Stabilizing Deep Convolutional Neural Networks for Image Segmentation

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Problem.

small perturbations in input cause large changes in segmentation output

Solution.

lower the Lipschitz constant for each convolutional layer in DCNN

At each layer, kernel $K = \begin{bmatrix} k_{-1,-1} & k_{-1,0} & k_{-1,1} \\ k_{0,-1} & k_{0,0} & k_{0,1} \\ k_{1,-1} & k_{1,0} & k_{1,1} \end{bmatrix}$

apply convolution kernel $u \longmapsto K * u + b$

or, express as a linear operator $\vec{u} \longmapsto A_{[K]}\,\vec{u} + b,$

where $A_{[K]} = \begin{bmatrix} T_0 & T_1 & & & \\ T_{-1} & \cdots & \cdots & & \\ & \cdots & \cdots & \cdots & \\ & & \cdots & \cdots & T_1 \\ & & & T_{-1} & T_0 \end{bmatrix}$ with $T_i = \begin{bmatrix} k_{i,0} & k_{i,1} & & & \\ k_{i,-1} & \cdots & \cdots & & \\ & \cdots & \cdots & \cdots & \\ & & \cdots & \cdots & k_{i,1} \\ & & & k_{i,-1} & k_{i,0} \end{bmatrix}$

Lipschitz constant of convolution layer $= \|A_{[K]}\|_2$

Problem.

$A_{[K]}$ is too big to compute $\|A_{[K]}\|_2$ quickly

Solution.

use Hölder's Inequality to bound $\|A_{[K]}\|_2$ instead:

$$\|A_{[K]}\|_2 \leq \|A_{[K]}\|_1 \|A_{[K]}\|_\infty \leq \|K\|_{1,ent}$$

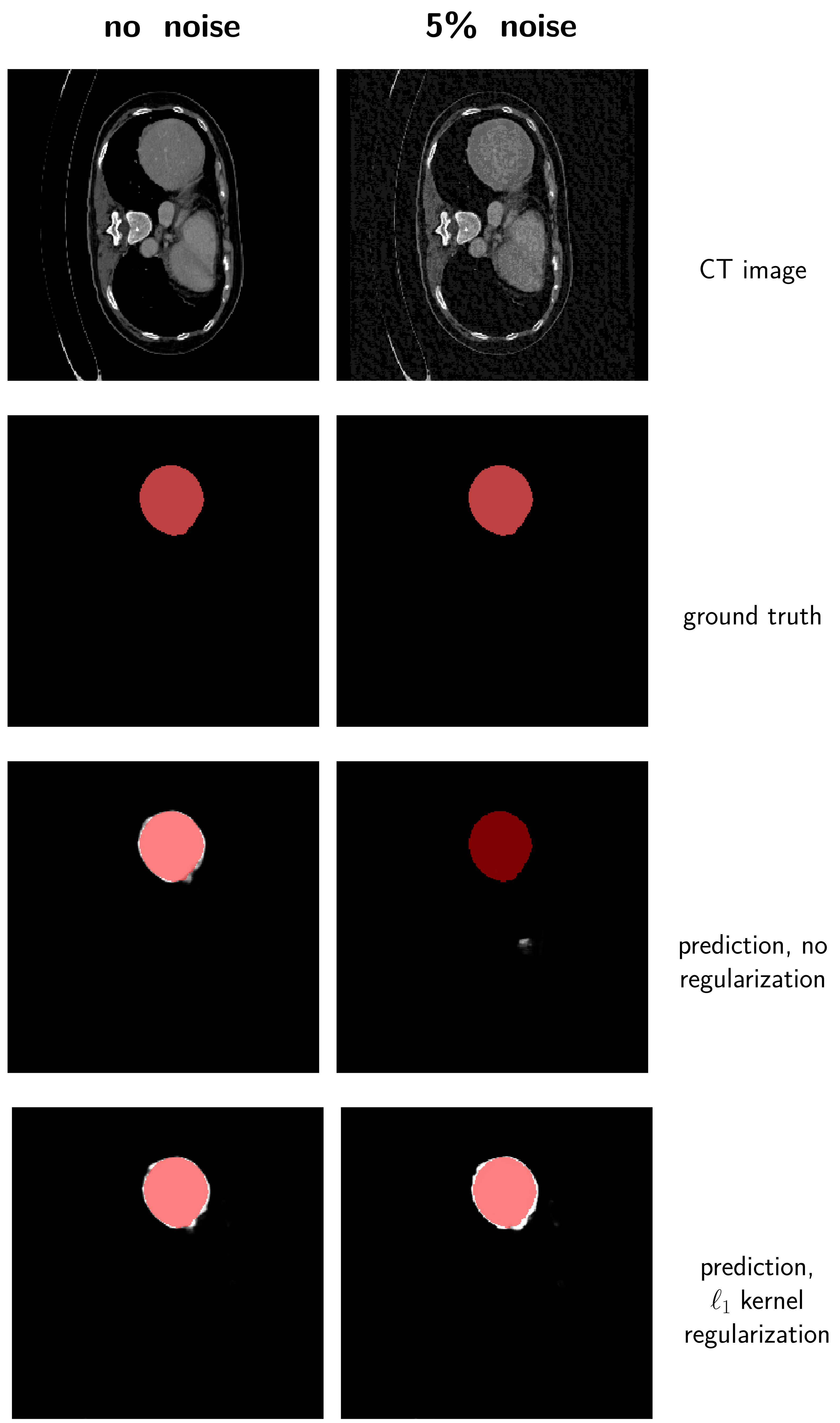
Implementation and Results

- use ℓ_1 regularization on kernels
- implement with Keras + Tensorflow
- compare built-in method with proximal gradient method
- train DCNN on MICCAI LiTS 2017 Challenge liver CT data
- assess accuracy using Dice Similarity Coefficient (DSC)

Regularization	Lipschitz bound	DSC (training)	DSC (testing)
none	9.34×10^{41}	0.938	0.930
ℓ_1	9.73×10^{31}	0.924	0.931
Proximal ℓ_1	1.67×10^{31}	0.938	0.920

Conclusions

- fast → linear complexity in size of kernel
- theoretically sound + empirically reliable
- no extra implementation



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