Tractseg

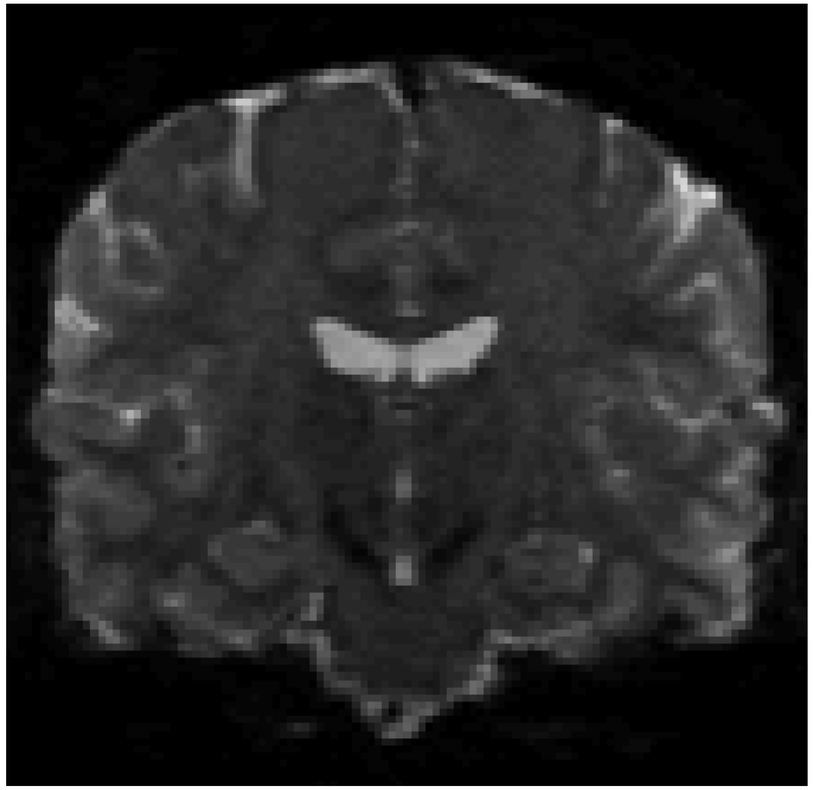
Reconstructing white matter bundles with Deep Learning

Jakob Wasserthal

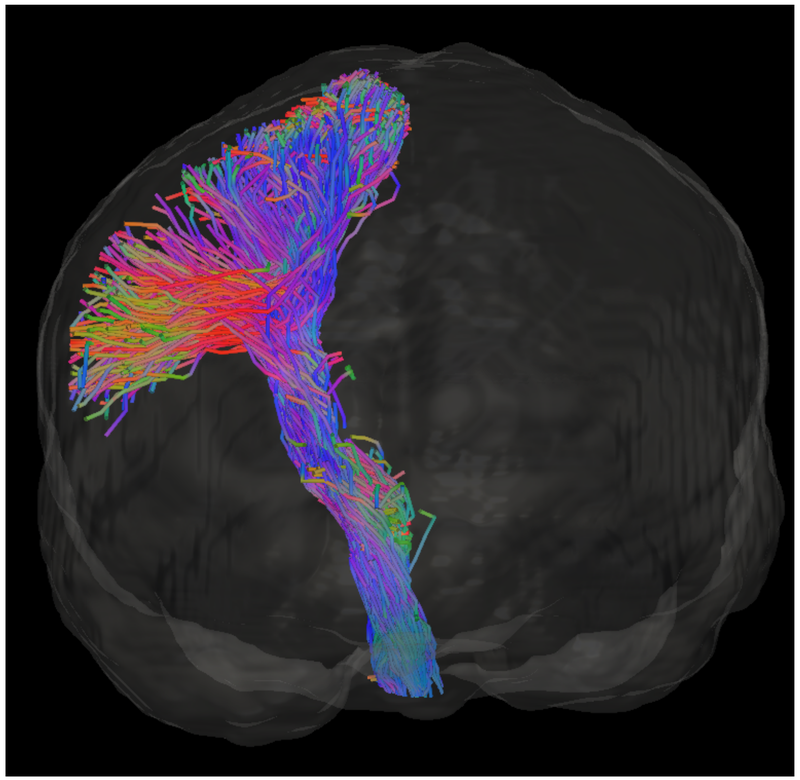
Division of Medical Image Computing, German Cancer Research Center, Heidelberg, Germany

Goal: Reconstruction of white matter fiber bundles

DWI image

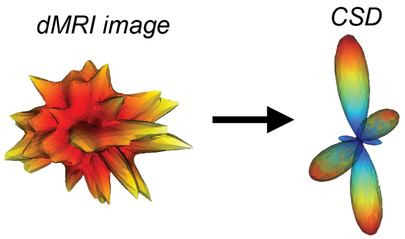


Reconstructed corticospinal tract

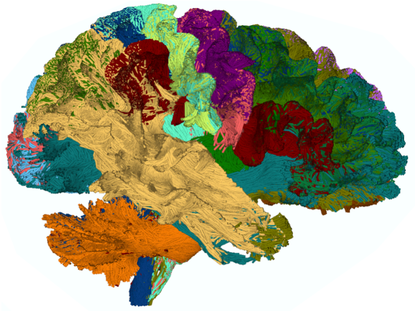


How would we normally do it?

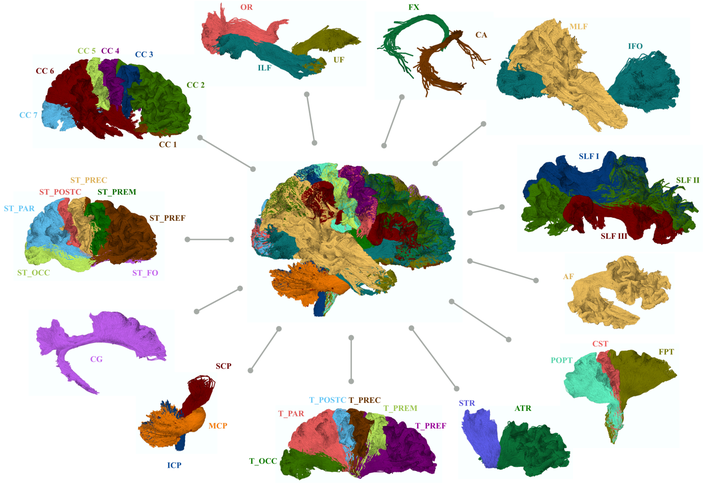
1. Model fiber orientations in each voxel



2. Run whole-brain tractography

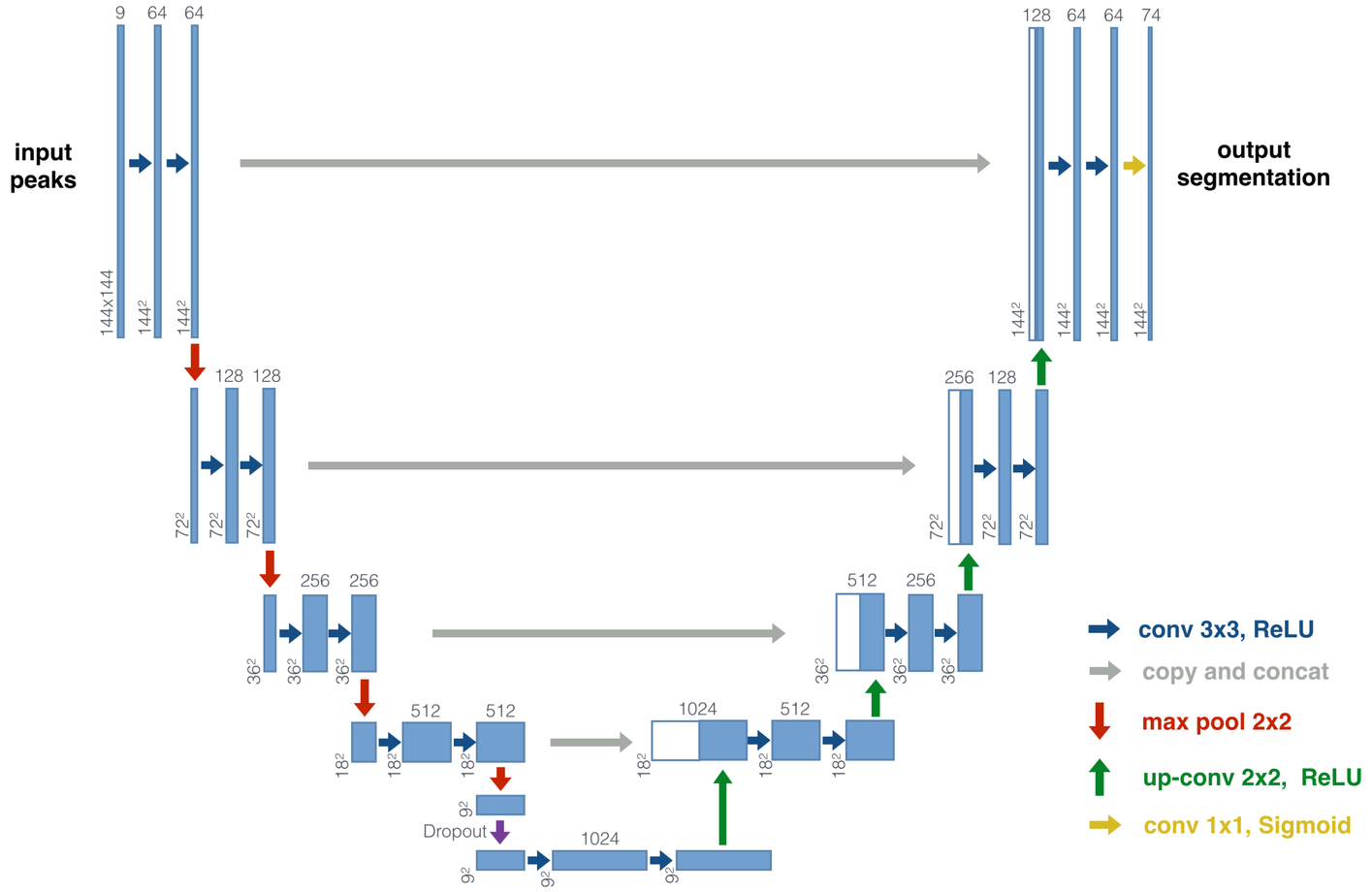


3. Extract anatomically defined bundles
   (manual / clustering / atlases / …)



=> Can we do better?

U-Net for semantic segmentation

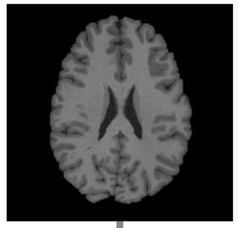


Ronneberger et al., MICCAI 2015

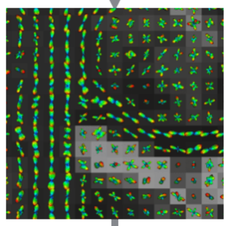
TractSeg

Preprocessing

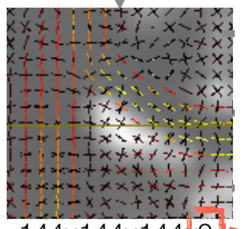
HCP dataset



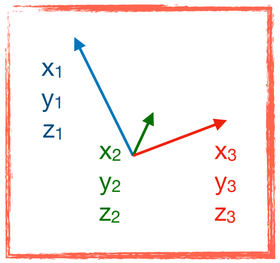
Constrained Spherical Deconv.



Peak extraction

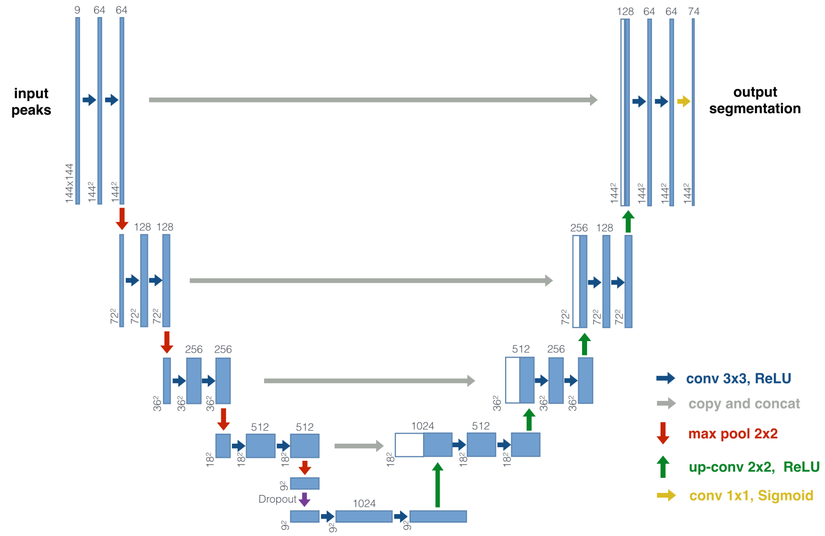


144x144x144x9

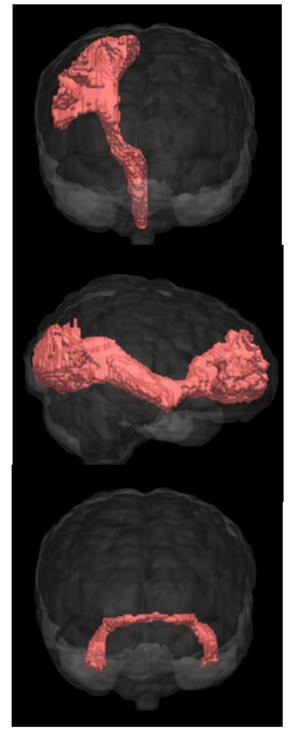


$$\begin{bmatrix} x_1 \\ y_1 \\ z_1 \\ x_2 \\ y_2 \\ z_2 \\ x_3 \\ y_3 \\ z_3 \end{bmatrix}$$

U-Net



Results



144x144x144x72

Wasserthal et al., NeuroImage 2018

dkfz.

How to deal with 3D data?

2D

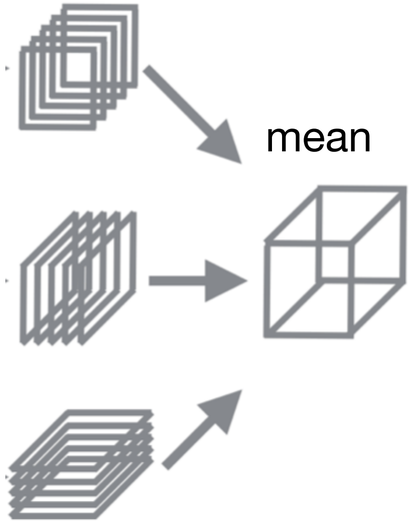
Process slice by slice using 2D U-Net

3D

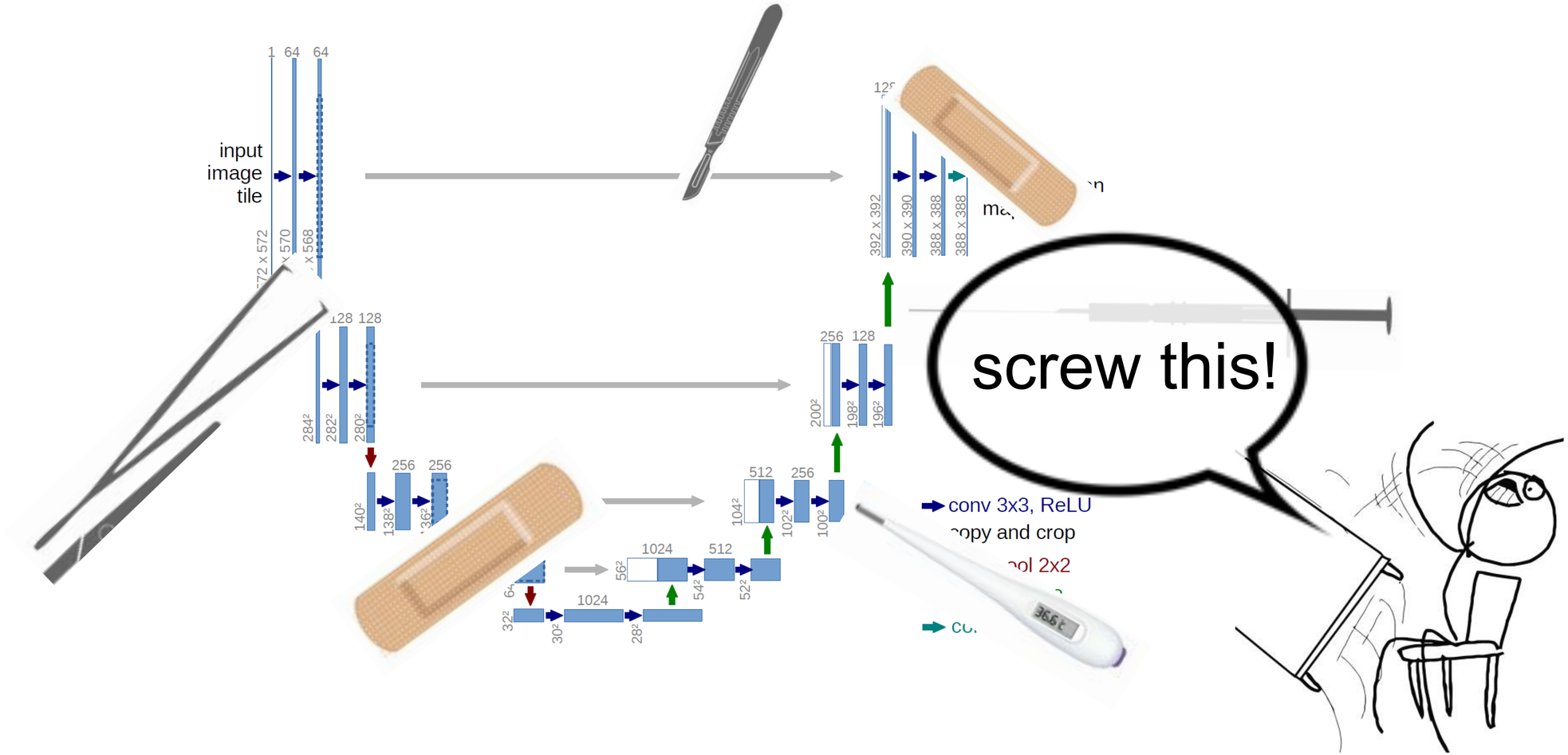
Process all slices at same time using 3D U-Net

2.5D

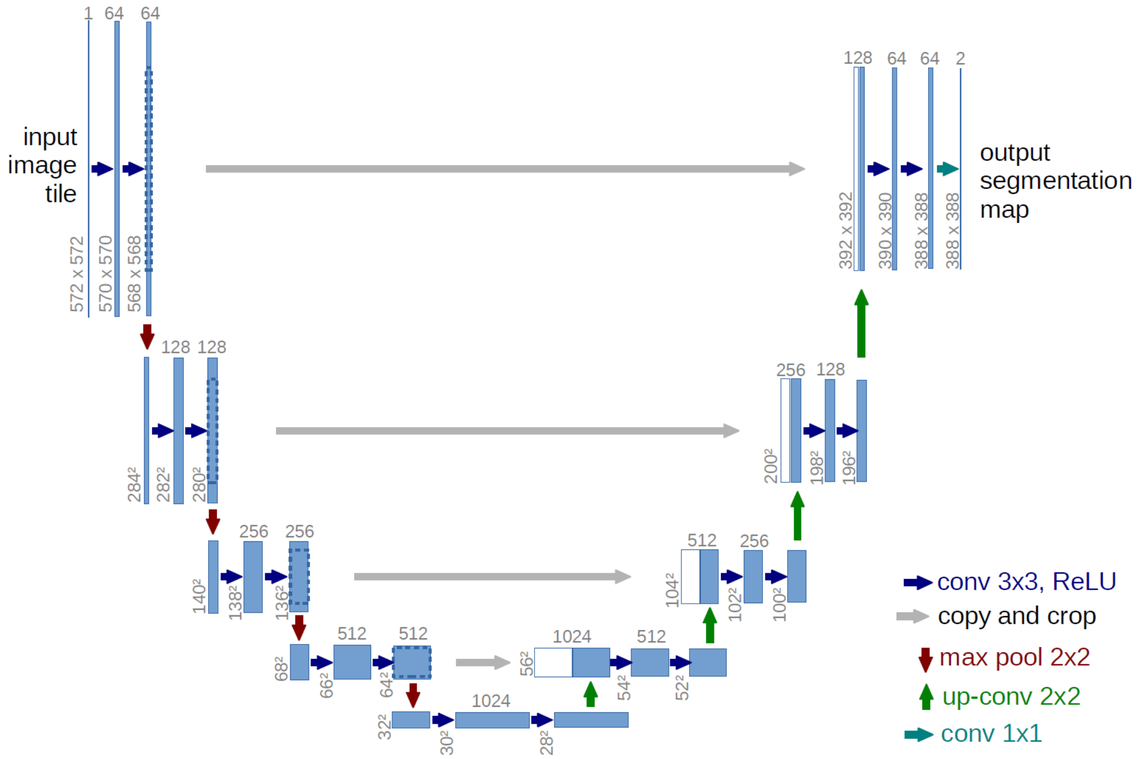
Sample slices from three different orientations. Use one 2D U-Net for each orientation.



What about all the other parameters and fancy U-Net extensions?



What about all the other parameters and fancy U-Net extensions?



Isensee et al. (2019): nnU-Net: Breaking the Spell on Successful Medical Image Segmentation

Data for training and evaluation

- 105 subject from Human Connectome Project

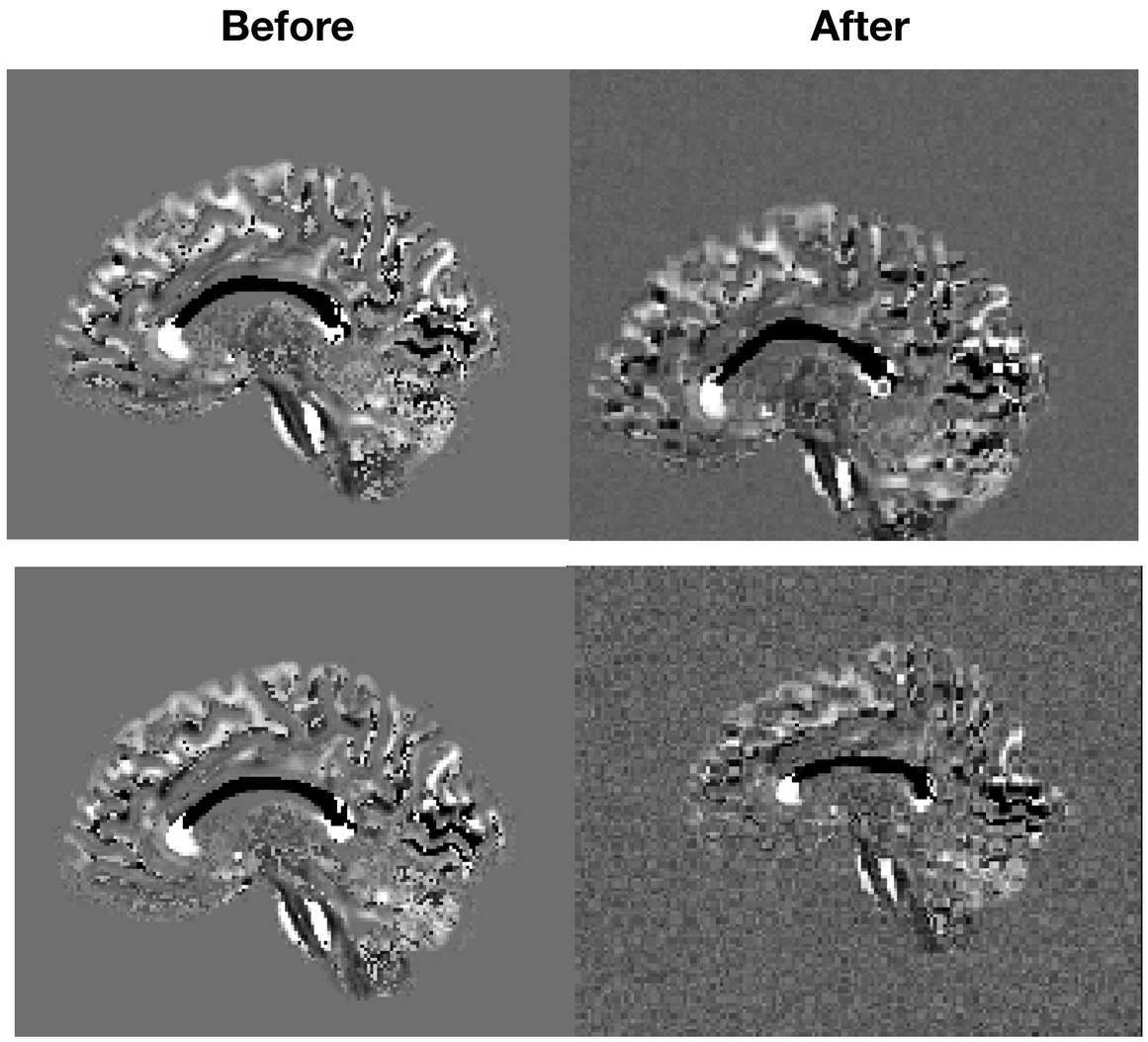
- Semi-automatic delineation of 72 bundles
  1. Estimate FODs (MRtrix msmt-CSD)
  2. Whole brain tractography (MRtrix probabilistic tracking)
  3. Tract extraction with TractQuerier (Wassermann et al.)
  4. Tract refinement (ROIs, Atlas, Clustering,…)
  5. Manual quality control and clean-up

Data augmentation

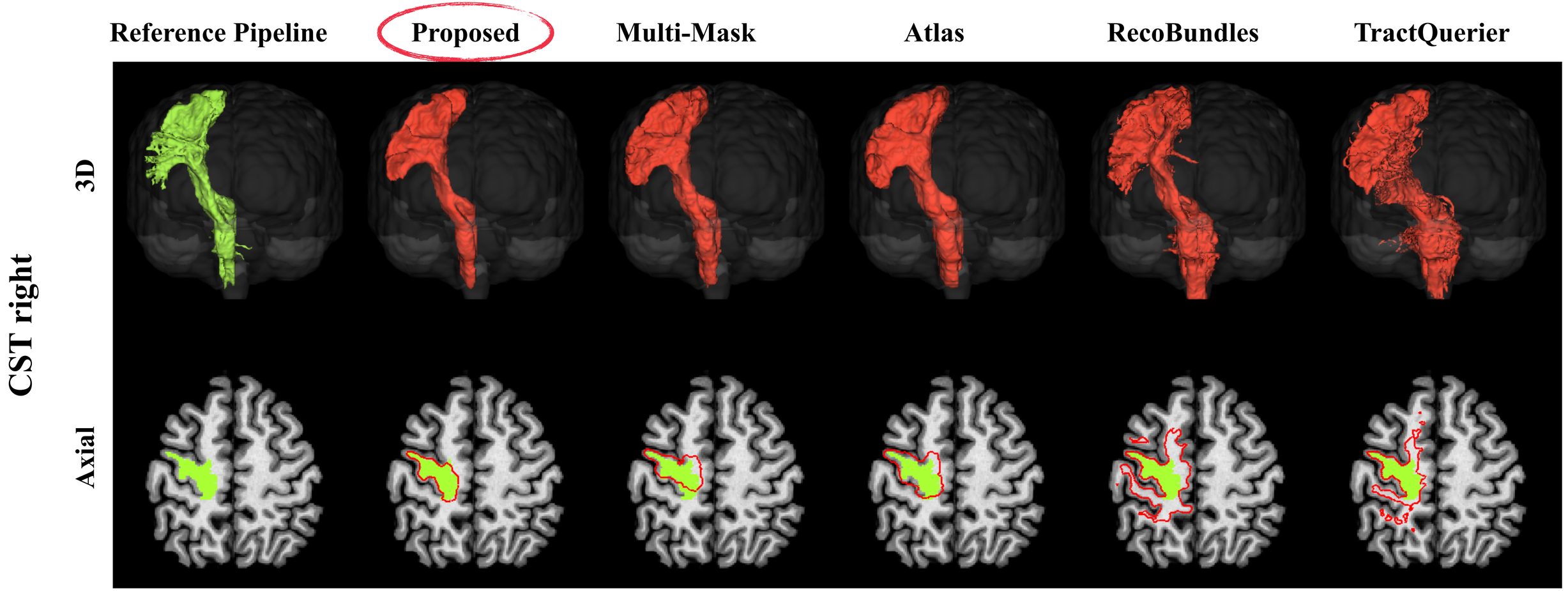
On peak images randomly do

- Elastic deformation
- Displacement
- Zooming
- Gaussian blurring
- Gaussian noise

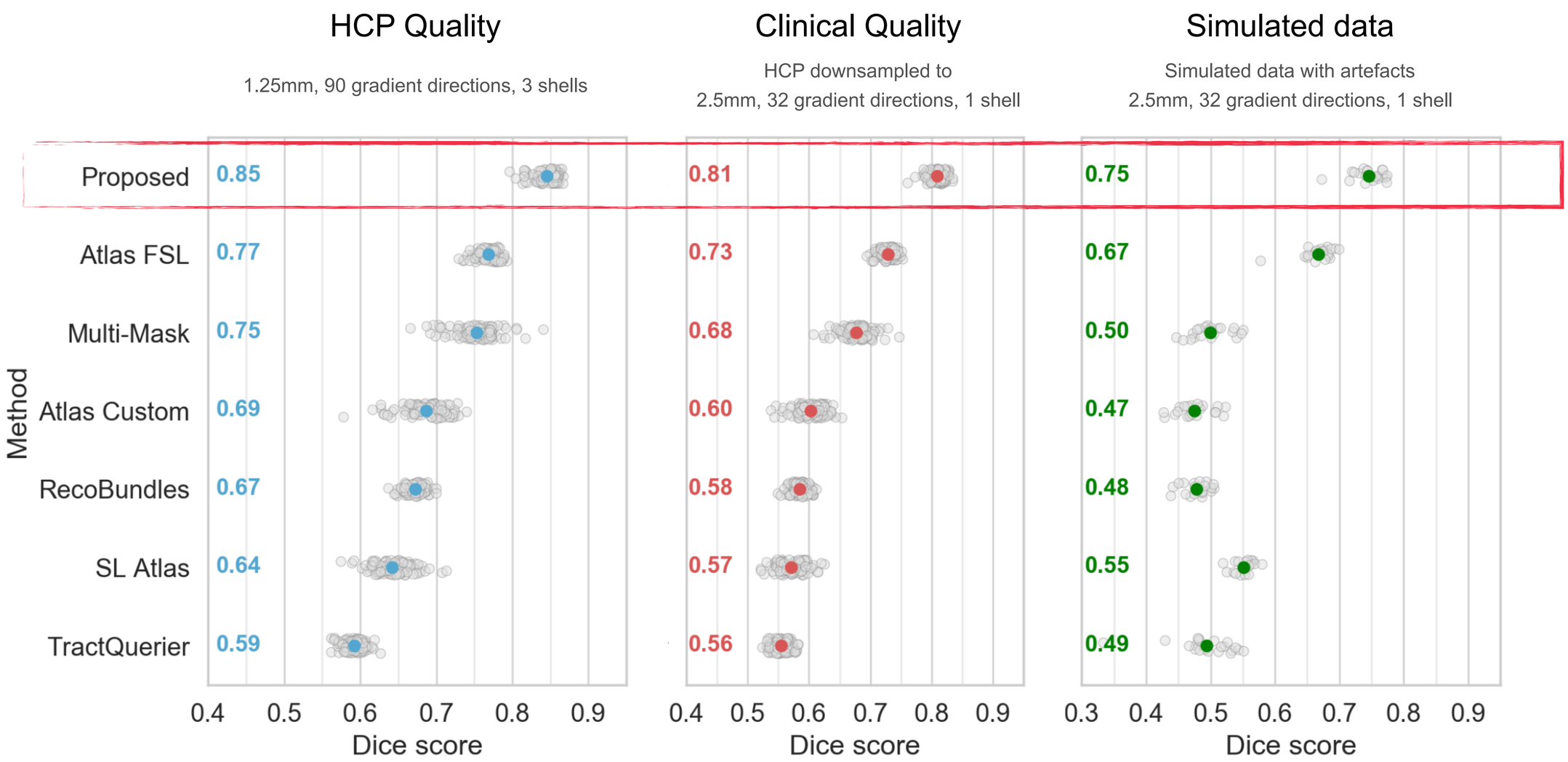
=> learns to work without registration



Results - Qualitative

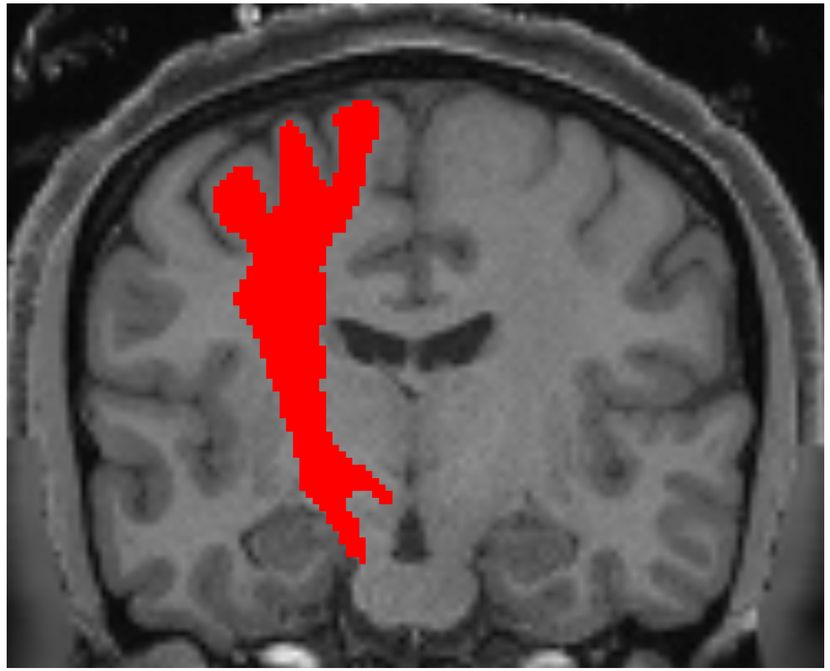


Results - Quantitative



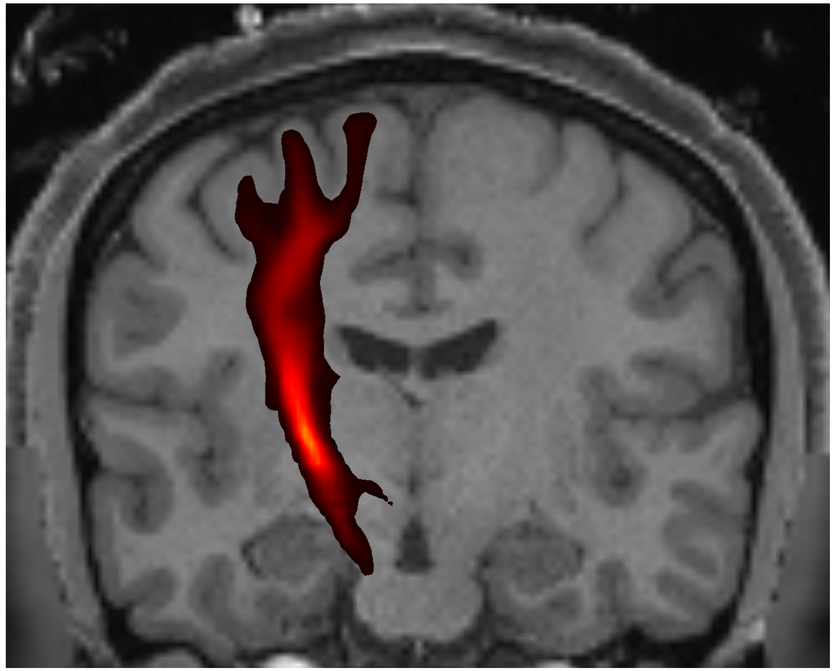
Can we do more than just segmentation?

binary segmentation



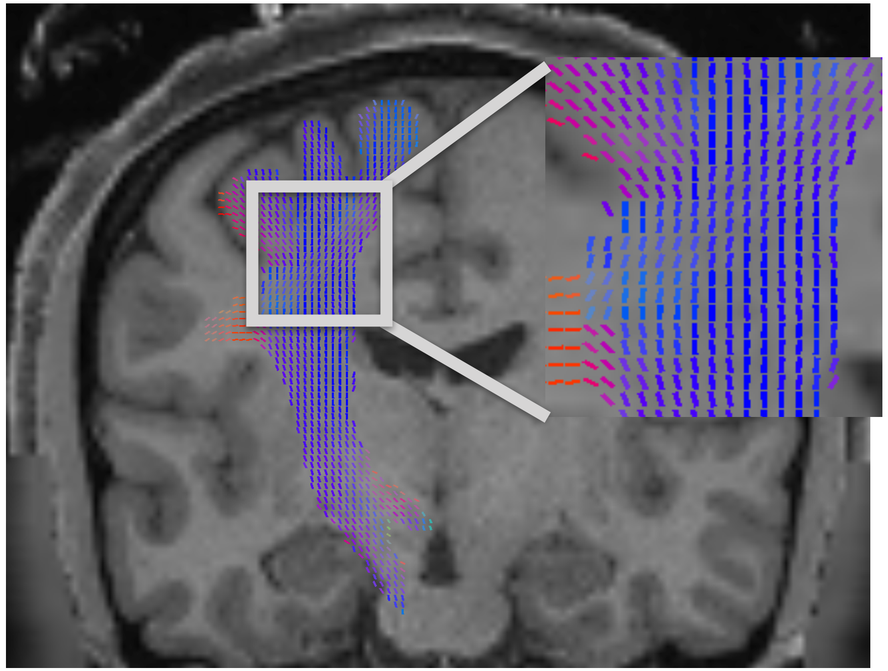
[width x height x 72*1]

density map

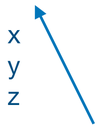


[width x height x 72*1]

vector field



[width x height x 72*3=216]



How to make U-Net learn peaks?

Simplest approach: **Mean squared error**

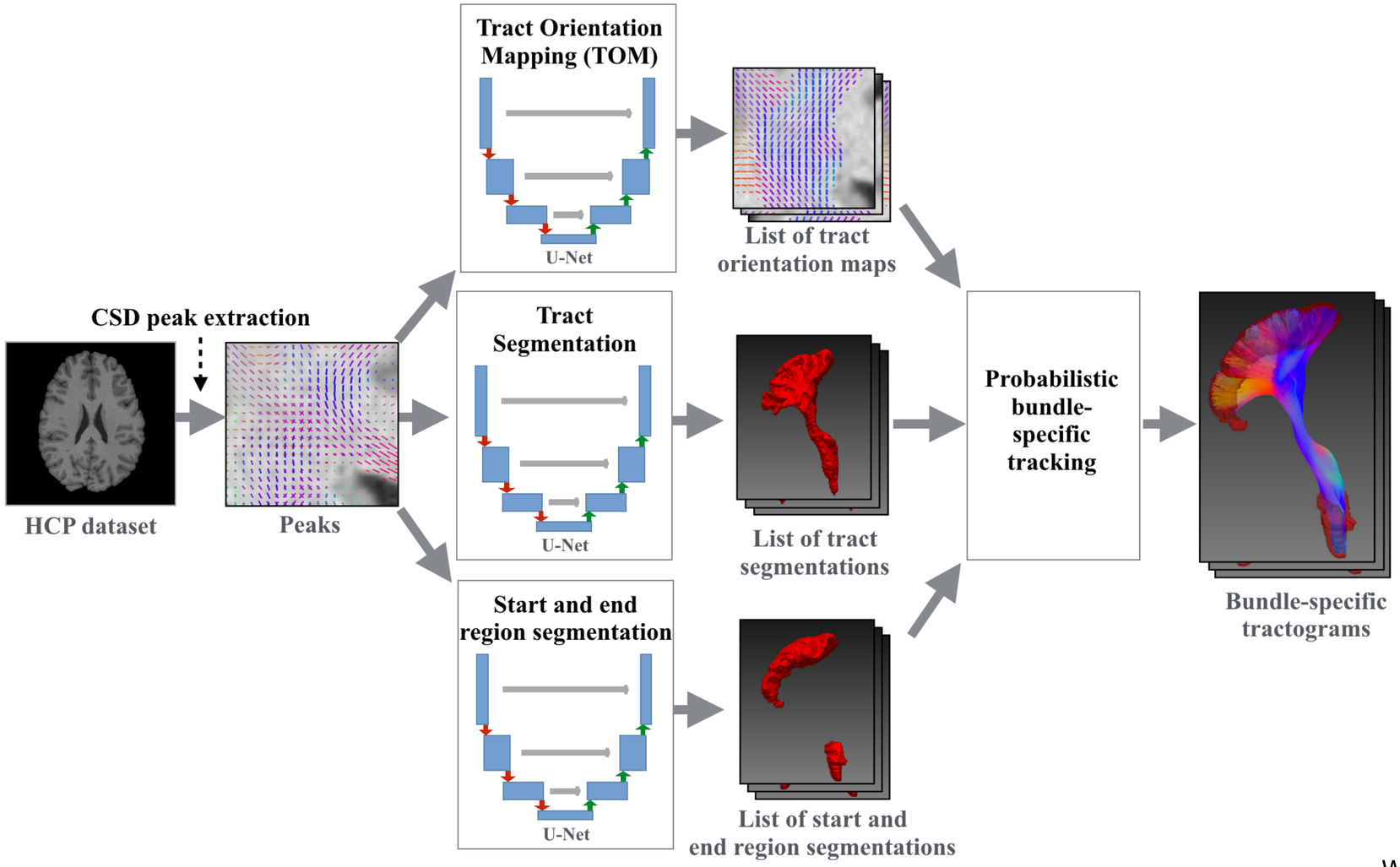
$$loss(\hat{y}, y) = \frac{1}{N}\sum_{i=0}^{N}(\hat{y}_{i2} - y_{i2})^2$$

Better: **Angular error**

$$loss(\hat{y}, y) = \frac{1}{N}\sum_{i=0}^{N}\frac{\left|\langle \hat{y}_i, y_i \rangle\right|}{\left\|\hat{y}_i\right\|_2 * \left\|y_i\right\|_2}$$

Wasserthal et al., MICCAI 2018

Overall pipeline



Wasserthal et al., MICCAI 2018

Bundle-specific tracking — result

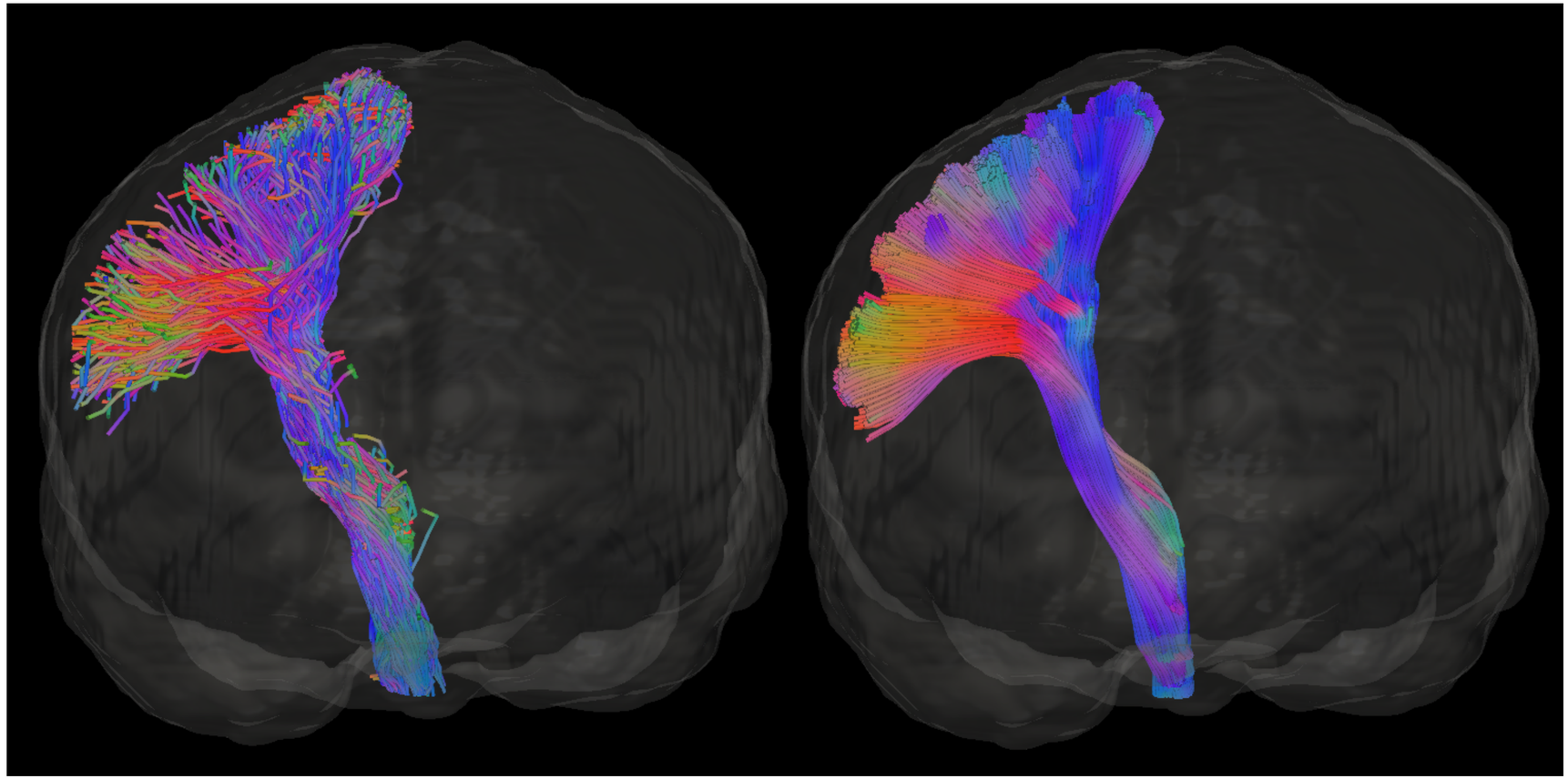
Manual

runtime > 7min + manual work > 9min

Proposed

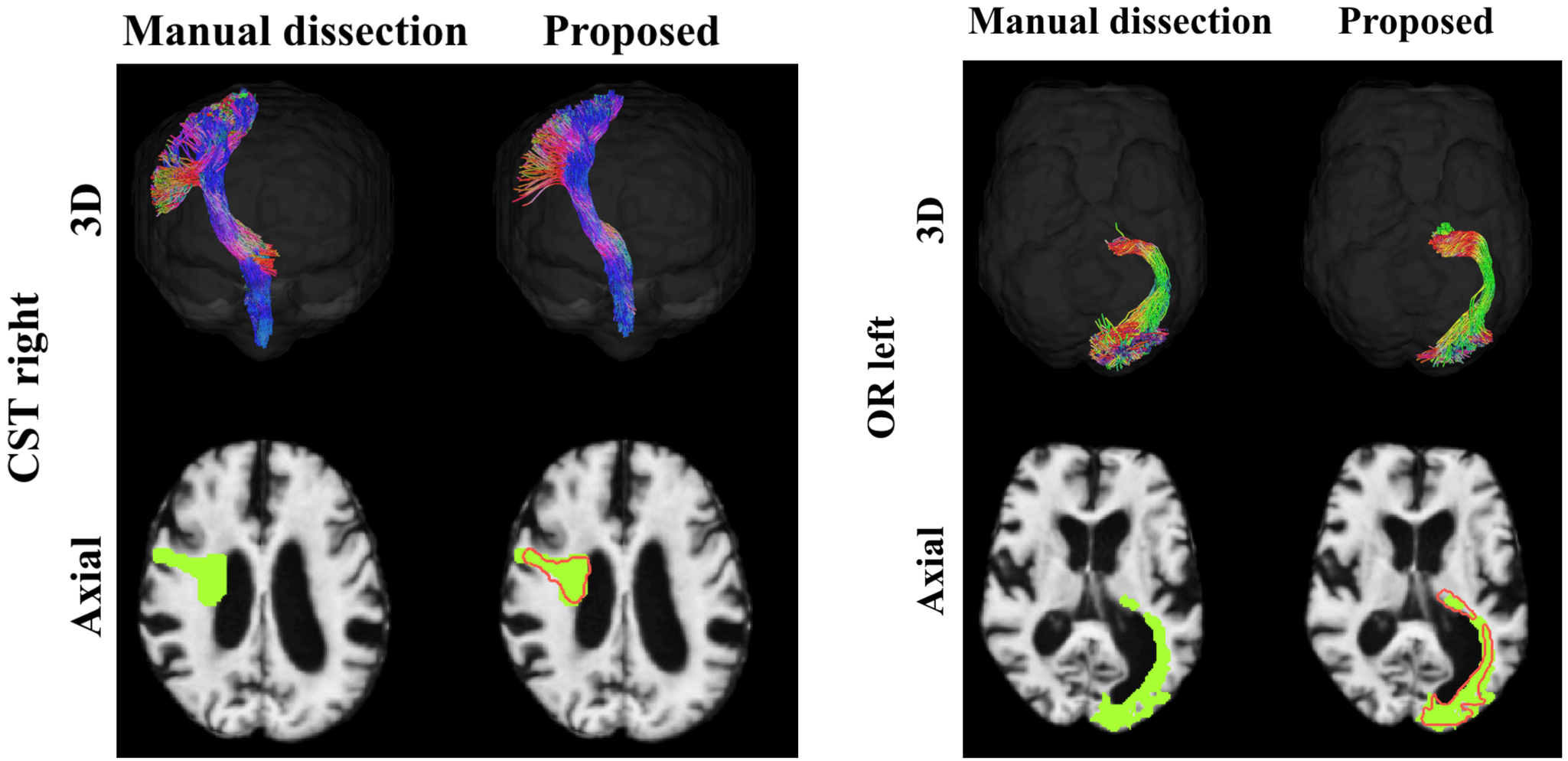
runtime < 2min, fully automatic

CST right



Subject with schizophrenia, 2mm isotropic, 30x b=800mm/s^2

Generalises well to new datasets and pathologies



Subject with Alzheimer, 2.5mm isotropic, 64x b=1000mm/s^2

Open-source

- Easy to use: python package with pretrained model
  https://github.com/MIC-DKFZ/TractSeg

- Open dataset: 72 reference tracts for 105 HCP subjects
  https://doi.org/10.5281/zenodo.1088277

Let’s try it out!