Probabilistic Segmentation of Differently-sized Brain Metastases Using an Ensemble of Neural Networks

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Background

- Physicians manually contour tumors to define targets for radiation therapy and to track tumor volumes
- Manual contouring is prone to inter- and intra-observer variability
- Machine-learning segmentation could increase consistency

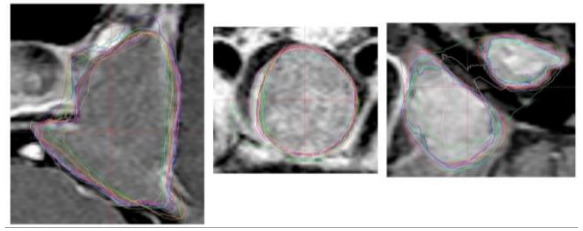

Figure 1. Inter-observer variability in manual segmentation[3]

Hypothesis

We hypothesize that an ensemble including three different neural networks (each better suited for specific tumor sizes) will optimize segmentation for all sizes of brain metastases.

Methods

General Methods
- 3D post-contrast T1-weighted MRIs
- MRIs manually contoured and grouped by size for training
- Outputs from 3 neural networks combined into probability map

Small Tumors
- <0.5 cm diameter
- LSM (liquid state machine) ensemble and random forest classification
- LSM has signal separating properties to differentiate between small tumors and blood vessels

Medium Tumors
- 0.5-1.5 cm
- 3D CNN (convolutional neural network)

Large and Very Large Tumors
- Large: 1.5-3 cm; Very large: >3 cm
- U-net deep learning network is effective for detecting tumors that occupy large areas

Methods (continued)

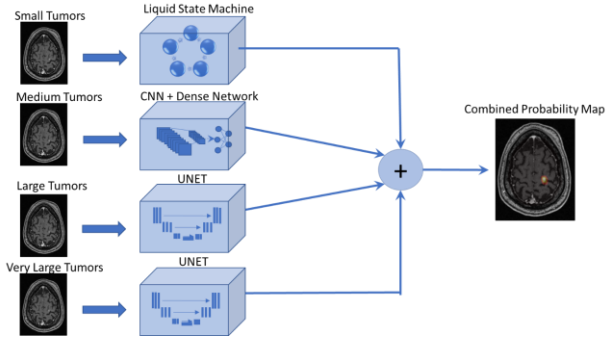

Figure 2. Pipeline for processing differently-sized tumors with a neural network ensemble[1]

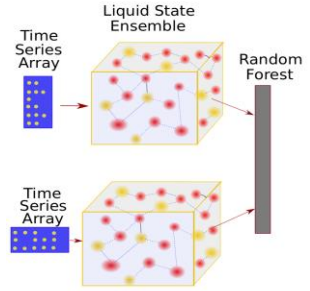

Figure 3. LSM ensemble and random forest classifier for small tumors[1]

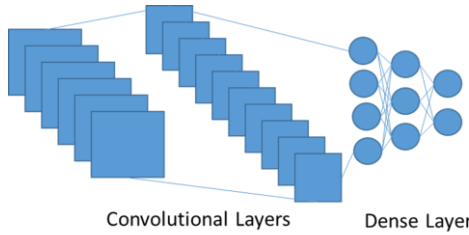

Figure 4. 3D CNN for medium tumors[1]

Methods (continued)

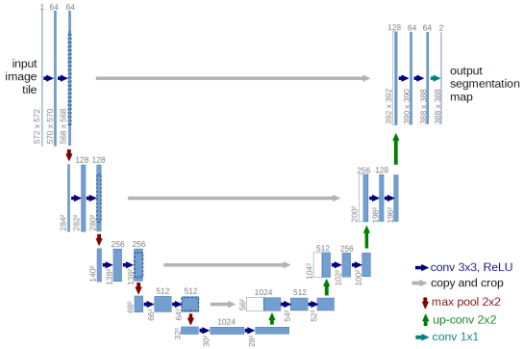

Figure 5. U-net deep learning network for (very) large tumors[2]

Results

- LSM ensemble detected small tumors with 90-100% probability and no false positives
- Single LSM and CNN yielded false positives of 80-100% probability

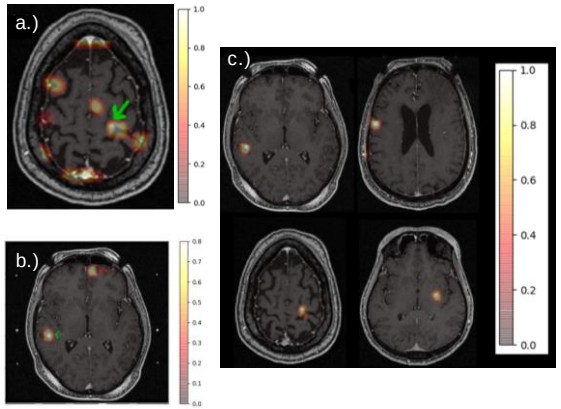

Figure 6. a. CNN results b. Single LSM results c. LSM ensemble results[1]

Results (continued)

- Over 900 data points verified to train 3D CNN for medium tumors
- The Bayesian CNN will output probability and uncertainty
- U-net is being developed to detect (very) large tumors

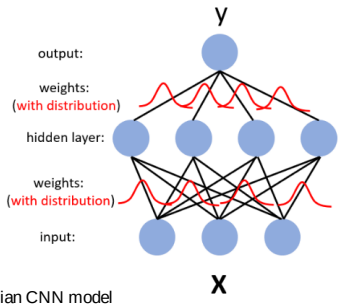

Figure 7. Bayesian CNN model

Conclusions

- LSM ensemble can detect tumors <0.5cm without false positives
- CNN in development to detect medium tumors
- U-net in development to detect (very) large tumors
- Combination of these 3 neural networks can auto-segment tumors in a clinical setting
- Consistent segmentation may improve treatment outcomes in a quantitative outcomes assessment

References

1. Andrew Elliott, Cole Morgan, Carlo Torres, and Caroline Chung "Probabilistic segmentation of small metastatic brain tumors using liquid state machine ensemble", Proc. SPIE 11597, Medical Imaging 2021: Computer-Aided Diagnosis, 115972L (15 February 2021); https://doi.org/10.1117/12.2582154

2. Ronneberger O., Fischer P., Brox T. (2015) U-Net: Convolutional Networks for Biomedical Image Segmentation. In: Navab N., Hornegger J., Wells W., Frangi A. (eds) Medical Image Computing and Computer-Assisted Intervention – MICCAI 2015. MICCAI 2015. Lecture Notes in Computer Science, vol 9351. Springer, Cham. https://doi.org/10.1007/978-3-319-24574-4_28

3. Sandstrom H. Toma-Dasu I., Chung C. (2021) Simultaneous Truth and Performance Level Estimation Method for Evaluation of Target Contouring in Radiosurgery. ms.

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