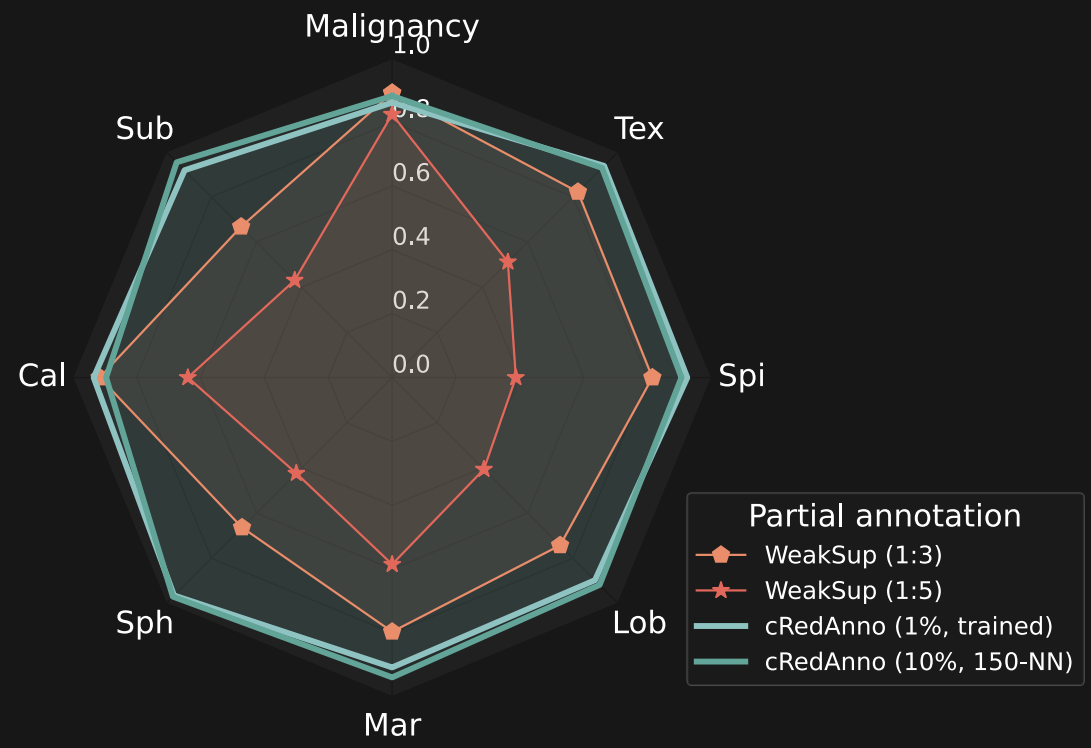
[1] S. Shen *et al.*, "An interpretable deep hierarchical semantic convolutional neural network for lung nodule malignancy classification," *Expert Systems with Applications*, vol. 128, pp. 84–95, Aug. 2019.
[2] R. LaLonde *et al.*, "Encoding Visual Attributes in Capsules for Explainable Medical Diagnoses," in *Medical Image Computing and Computer Assisted Intervention – MICCAI 2020*, Cham, 2020, pp. 294–304.
[3] W. Chen *et al.*, "End-to-End Multi-Task Learning for Lung Nodule Segmentation and Diagnosis," in *2020 25th International Conference on Pattern Recognition (ICPR)*, Milan, Italy, 2021, pp. 6710–6717.
[4] L. Liu *et al.*, "Multi-Task Deep Model With Margin Ranking Loss for Lung Nodule Analysis," *IEEE Trans. Med. Imaging*, vol. 39, no. 3, pp. 718–728, Mar. 2020.
[5] A. Joshi et al., "Lung nodule malignancy classification with weakly supervised explanation generation," *J. Med. Imag.*, vol. 8, no. 04, Aug. 2021.

Results:
Predicting nodule attributes and malignancy

Full annotation

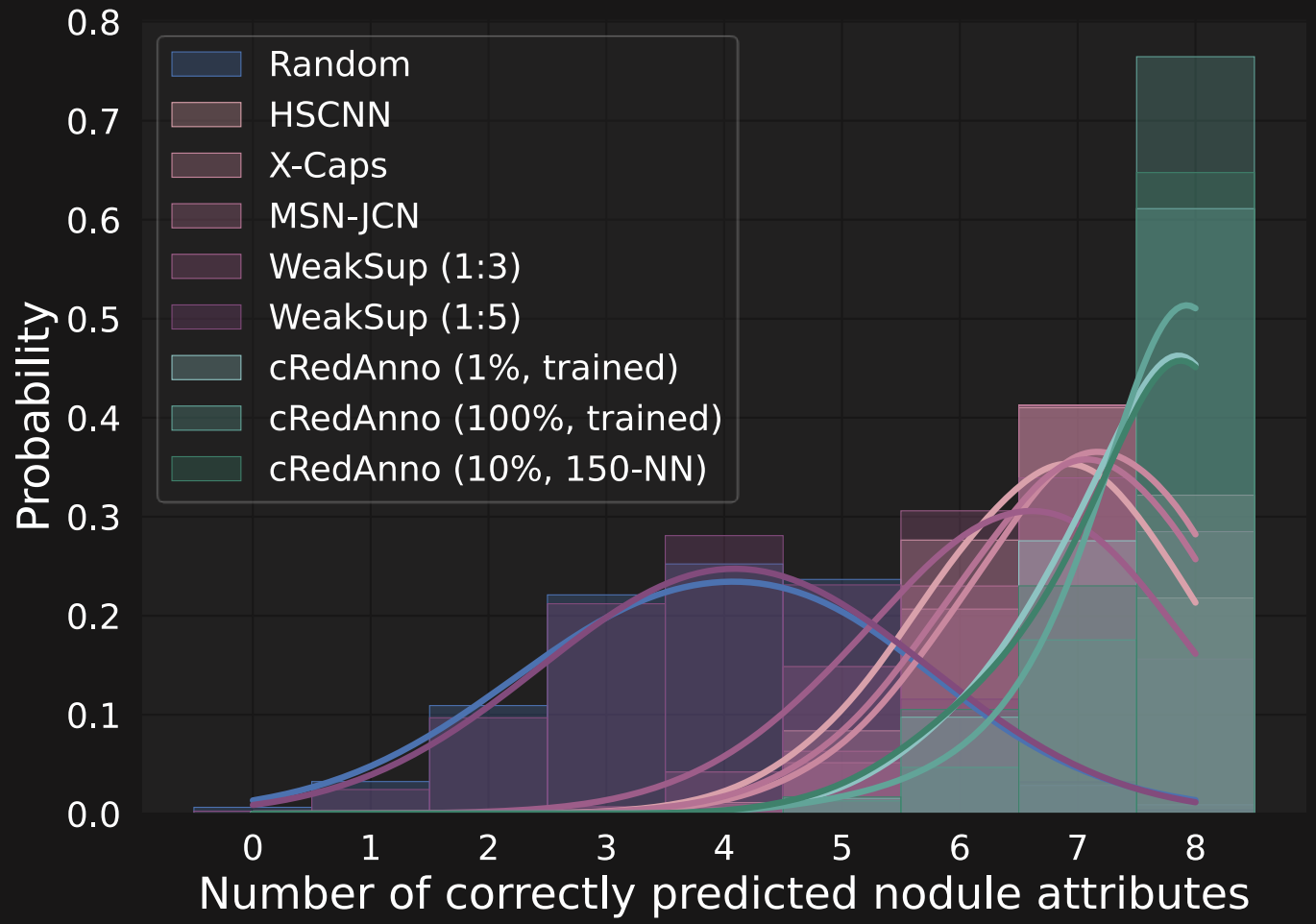


Partial annotation



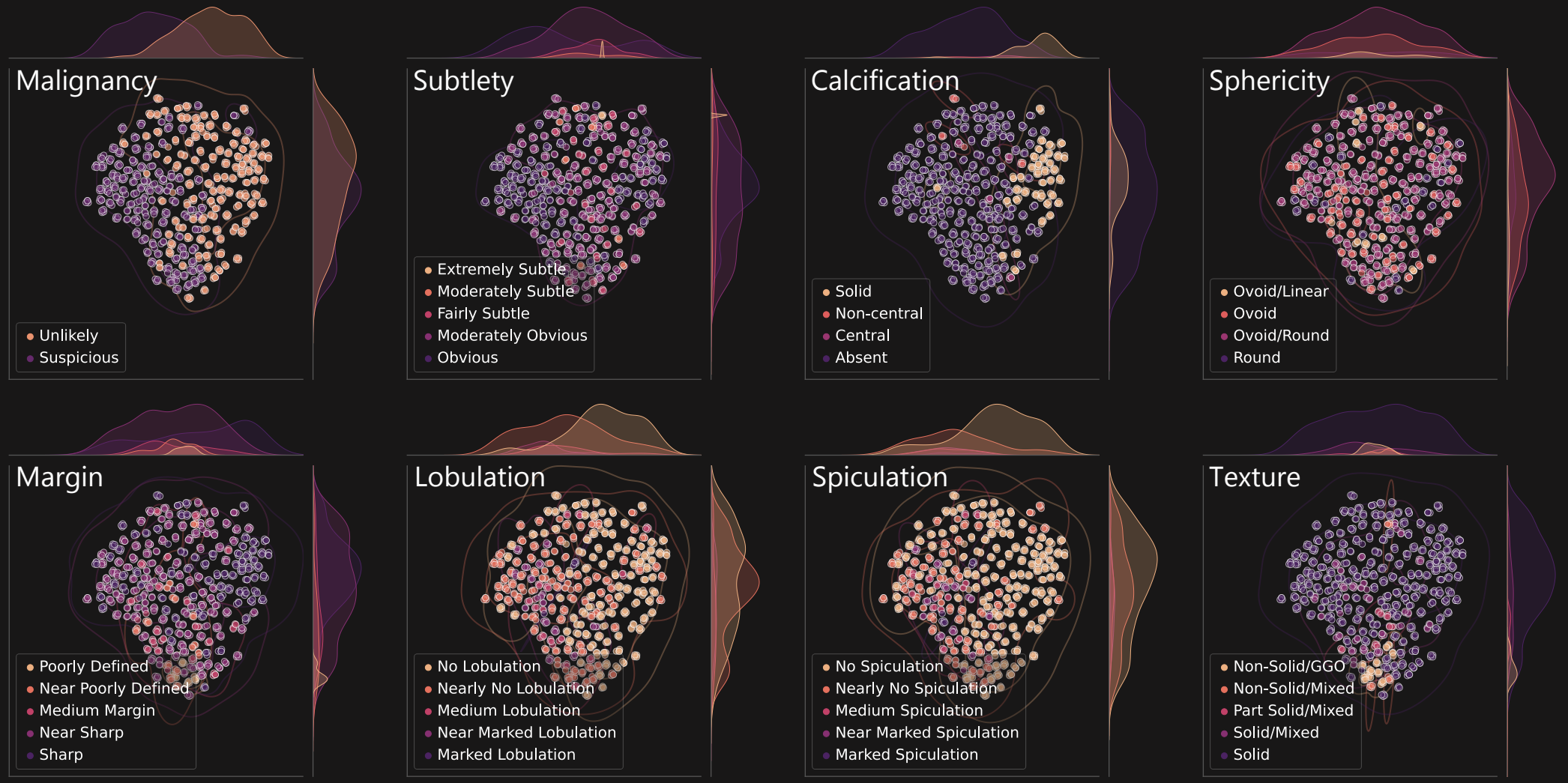
Simultaneously high accuracy in predicting malignancy and all nodule attributes.

Results:
Predicting nodule attributes



- cRedAnno shows a significantly larger probability of simultaneously predicting all 8 nodule attributes correctly.
- Approximately 90% nodules have at least 7 attributes correctly predicted.

Results:
Analysis of extracted features in learned space



Results: Ablation study

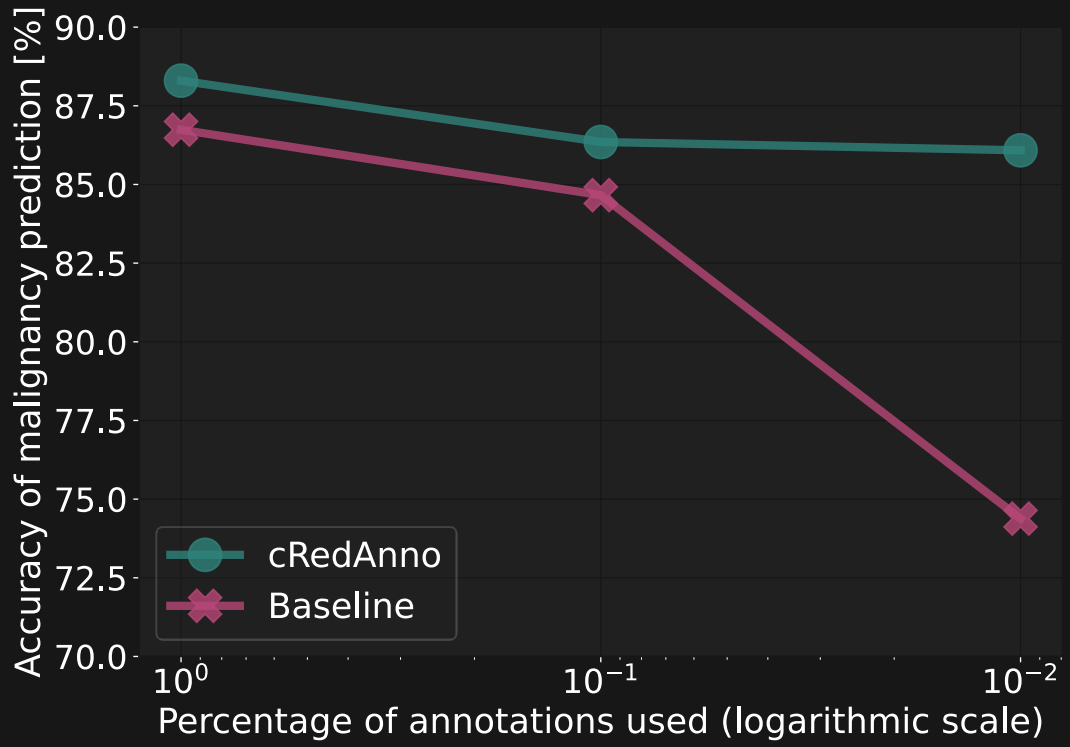
Validation of components

Accuracy of malignancy prediction (%). All annotations are used during training.

Arch	#params	Training strategy	ImageNet pretrain	Acc
		end-to-end	×	86.74*
ResNet-50	23.5M	two-stage	×	70.48
		two-stage	√	70.48
		end-to-end	×	64.24
ViT	21.7M	two-stage	×	79.19
		two-stage	√	**88.30**

* Representative setting and performance of previous works using CNN architecture

Annotation reduction



Conclusion

- A data-/annotation-efficient self-explanatory approach for lung nodule diagnosis

- Comparing with SOTA:
  - 1% annotation, fewer samples
  - comparable in malignancy prediction
  - significantly better in predicting all nodule attributes as explanations

- Visualising the learned space:
  - extracted features are highly separable
  - clustering coincides with clinical knowledge

- Open-source code

github.com/diku-dk/credanno

  - Implementation
  - Sample selection
  - Pre-processing
  - Experiments
  - Plots

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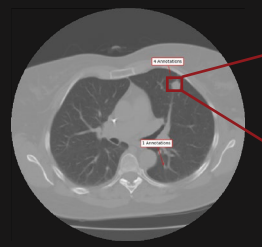

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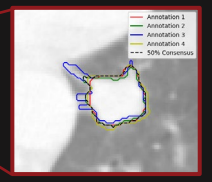

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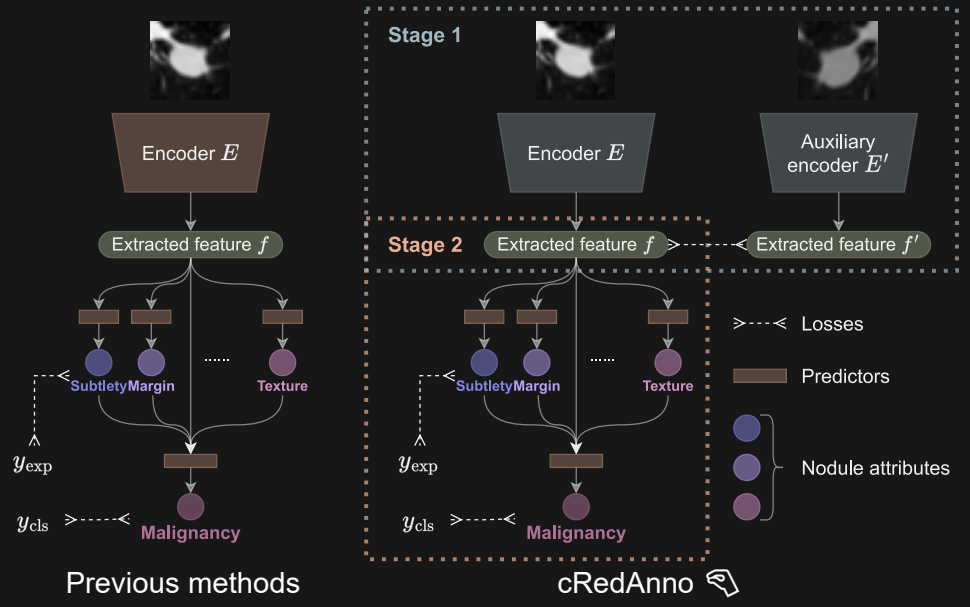

Results