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TU/e Technische Universiteit Eindhoven University of Technology

Deep learning for brain MRI segmentation

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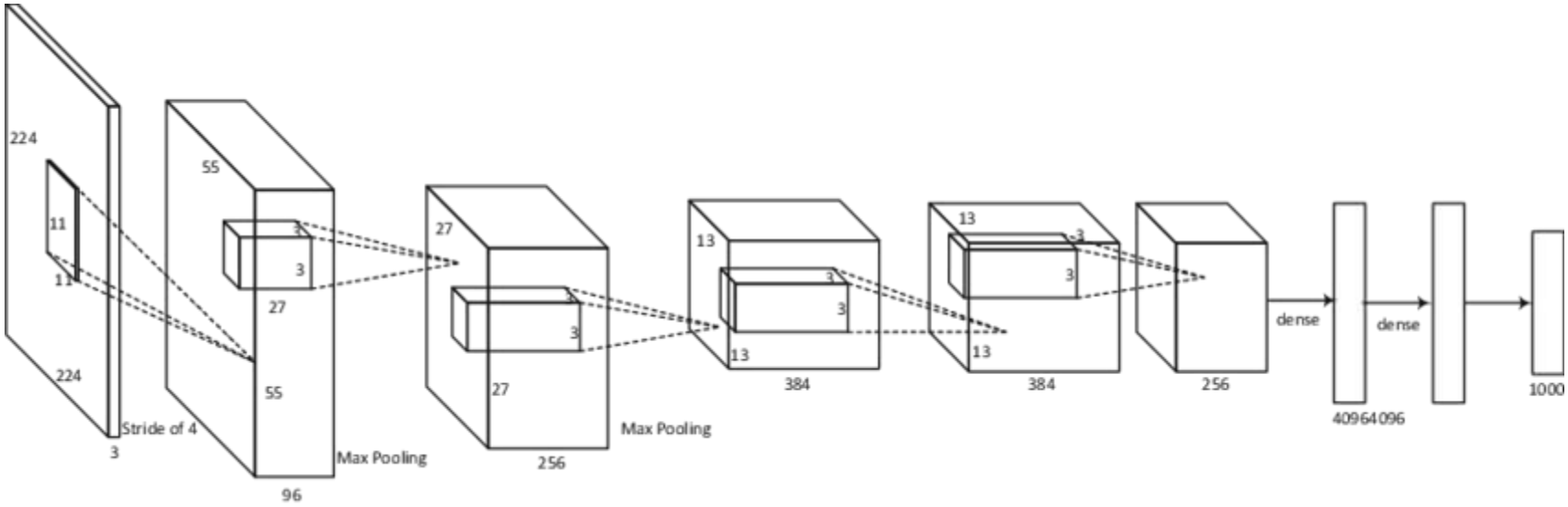
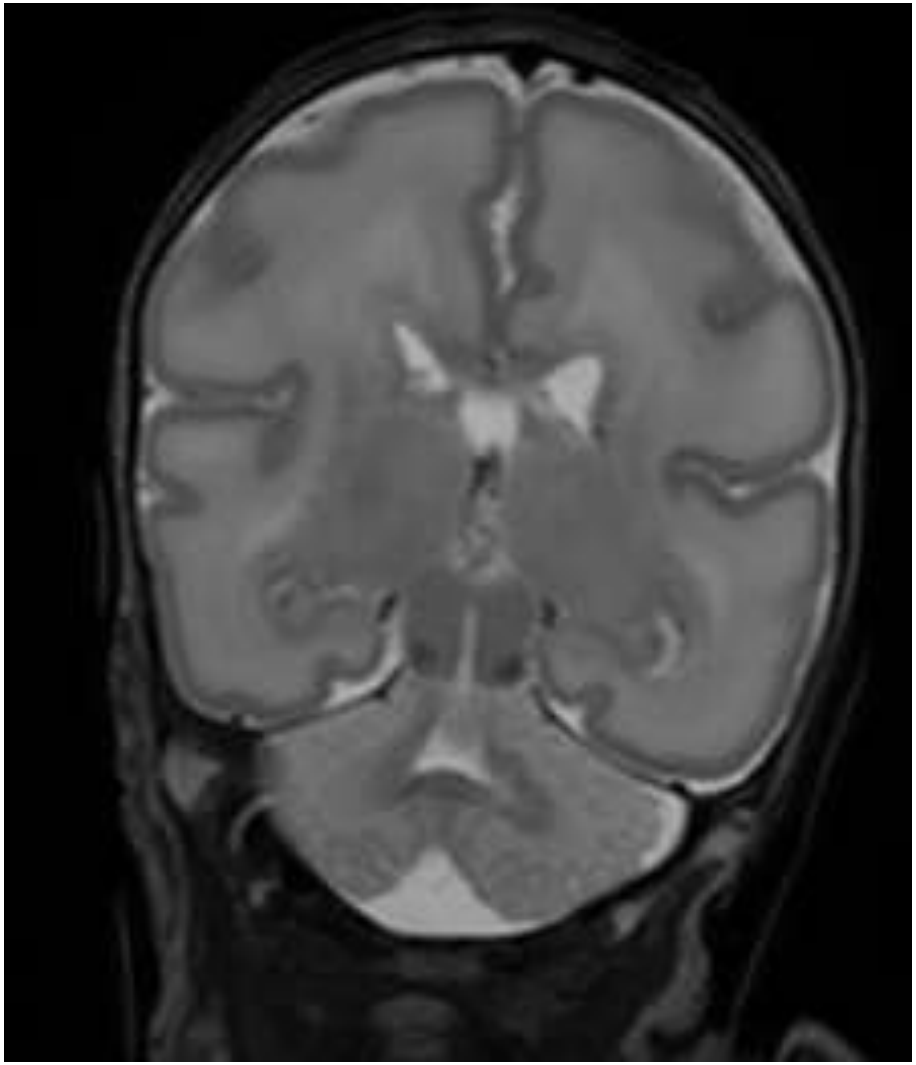
Where innovation starts

Convolutional neural networks

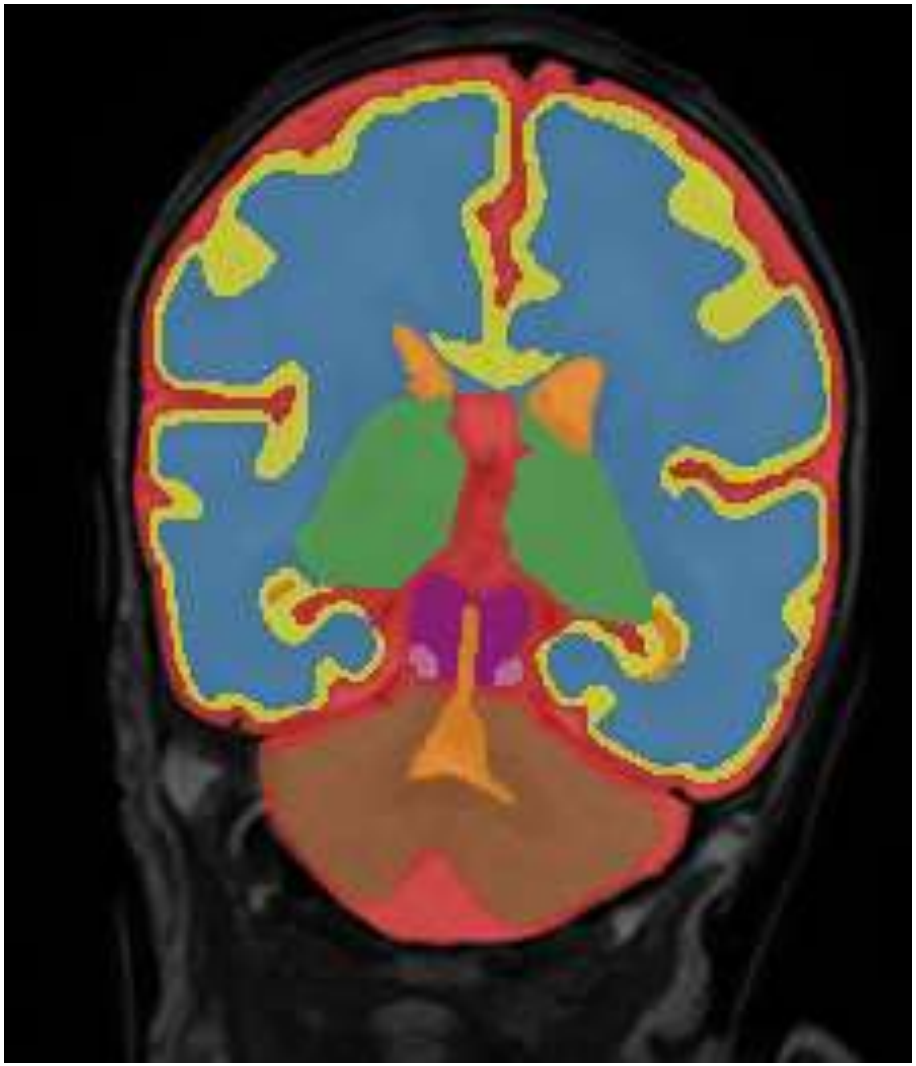


Krizhevsky, Alex, Ilya Sutskever, and Geoffrey E. Hinton. "Imagenet classification with deep convolutional neural networks." In: NIPS, 2012



30 weeks PMA, coronal T2-w

Neonatal brain MRI



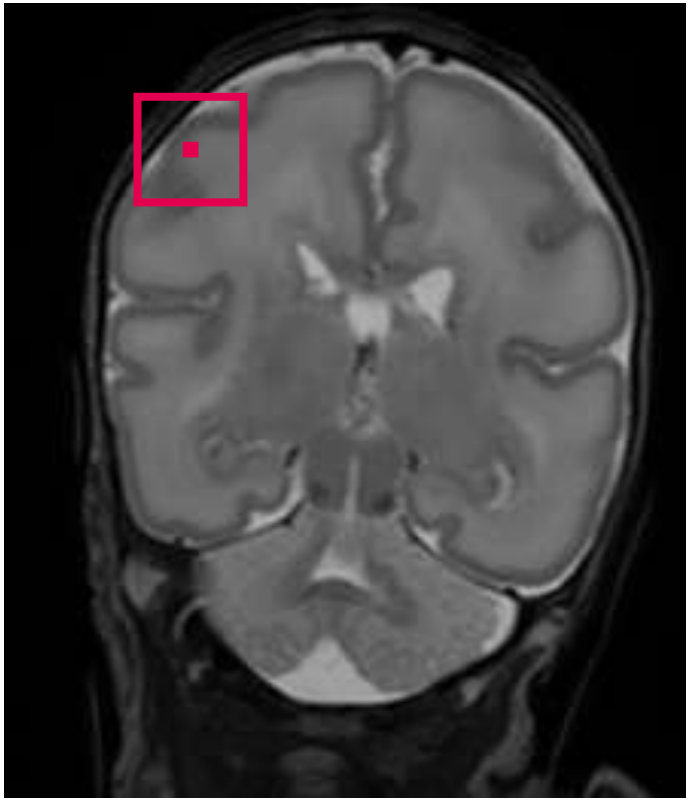
Manual reference segmentation

Neonatal brain MRI

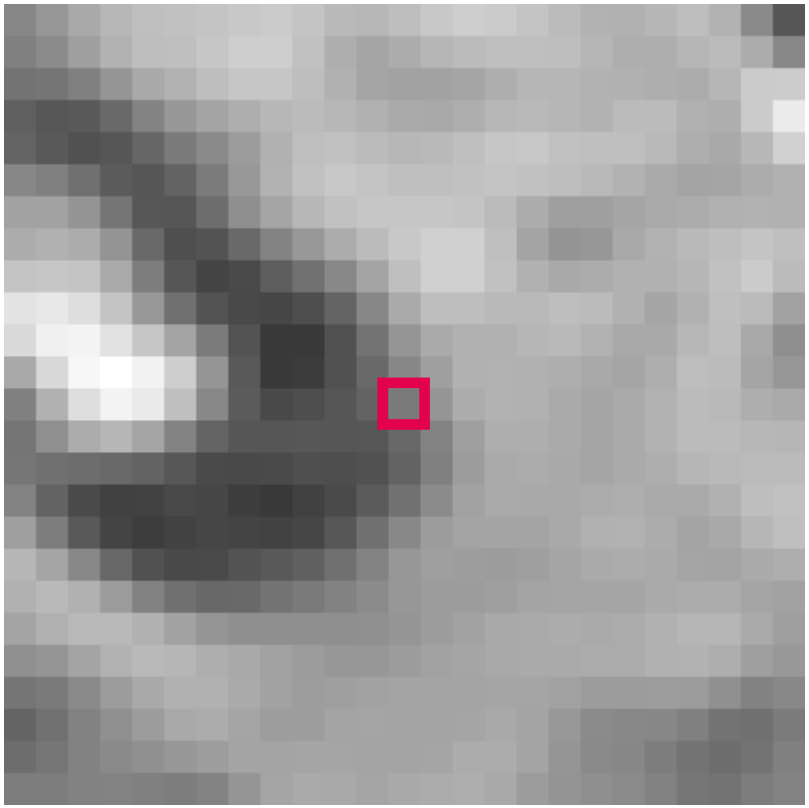
- Unmyelinated white matter
- Cortical grey matter
- Extracerebral CSF
- Ventricular CSF
- Basal ganglia and thalami
- Brain stem
- Cerebellum
- Myelinated white matter

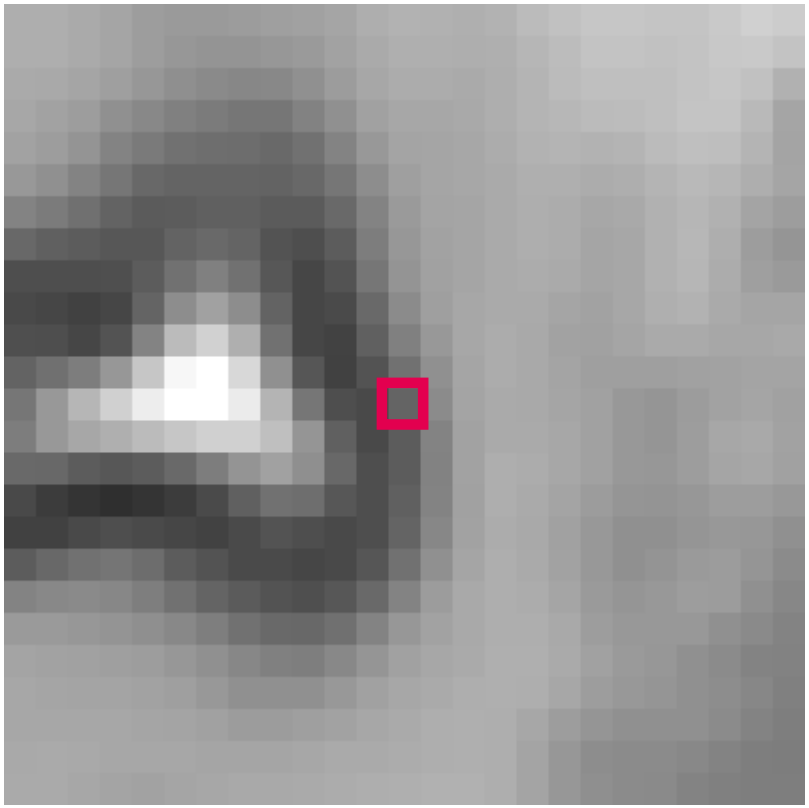
Segmentation with CNNs

- Patch-based approach



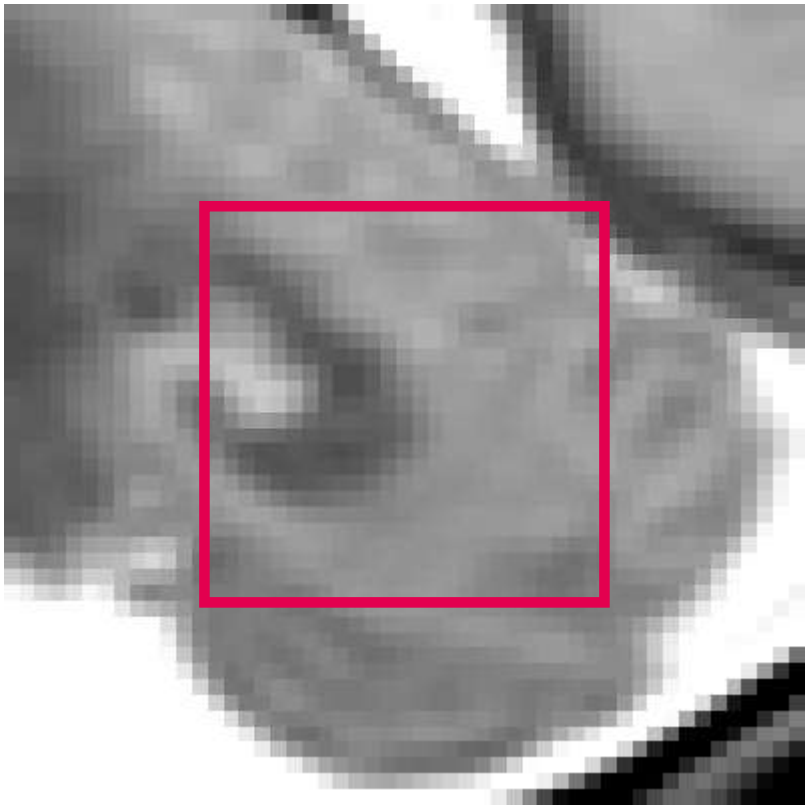
Multi-scale patch-based CNN

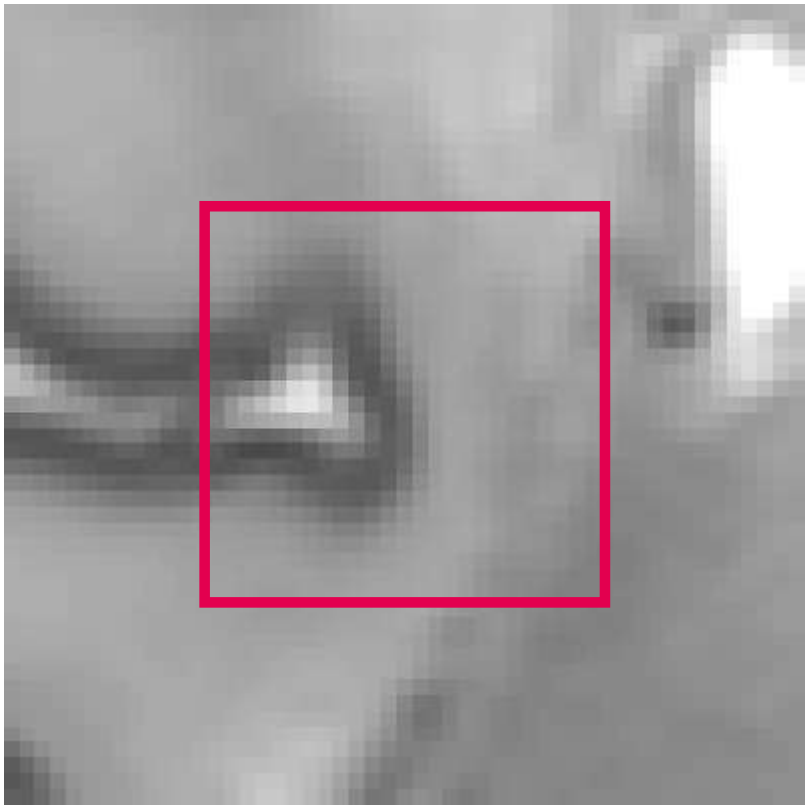




25 × 25 voxels

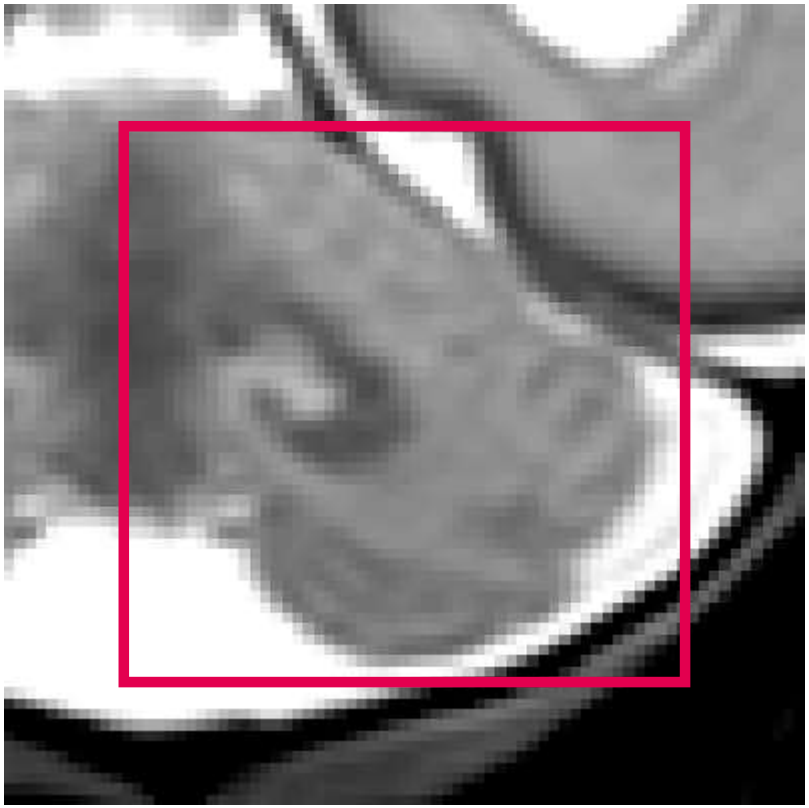
Multi-scale patch-based CNN

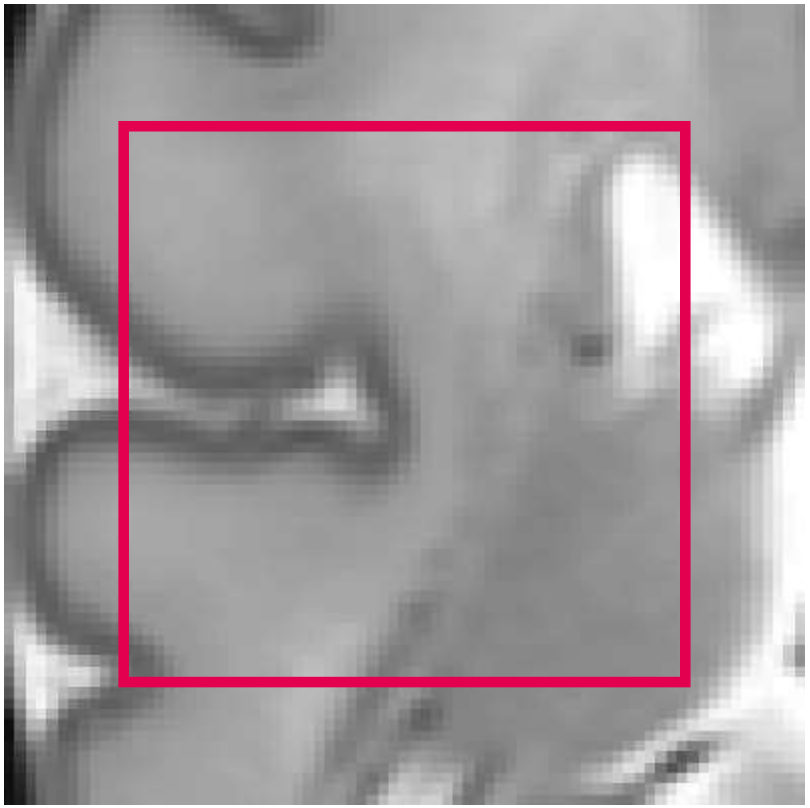




51 × 51 voxels

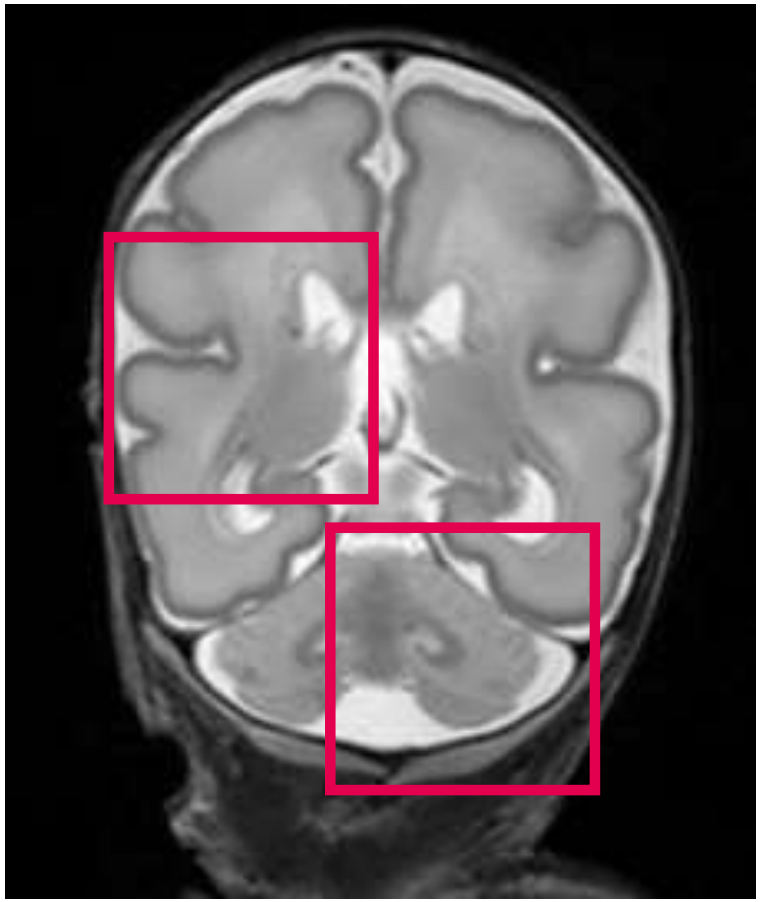
Multi-scale patch-based CNN



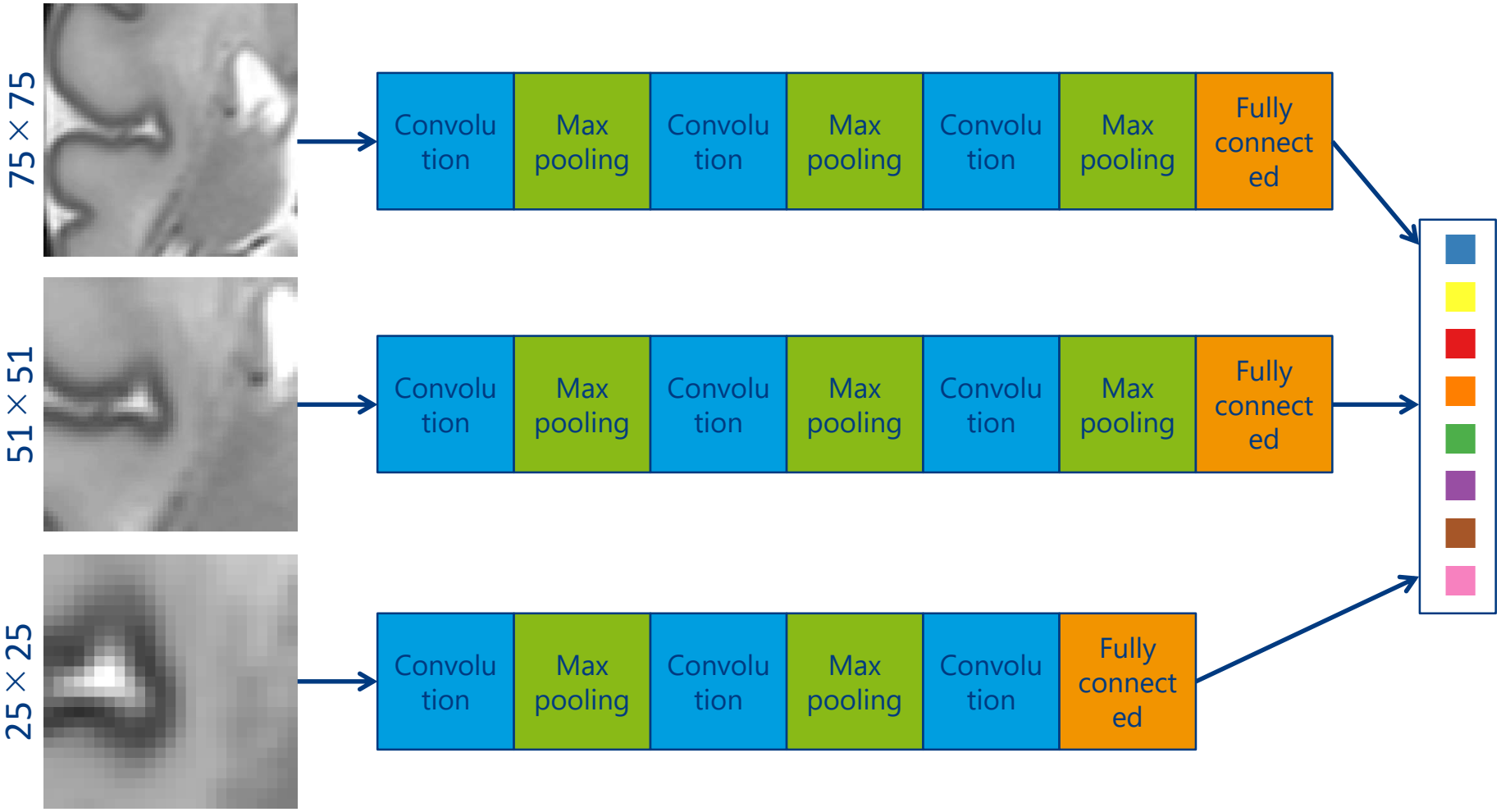


75 × 75 voxels

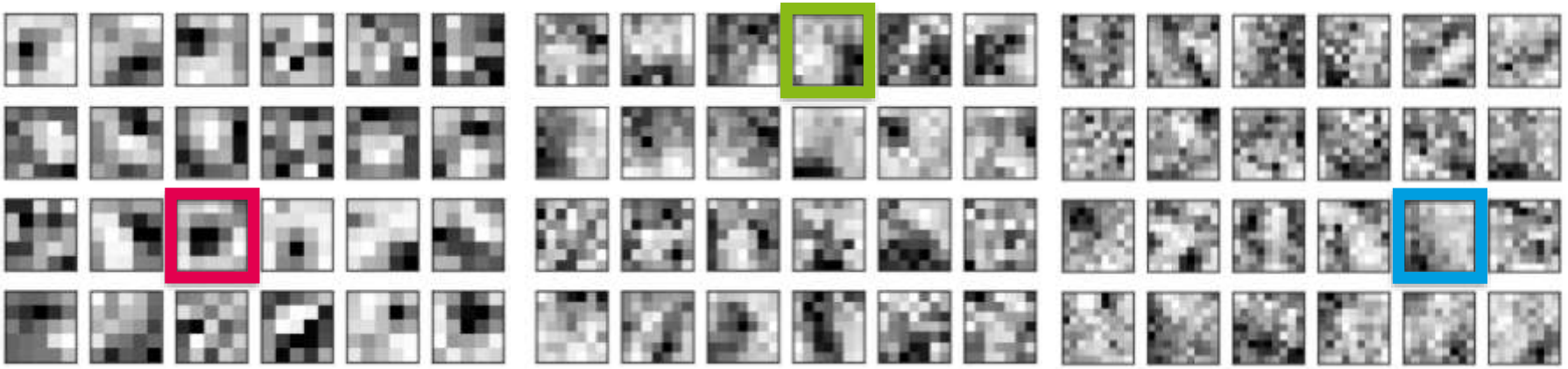
Multi-scale patch-based CNN



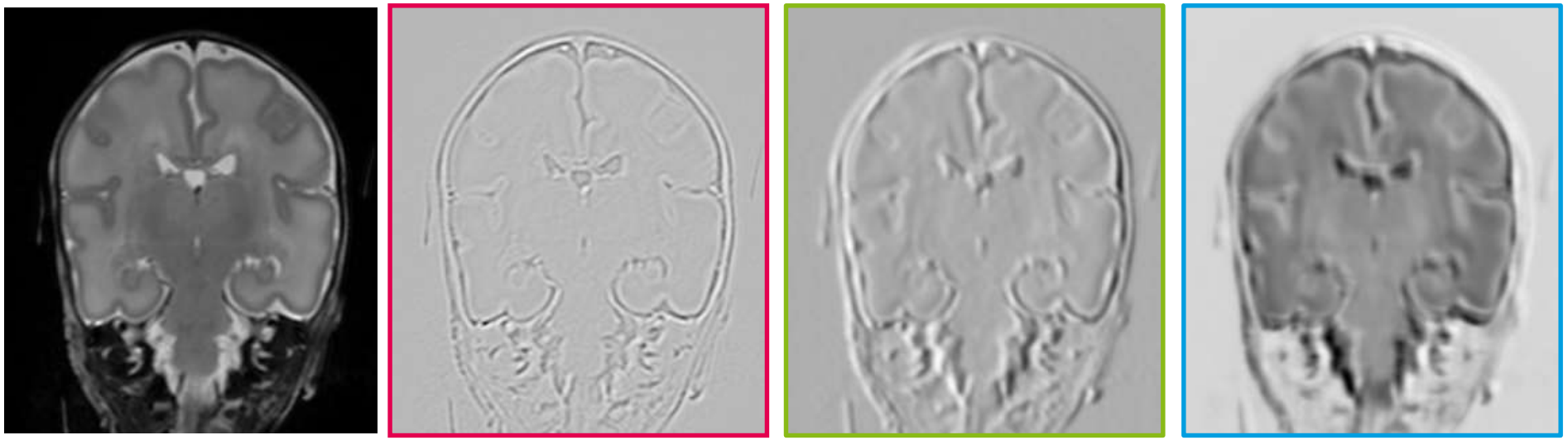
Multi-scale patch-based CNN



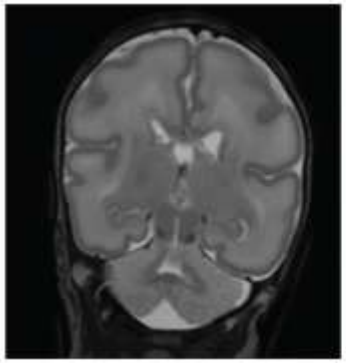
Moeskops, Pim, et al. "Automatic segmentation of MR brain images with a convolutional neural network." *IEEE TMI*, 2016.



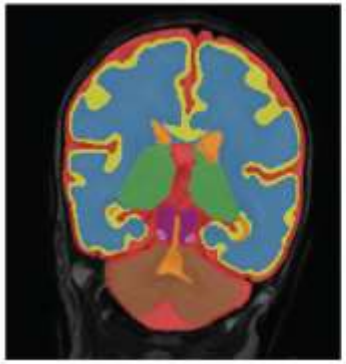
Trained CNN after the first layer



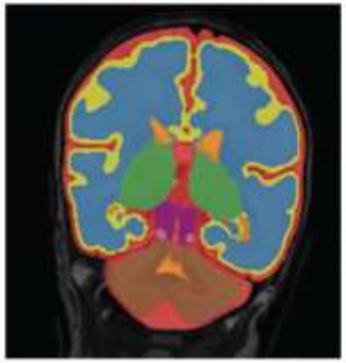
Image



Reference



Automatic



Moeskops, Pim, et al. "Automatic segmentation of MR brain images with a convolutional neural network." *IEEE TMI*, 2016.

Dice coefficients

	Neonatal 1	Neonatal 2	Neonatal 3	Adults 1	Adults 2
(Unmyelinated) white matter	0.96	0.92	0.92	0.94	0.88
Cortical grey matter	0.84	0.82	0.88	0.91	0.84
Extracerebral CSF	0.91	0.86	0.84	-	0.76
Ventricular CSF	0.88	0.85	0.81	0.85	0.92
Basal ganglia and thalami	0.91	0.86	0.91	0.85	0.81
Brain stem	0.87	0.78	0.84	0.92	0.90
Cerebellum	0.92	0.93	0.93	0.95	0.90
Myelinated white matter	0.69	0.56	0.55	-	-

Moeskops, Pim, et al. "Automatic segmentation of MR brain images with a convolutional neural network." *IEEE TMI*, 2016.

134 segmentation classes

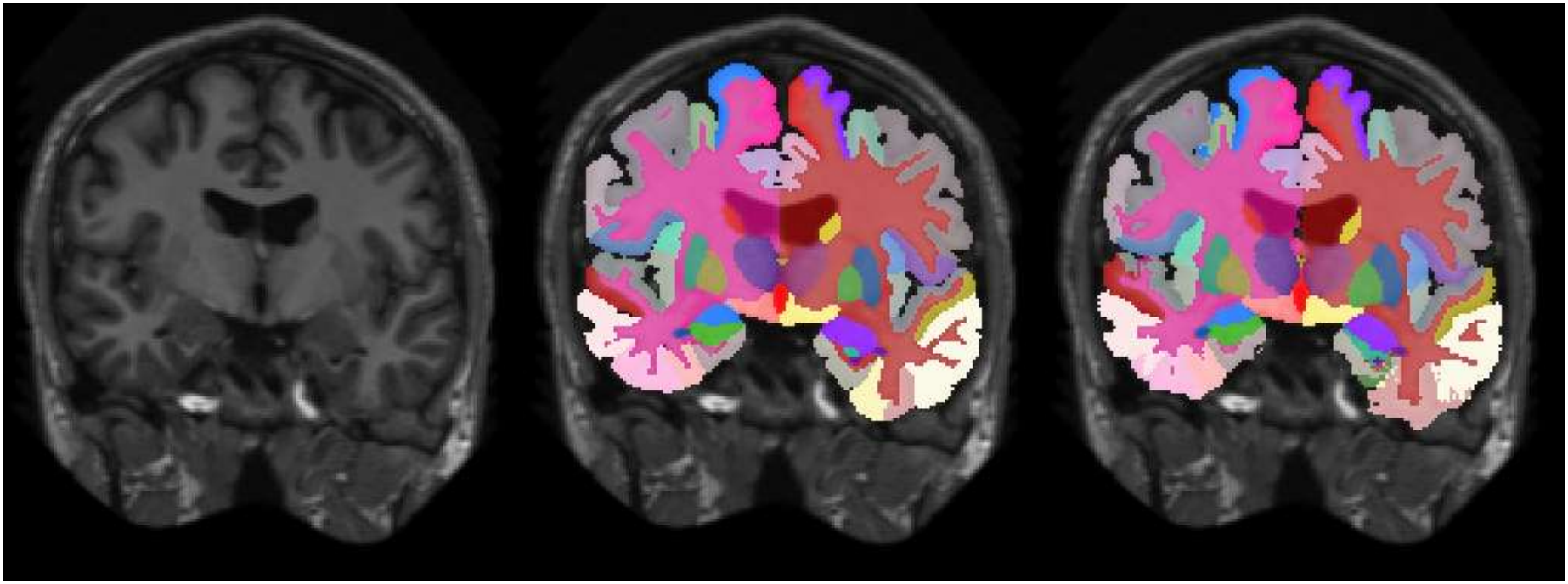
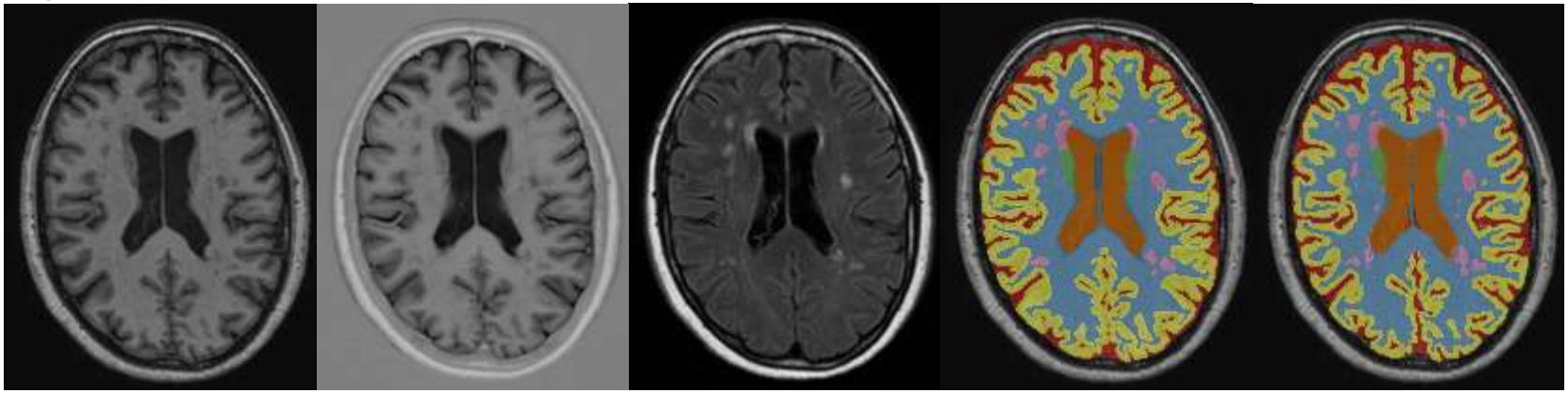


Image Reference Automatic

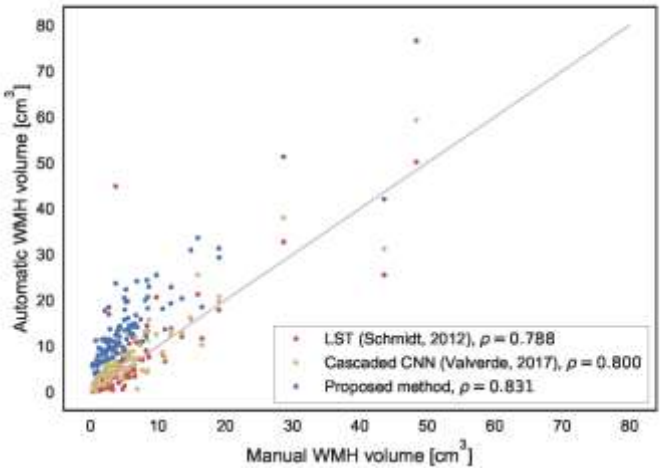
Average Dice of 0.74

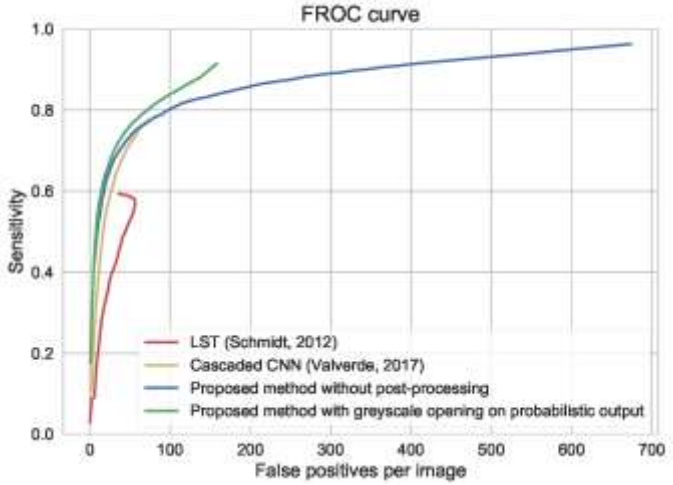
Moeskops, Pim, et al. "Automatic segmentation of MR brain images with a convolutional neural network." *IEEE TMI*, 2016.

Segmentation of white matter hyperintensities



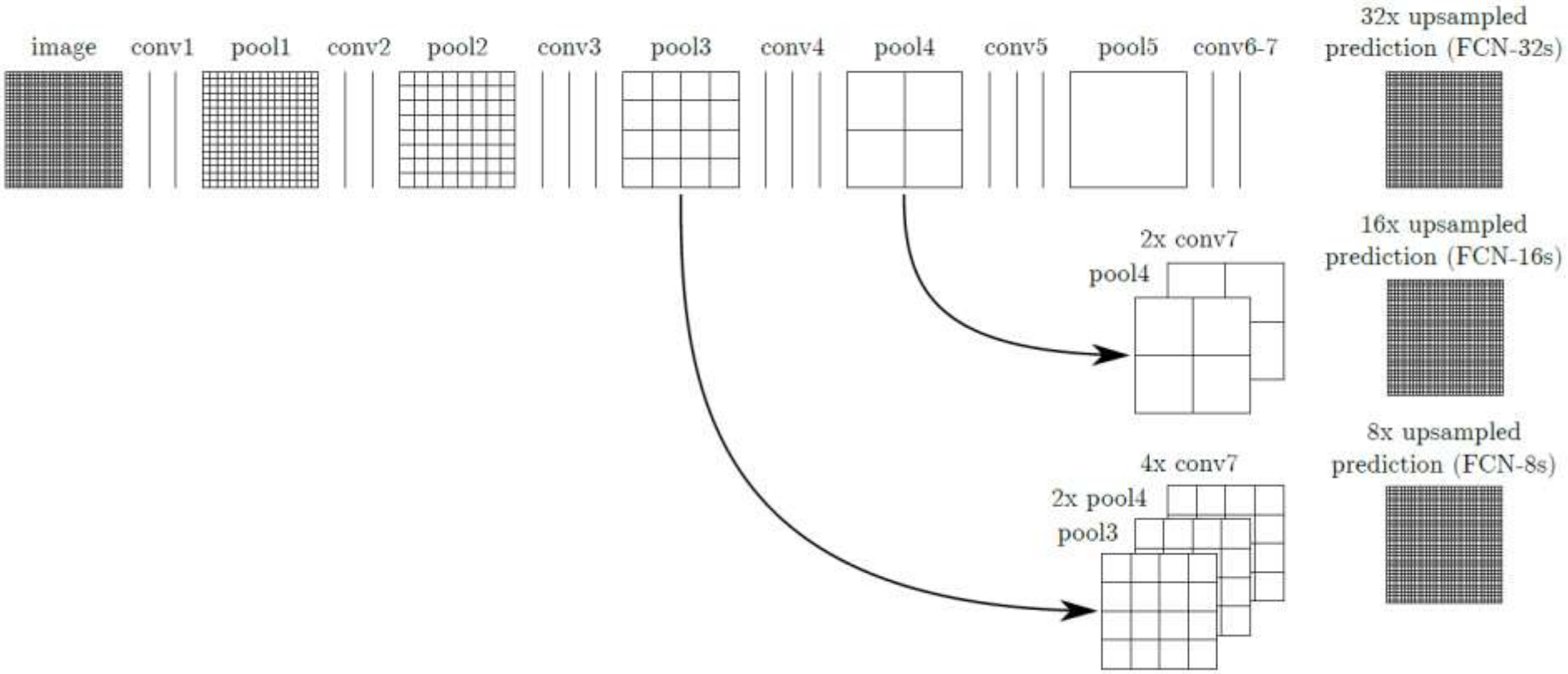
T1 T1 IR T2 FLAIR Reference Automatic





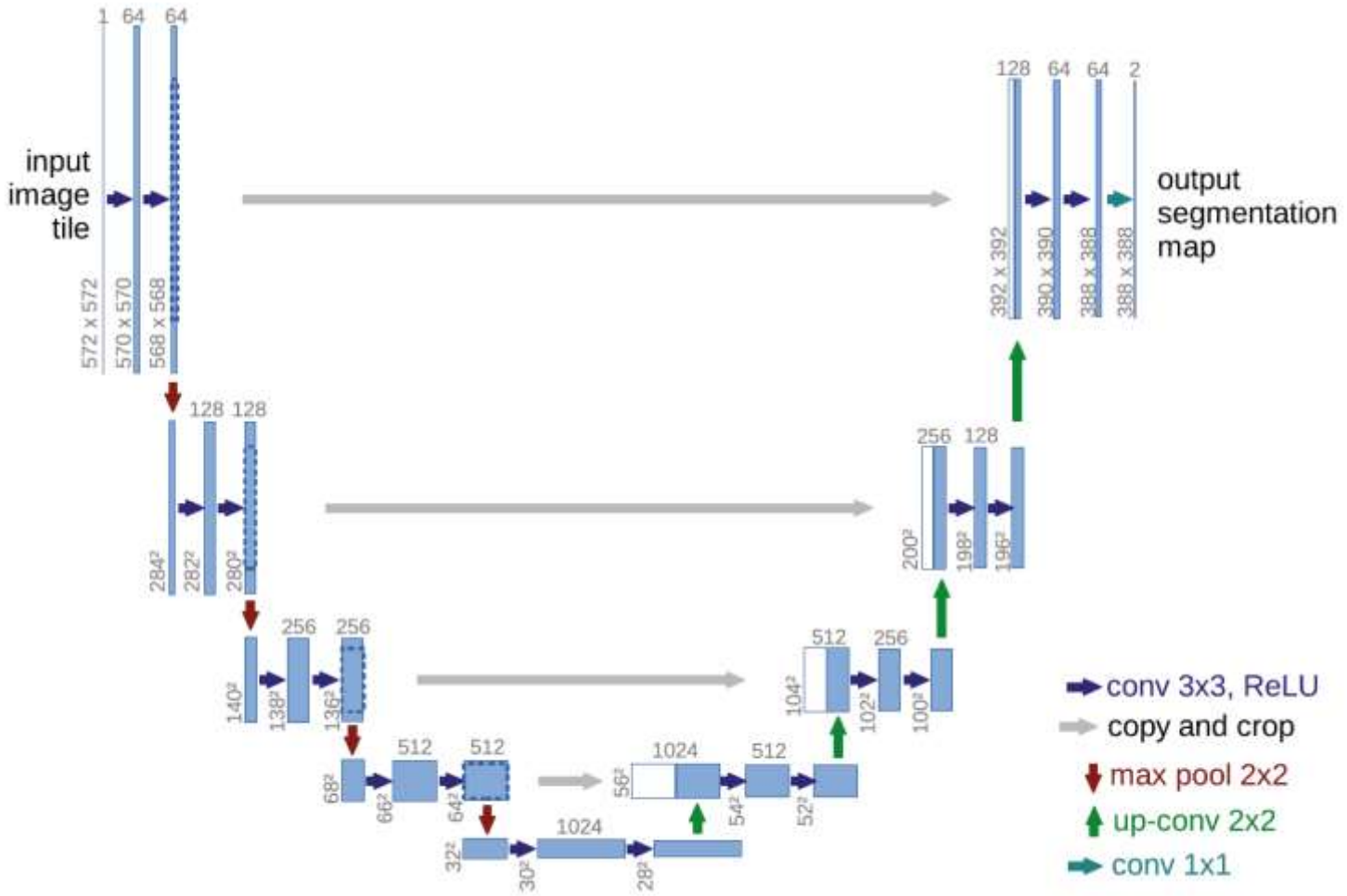
Moeskops et al., Evaluation of a deep learning approach for the segmentation of brain tissues and white matter hyperintensities of presumed vascular origin in MRI, *NeuroImage: Clinical*, 2018.

Fully convolutional CNNs



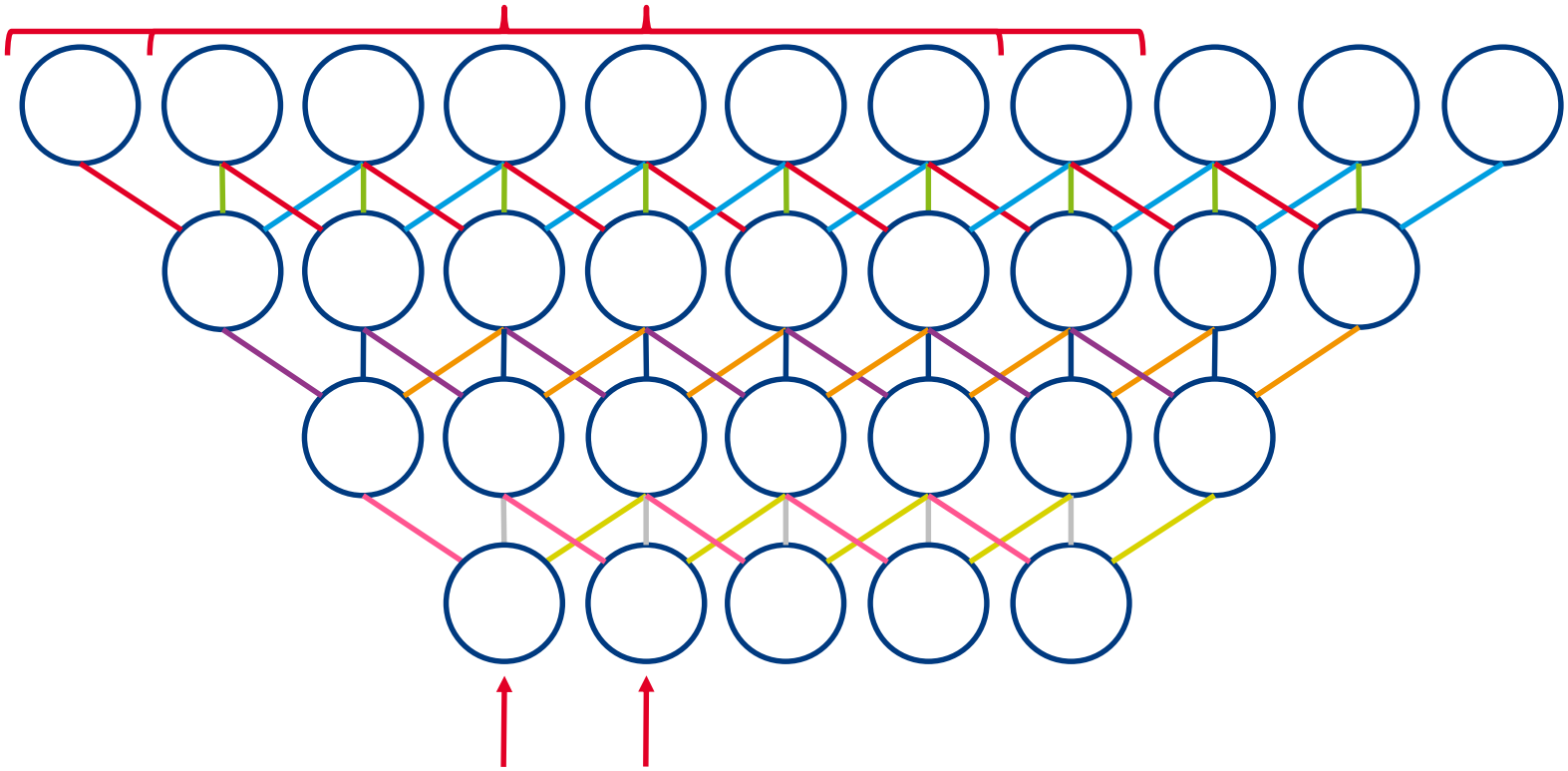
Long, J., Shelhamer, E., & Darrell, T. “Fully convolutional models for semantic segmentation.” In: *CVPR* (Vol. 3, p. 4), 2015.

UNet



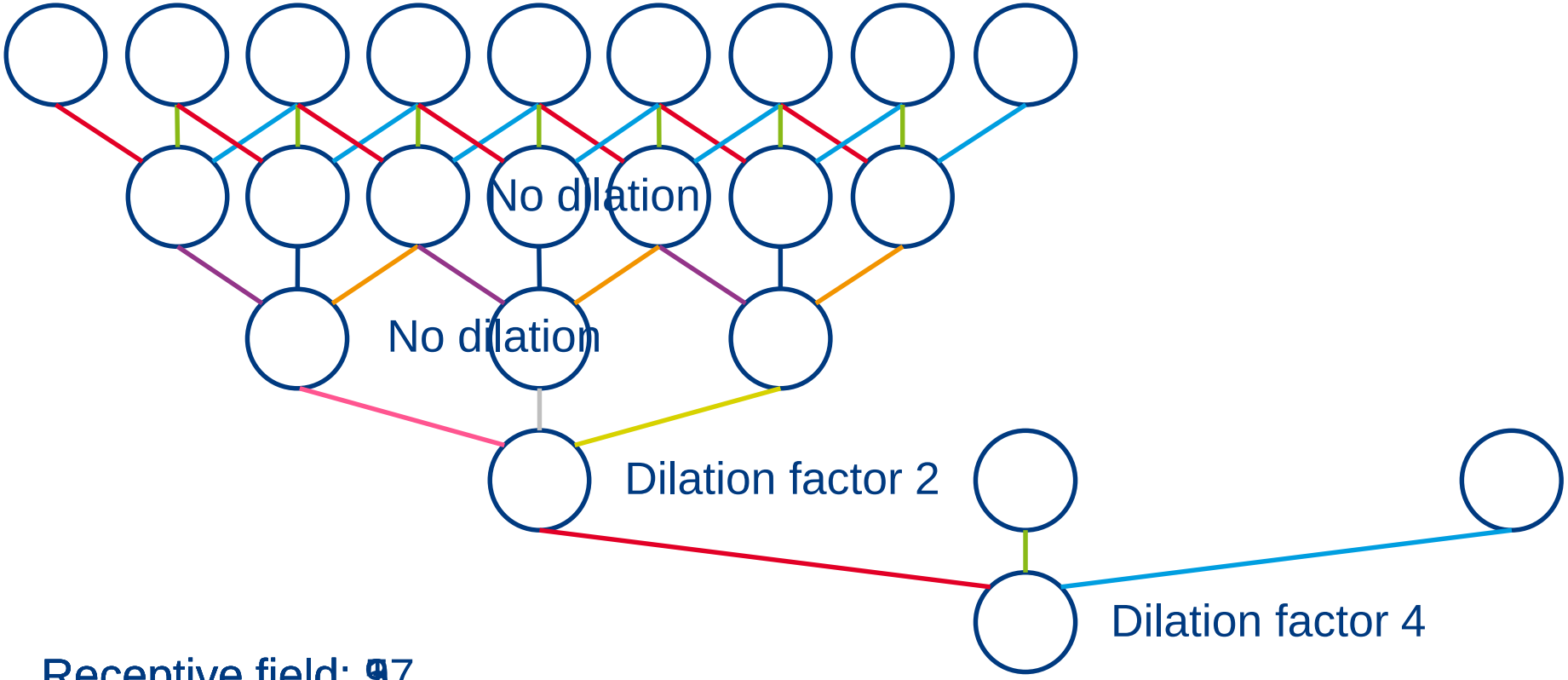
Ronneberger, Olaf, et al. "U-net: Convolutional networks for biomedical image segmentation." In: *MICCAI*, 2015

Applying a patch-based method to full images (in 1D)



Receptive field: 7

Dilated convolutional neural networks (in 1D)



Receptive field: 9 17

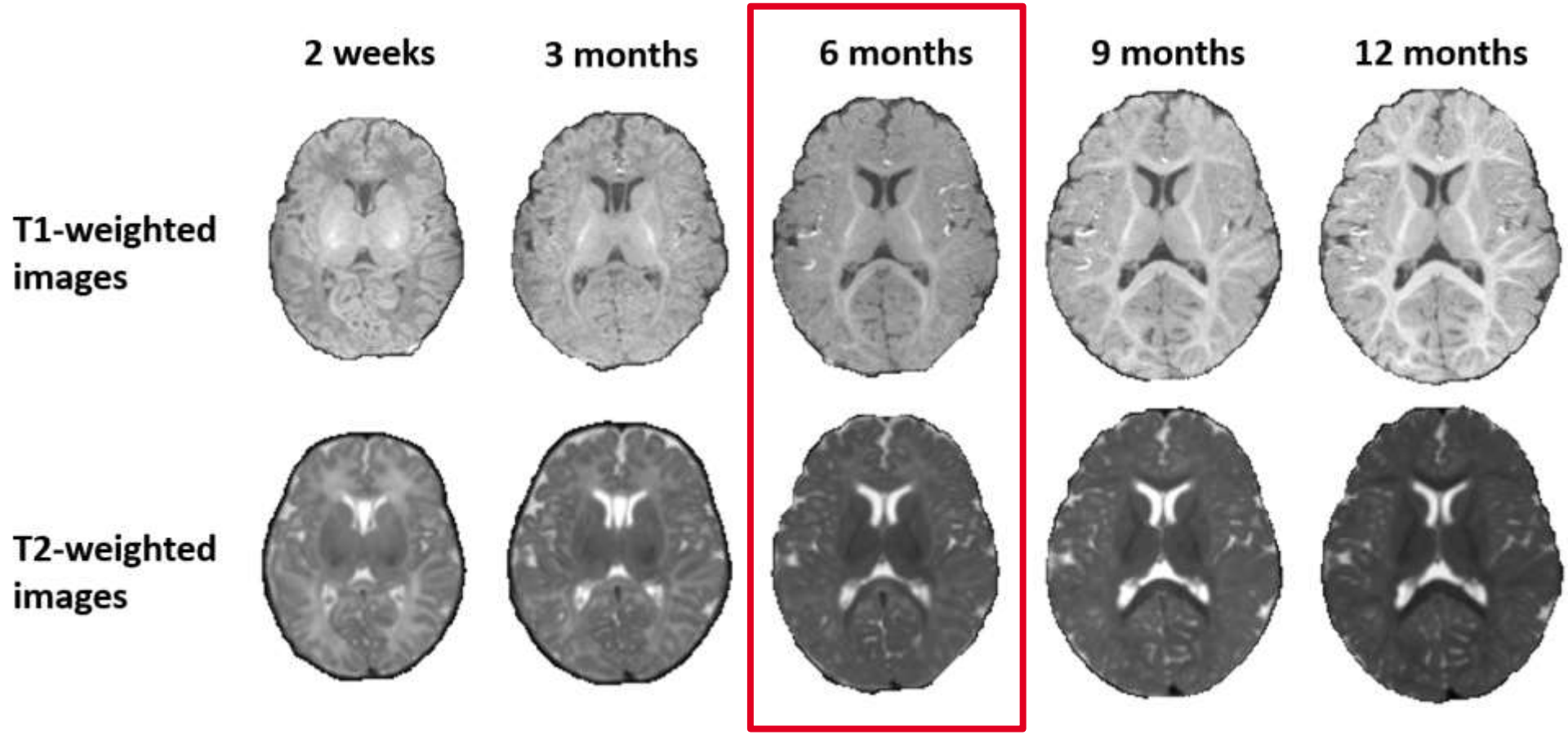
Yu et al., “Multi-Scale Context Aggregation by Dilated Convolutions” In: *ICLR*, 2016

Dilated convolutional neural networks (in 2D)

Layer	1	2	3	4	5	6	7	8
Convolution	3×3	3×3	3×3	3×3	3×3	3×3	3×3	1×1
Dilation	1	1	2	4	8	16	1	1
Truncation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Receptive field	3×3	5×5	9×9	17×17	33×33	65×65	67×67	67×67

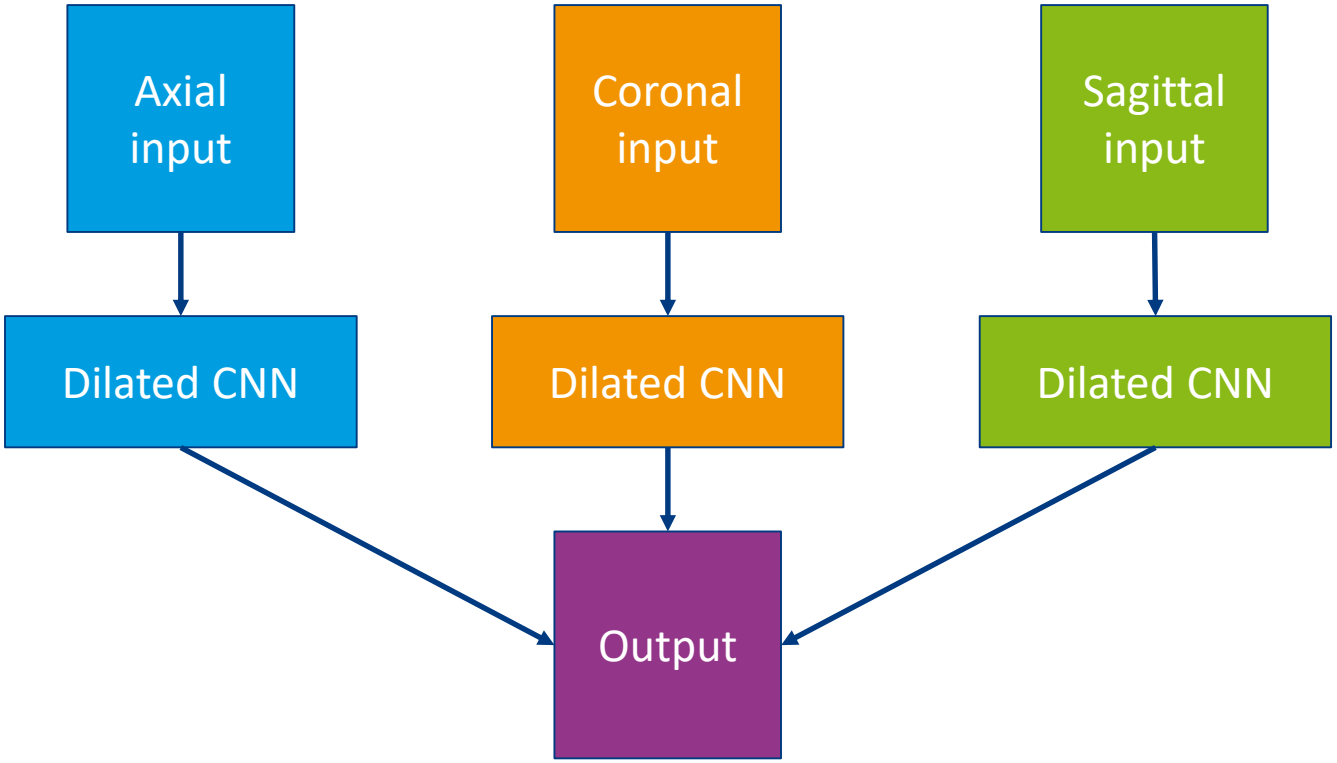
Yu et al., “Multi-Scale Context Aggregation by Dilated Convolutions” In: *ICLR*, 2016

MICCAI Challenge on 6-month infant brain MRI segmentation

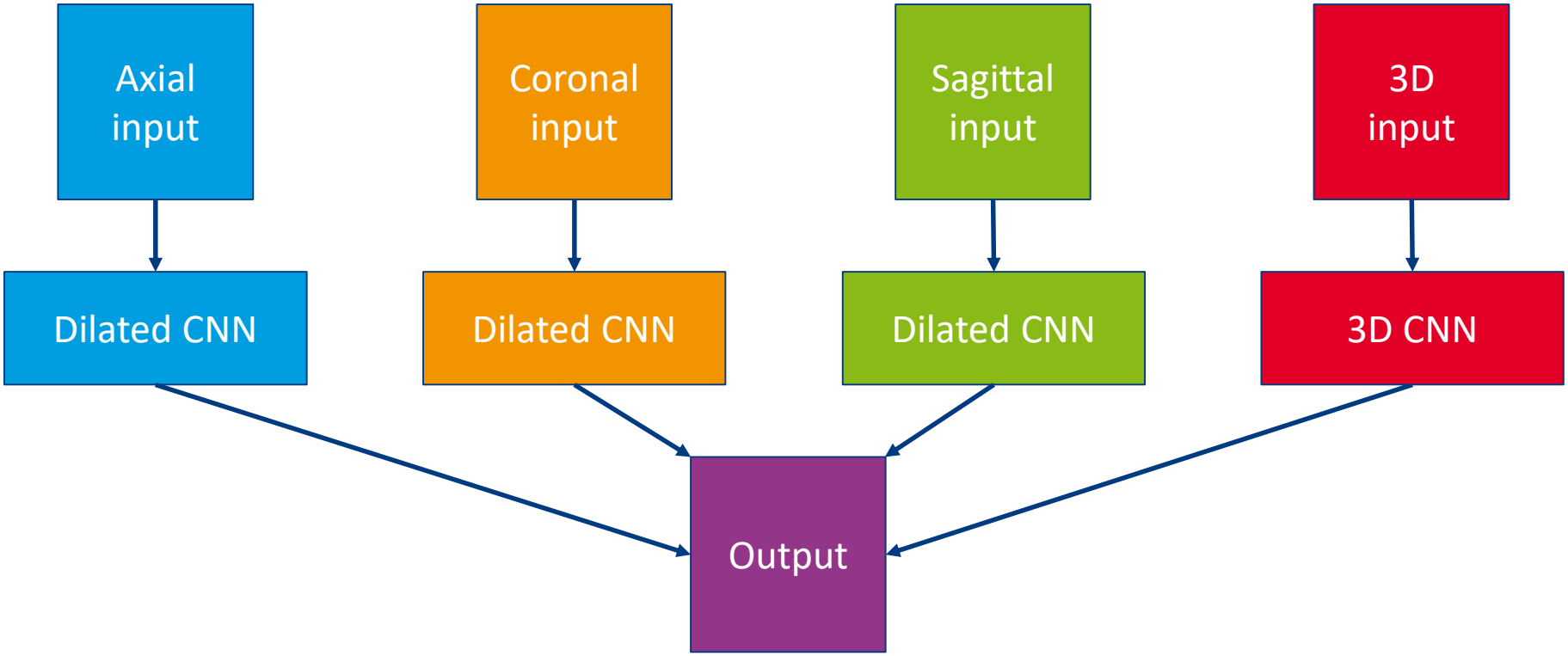


http://iseg2017.web.unc.edu

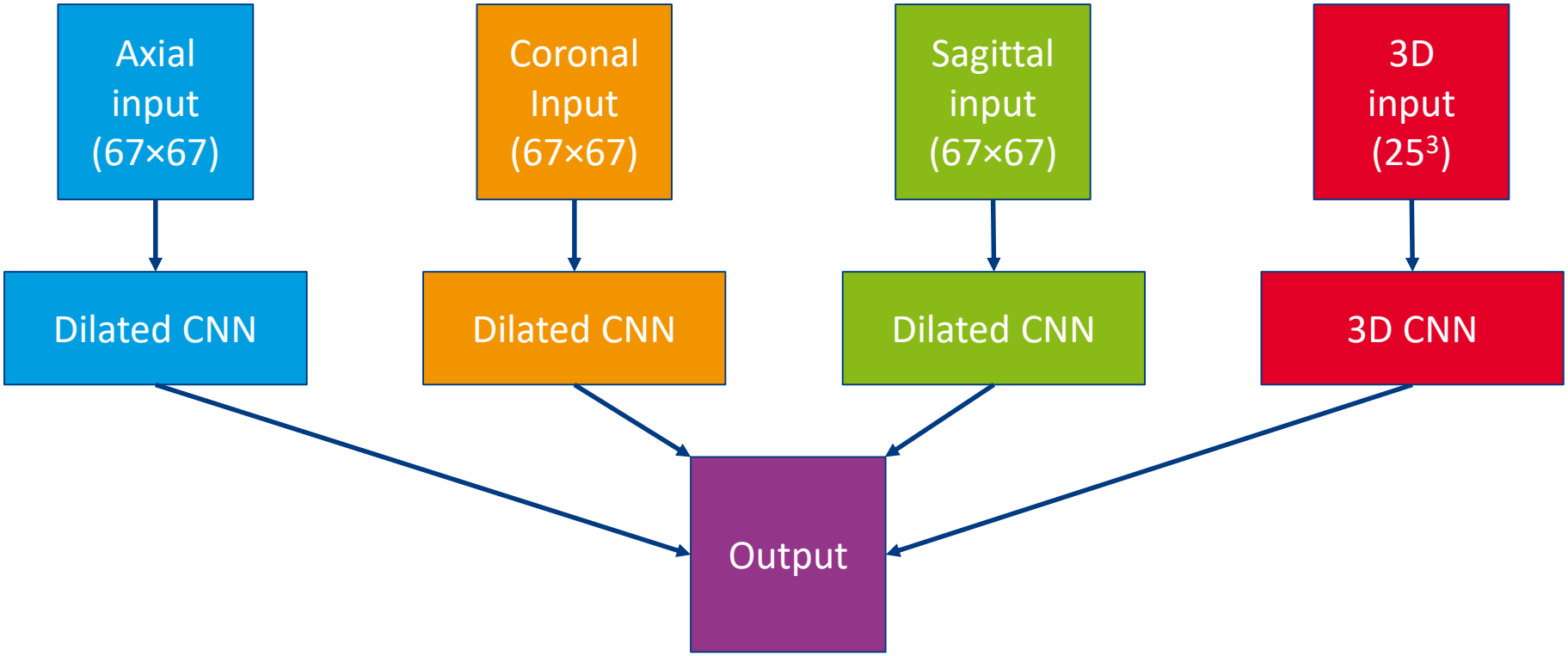
Triplanar dilated CNN



Triplanar dilated CNN + 3D CNN



Triplanar dilated CNN + 3D CNN

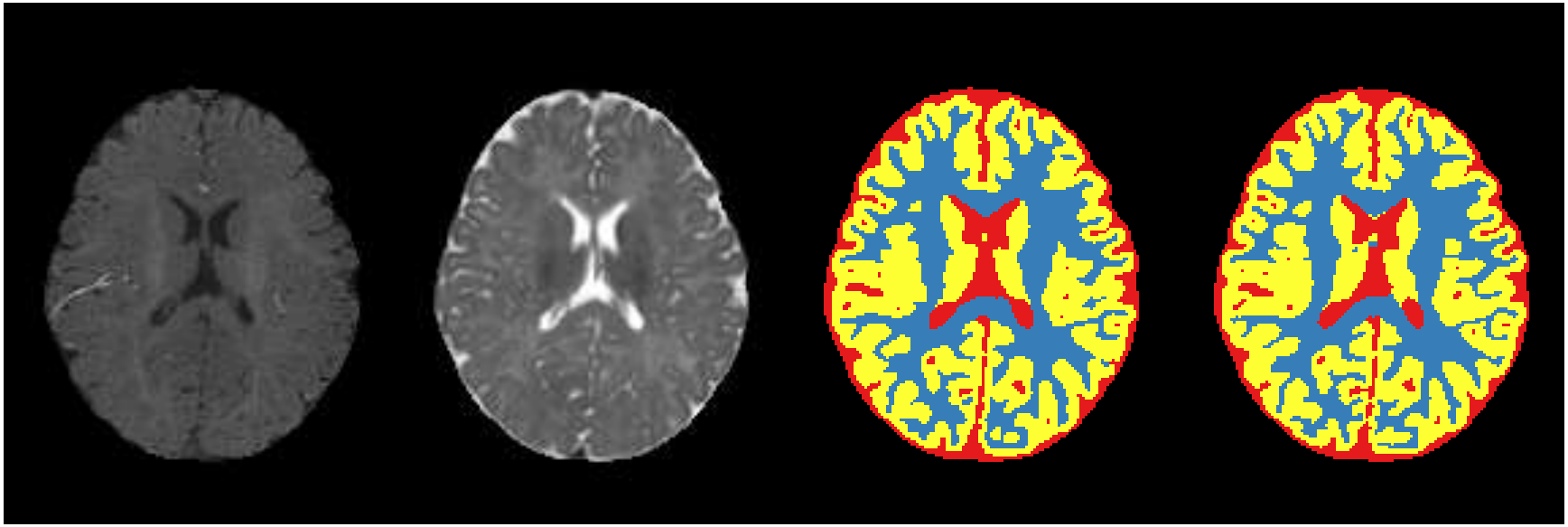


Results: validation set

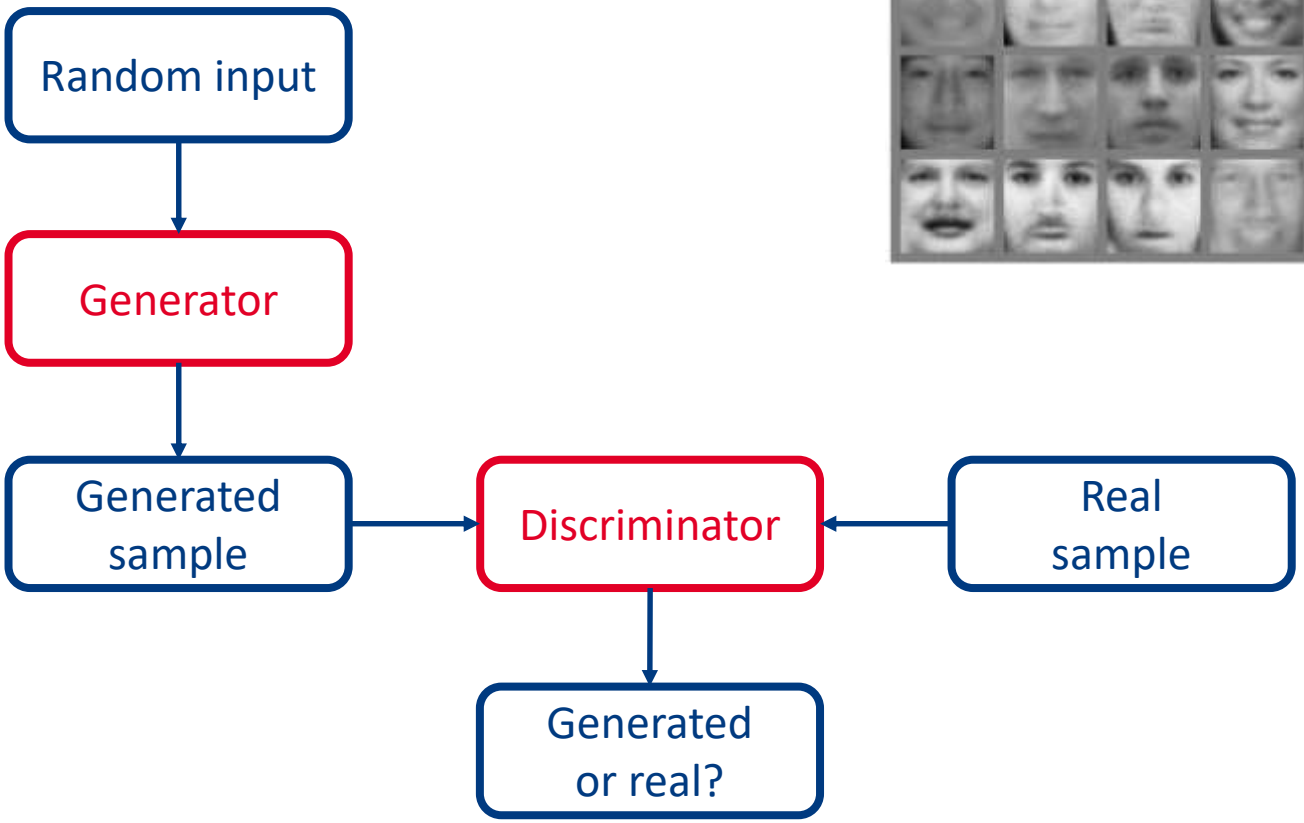
Average Dice coefficients (3 images)	WM	GM	CSF
Triplanar with shared weights	0.856	0.846	0.905
Triplanar with separate weights	0.868	0.871	0.908
Triplanar plus 3D network	0.874	0.877	0.932

Results: validation set

T_1-weighted | T_2-weighted | Automatic | Reference

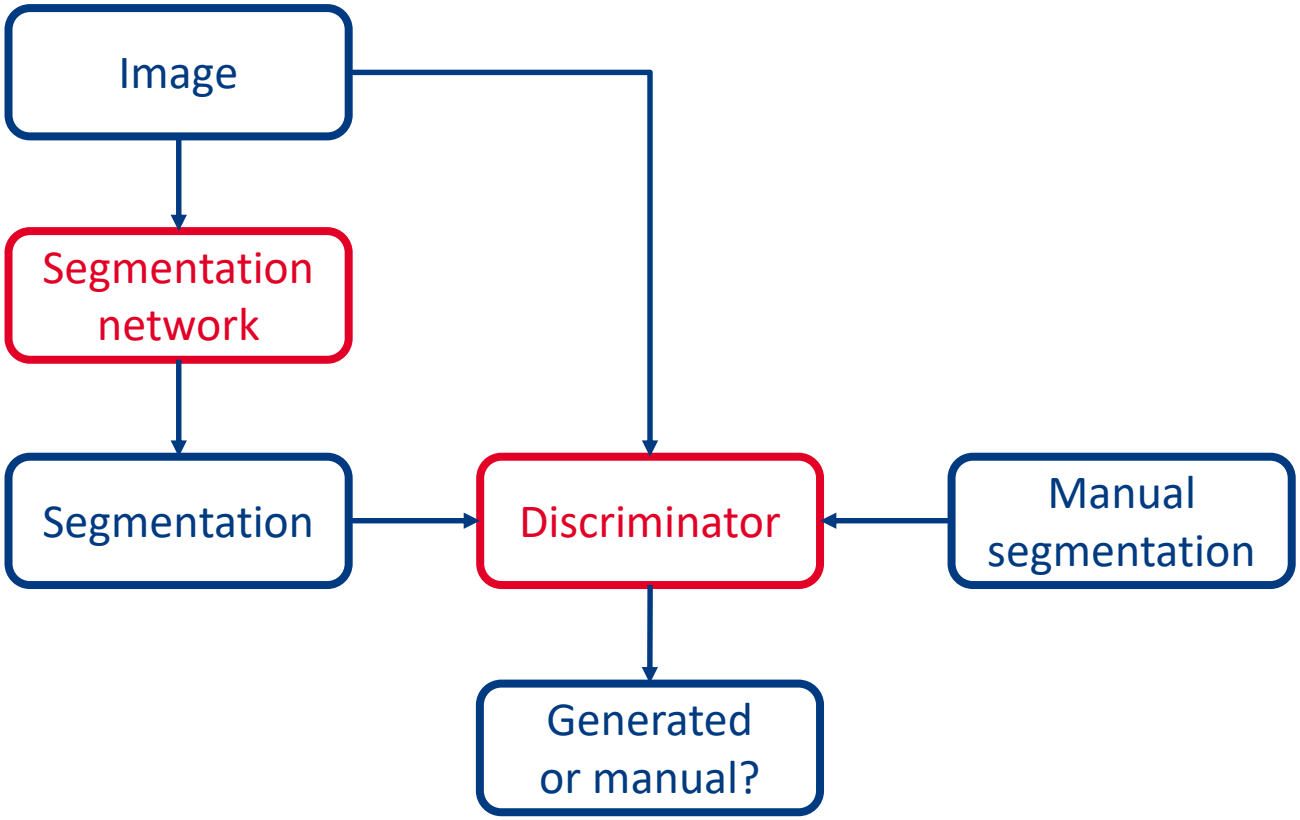


Generative adversarial networks (GANs)



Goodfellow et al., NIPS, 2014

Adversarial networks for segmentation



Luc et al., NIPS workshop on adversarial training, 2016

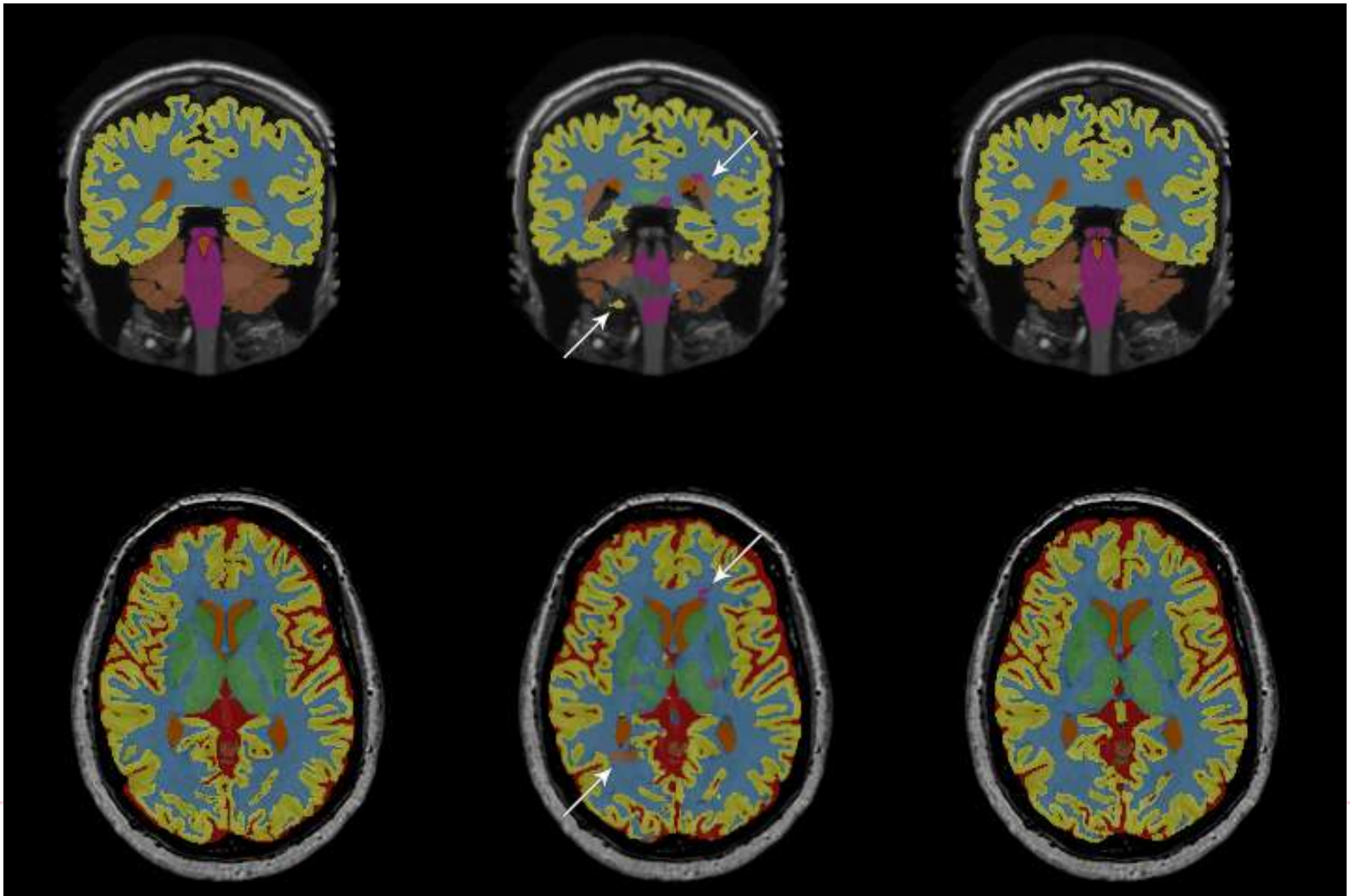
Moeskops et al., MICCAI deep learning in medical image analysis workshop, 2017

Adversarial networks for segmentation

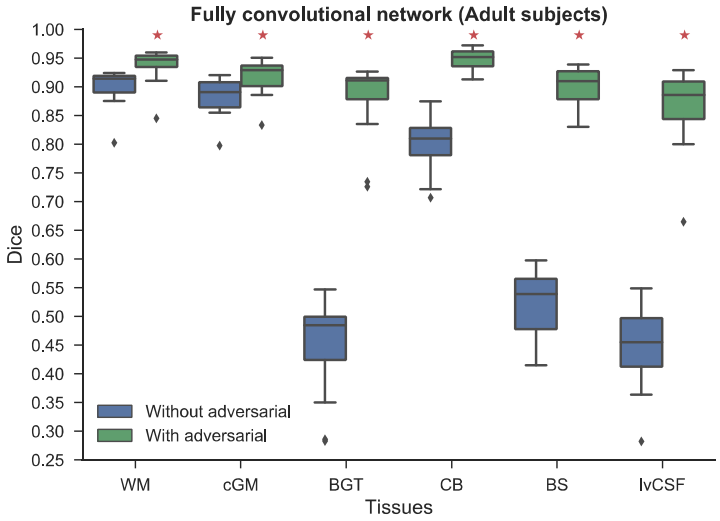
Reference | Without adversarial | With adversarial

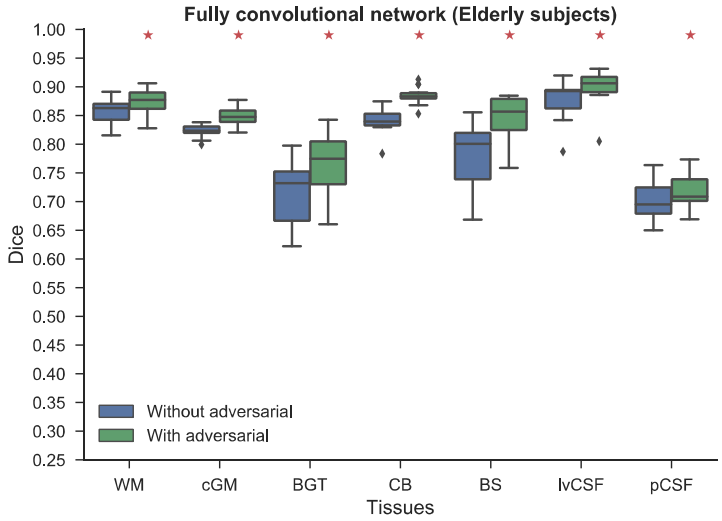
Adult subjects

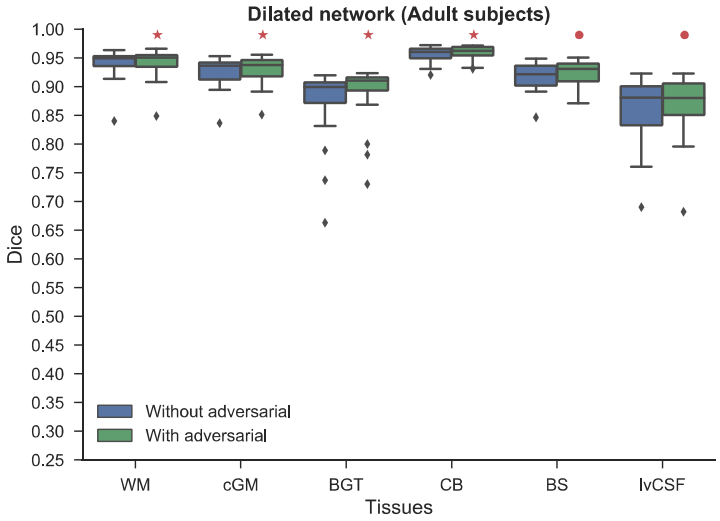
Elderly subjects

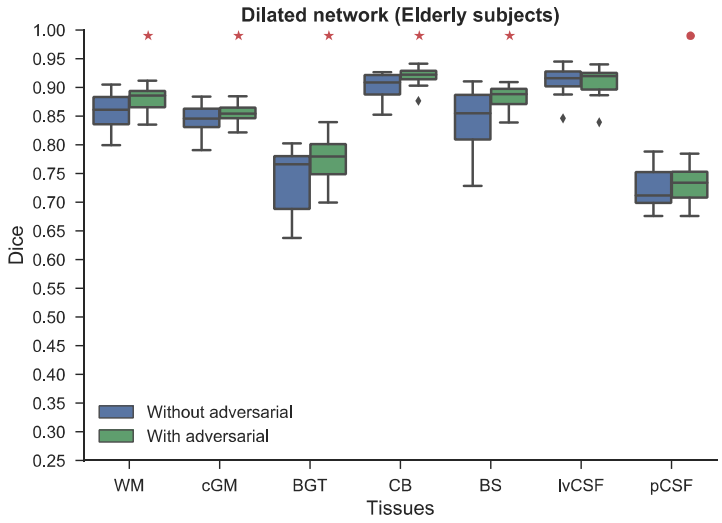


Dice coefficients



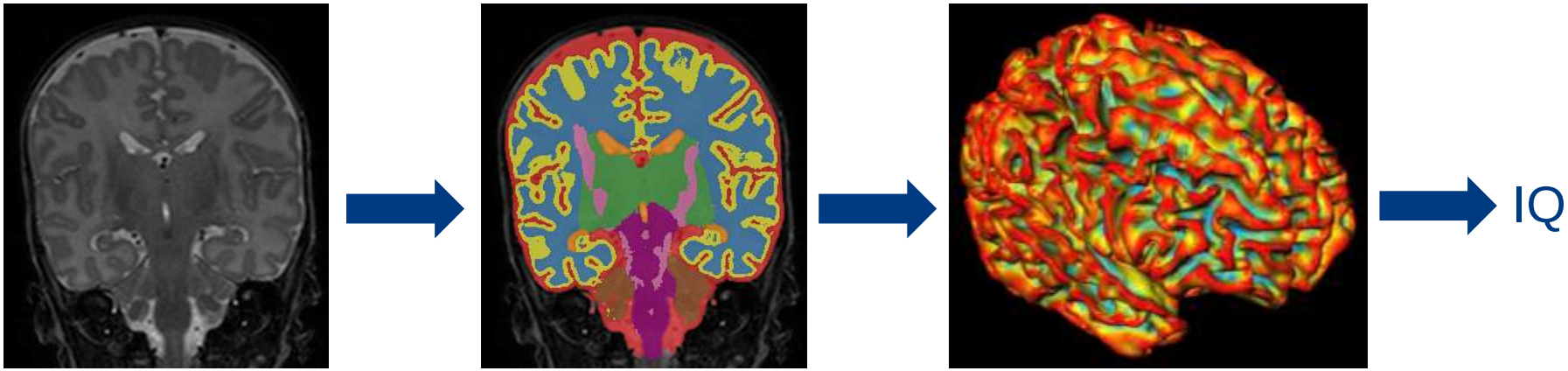




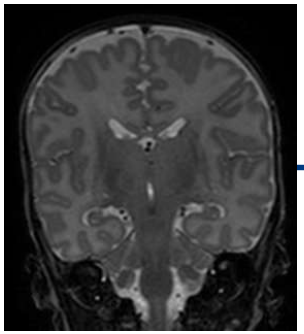


Pipeline in neonatal brain imaging

- Segmentation
- Quantification
- Prediction



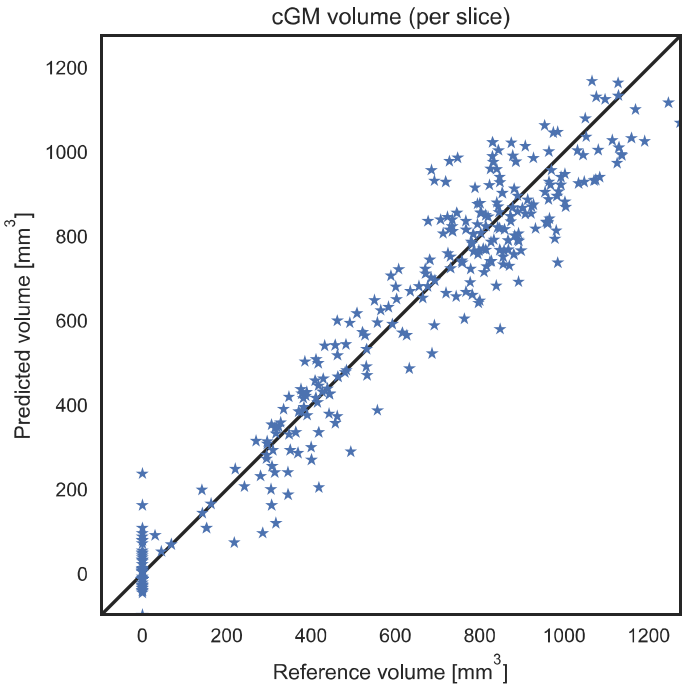
Deep learning: direct prediction



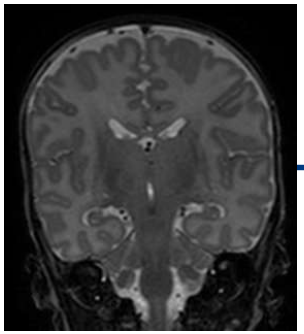
Convolutional neural network

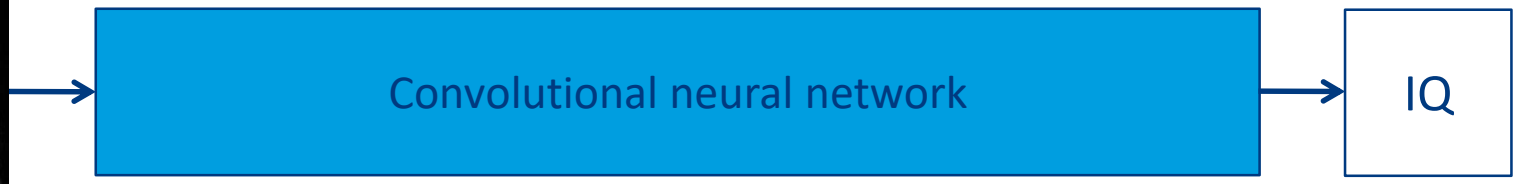
Output

cGM volume

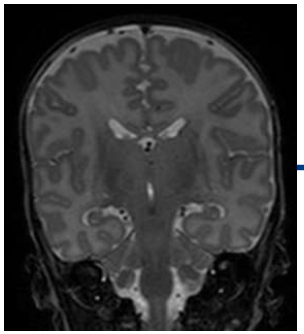


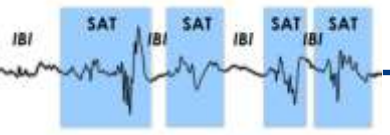
Deep learning: direct prediction





Deep learning: multi-source data





Output

Convolutional neural network

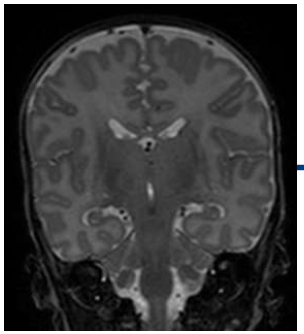
Convolutional neural network

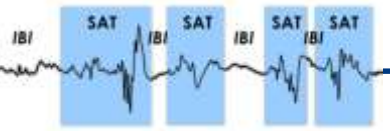
IQ

Patient information:
Age
Weight
Length
Partental education
Nutrition
Medicine

Neural network

Deep learning: multi-source data





Output

Convolutional neural network

Convolutional neural network

IQ

Patient information
Image descriptors:
Brain tissue volumes
Cortical surface area
Cortical thickness
Cortical folding

Neural network

Thanks!