Efficient and Robust CT Image Segmentation with a Level Set Network

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Goal : accurate, efficient, fast, robust image segmentation

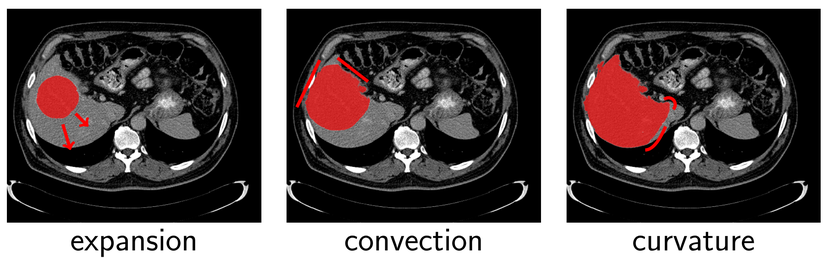
Why automate image segmentation?

- necessary for treatment plans for radiation therapy
- costly to perform by hand
- less interobserver variability

Current automated segmentation methods

Method 1 : Solve a PDE

- Evolution via expansion, convection, curvature
- Well-established theory to analyze approximation, stability
- Semiautomated : requires initialization by user
- Reliant on edge information + image gradients
- Robust to perturbation

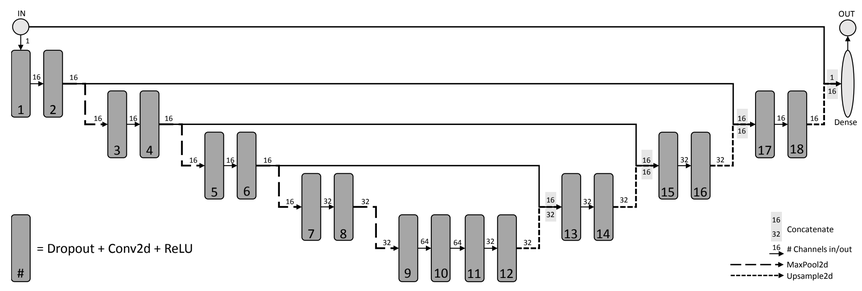


expansion | convection | curvature

$$\partial_t u - \underbrace{\gamma\ \nabla g_I \cdot \nabla u}_{\text{convection}} - \underbrace{g_I\ (\alpha + \beta\kappa(u))\ \|\nabla u\|}_{\text{mean curvature}} = 0$$

Method 2 : Use a Neural Network

- Fast, accurate, state-of-the-art prediction capabilities
- "Black box" : unclear why these work so well
- Fully automated, but requires hyperparameter to train
- Reliant on training data for generalization
- Sensitive to perturbation, adversarial attack



Structure of our sample CNN.

Both PDEs and CNNs use the same operations : convolutions followed by ReLU activations.

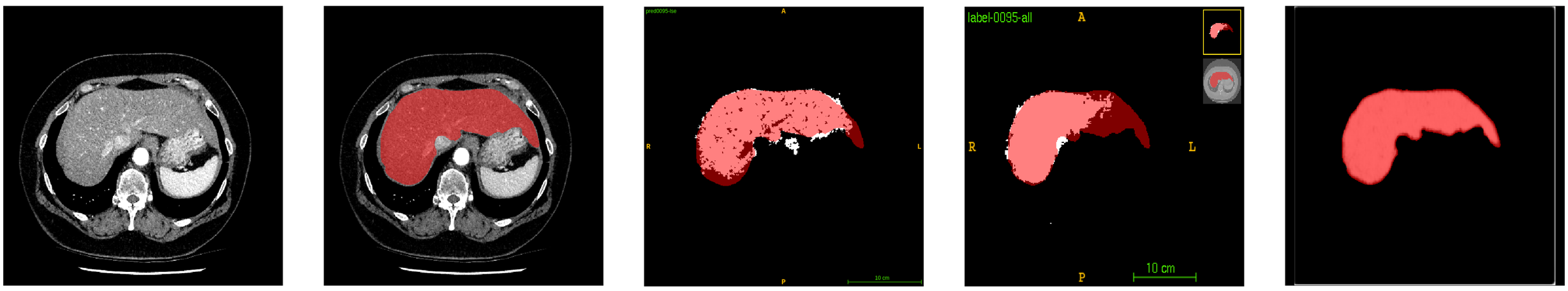
Our proposed method

Method 3 : PDE structure + CNN learning

- PDE structure to leverage image properties
- PDE numerical discretization for stability, robustness
- Learning kernels to obtain CNN accuracy
- Fewer parameters for more efficient learning

How to create a Level Set Network (LSN)

- Numerical discretization of PDE equation
- Replace derivatives with learned convolutions
- Upwind scheme becomes activation functions
- Timesteps become residual updates



Results

Method	PDE	LSN	CNN
# Parameters	3	69K	32M
Training Time	10mn	24hr	78hr
Avg DSC	0.745	0.804	0.955

Results: Parameters and DSC scores from three segmentation methods.

Conclusions

- CNNs more accurate than PDE methods, LSN
- PDE methods, LSN provide analytical structure
- Mechanism for converting between PDEs and CNNs

JAA is supported by the NLM Training Program in Biomedical Informatics & Data Science (T15LM007093), supplemented by the Ken Kennedy Institute Computer Science & Engineering Enhancement Fellowship via the Rice Oil & Gas HPC Conference.

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