

3 Introduction to the nnU-Net, a self-configuring segmentation method for biomedical datasets

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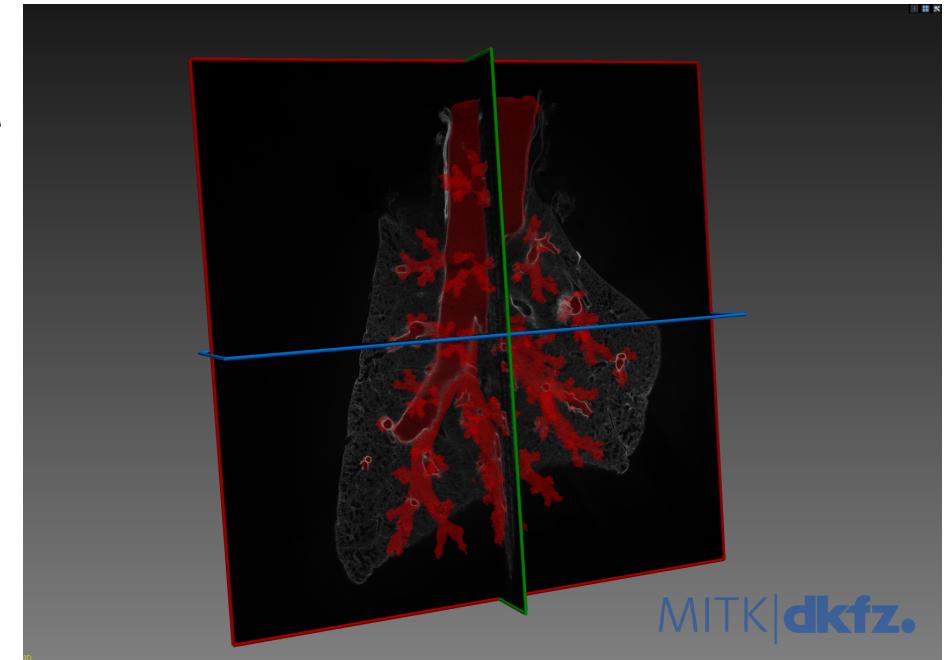
Hands-on Tutorial

Segmentation - Teaser

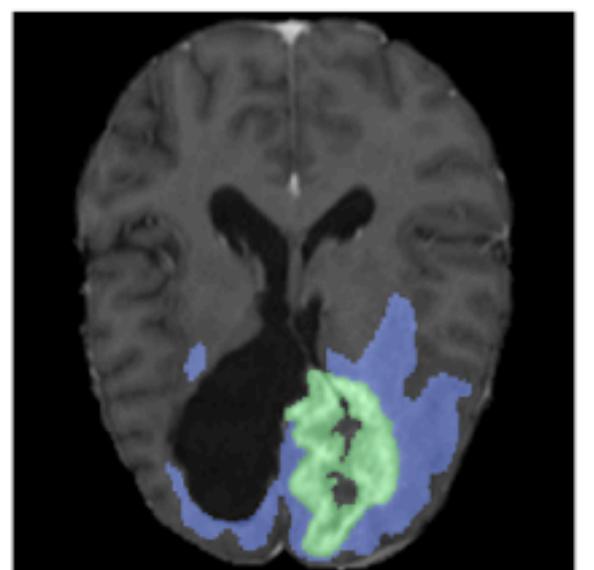
Self-Driving Cars



Research Question about
**optimal medicament
intake:**



Treatment Optimization
for **radiotherapy**:



- We want to read out information from Segmentations:
 - Cars Moving in a Scene
 - Murine lung follow certain blood vessels with and without medicament
 - Finding Tumors in a medical scan (and obtain the size etc.)
 - Creation of these masks is very expensive and slow
 - no chance for real time creation
- > Automate this with Segmentation Solutions

[Citation]

Segmentation described by the Task

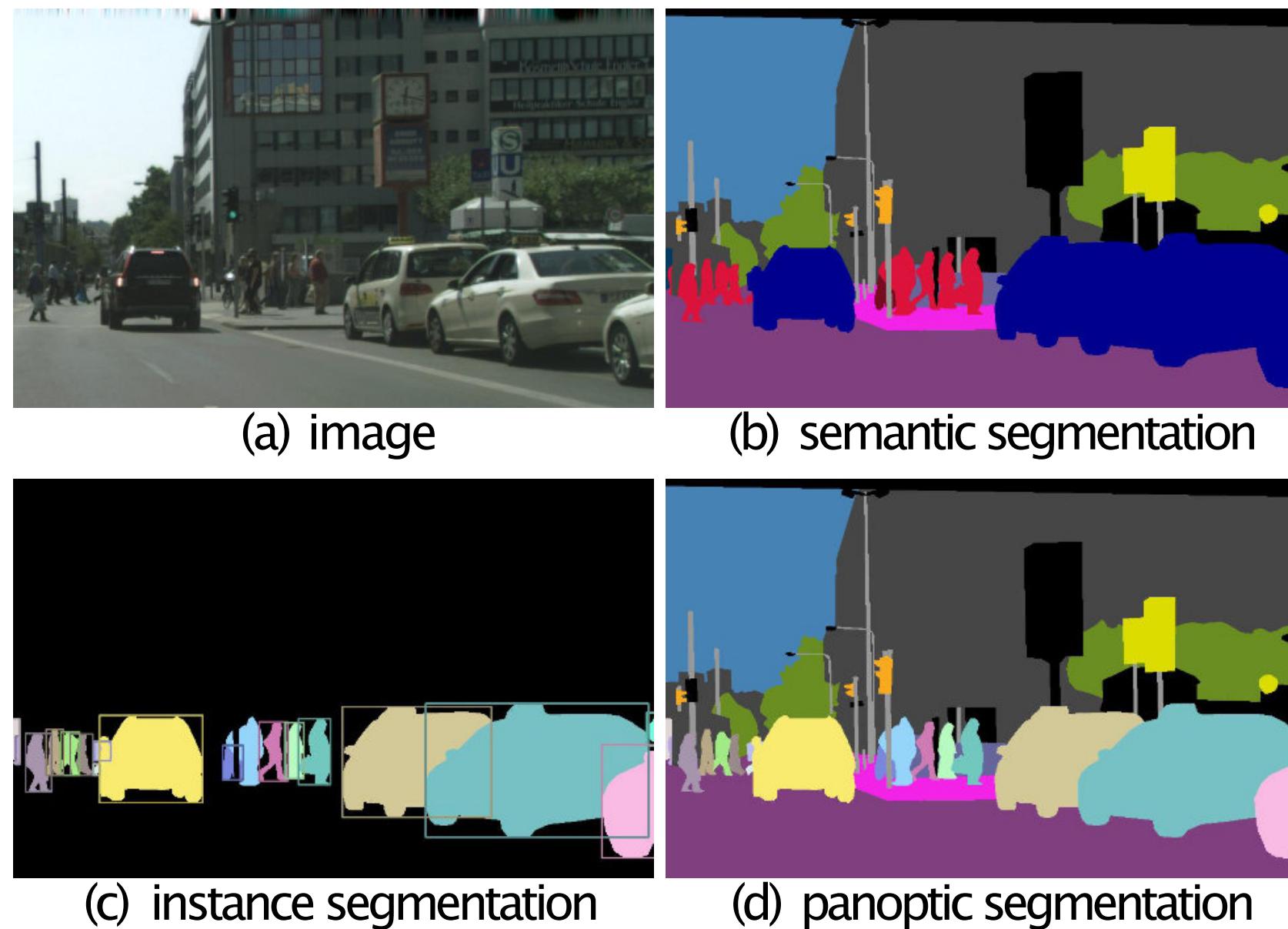


Video by Lex Fridman using segmentation for self-driving cars

<https://youtu.be/bzn7YEvoUaU?list=PLrAXtmErZgOfvrgXrKgzAFbqAW-ICG0Fv&t=45>

<https://www.youtube.com/watch?v=bzn7YEvoUaU&list=PLrAXtmErZgOfvrgXrKgzAFbqAW-ICG0Fv&t=45s>

Segmentation described by the Task

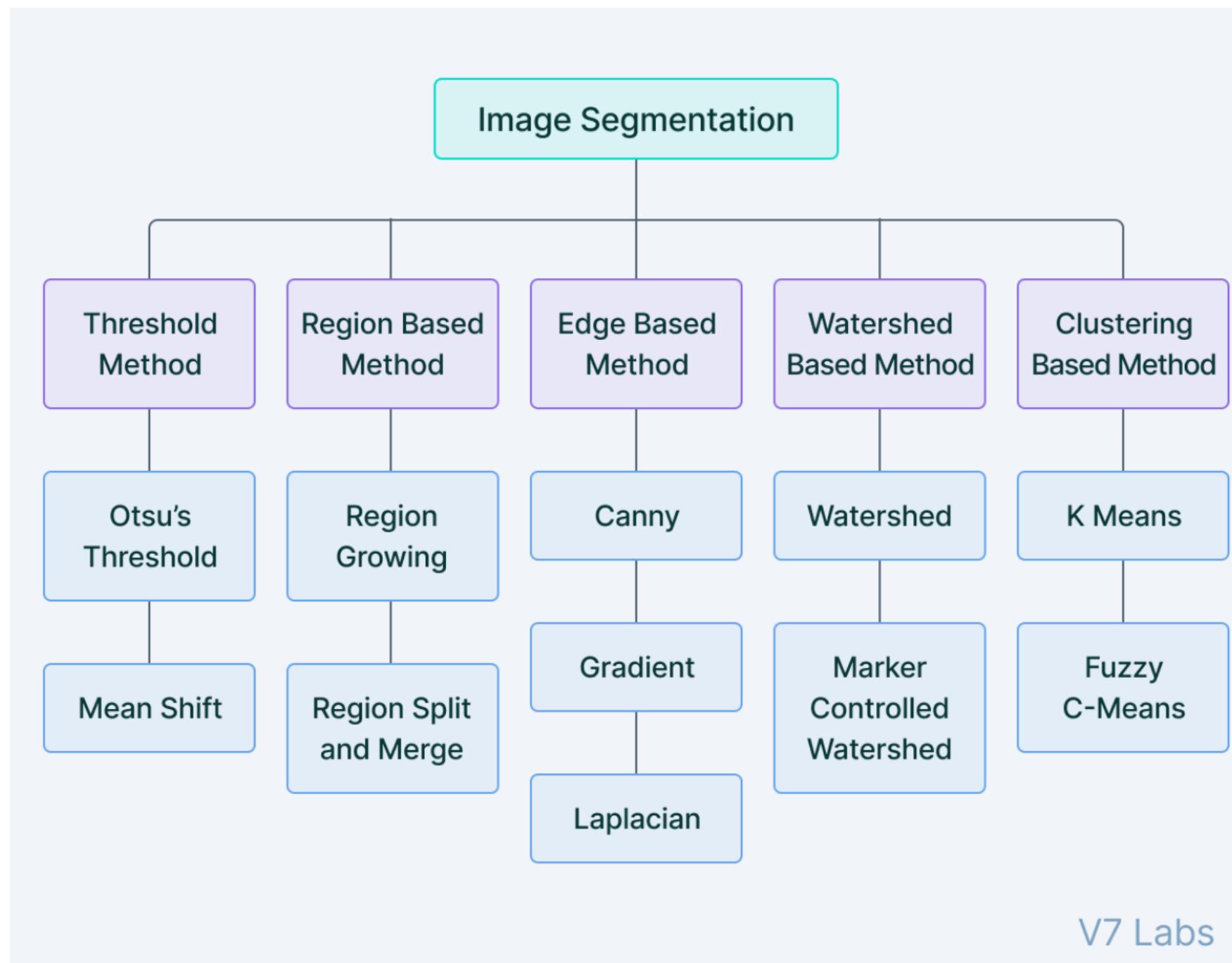


- **Which Question do we want to answer?**
- What types of classes are inside an image
 - > Brain Scan Tumor Detection
 - Semantic Segmentation (assign a class label to each pixel - studying stuff)
- What types of classes are present in an image and what is one Object?
 - > cell tracking (or the infamous brown motion experiment)
 - Instance Segmentation (detect and segment each object instance - studying things)
- Understanding of a scene.
 - Panoptic Segmentation (Classify every pixel an image and find joint objects - a reconciliation between stuff and things)
- The task is also always defined by the metric with which we measure and compare models

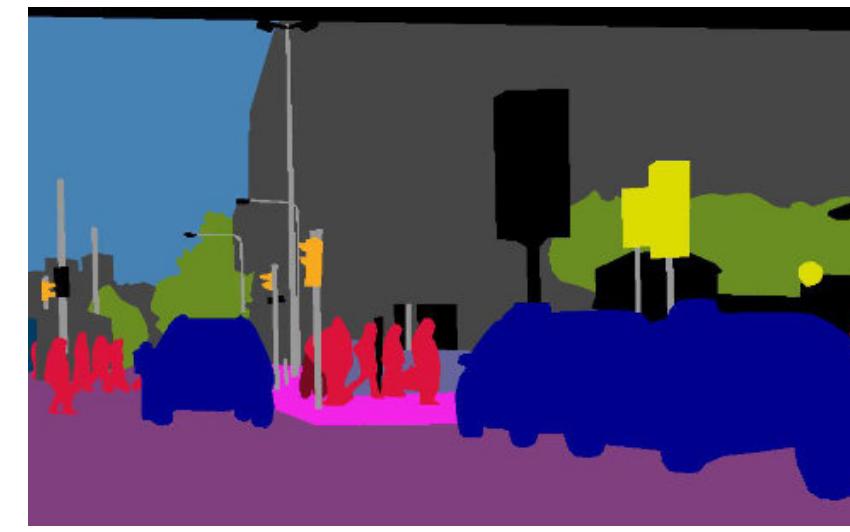
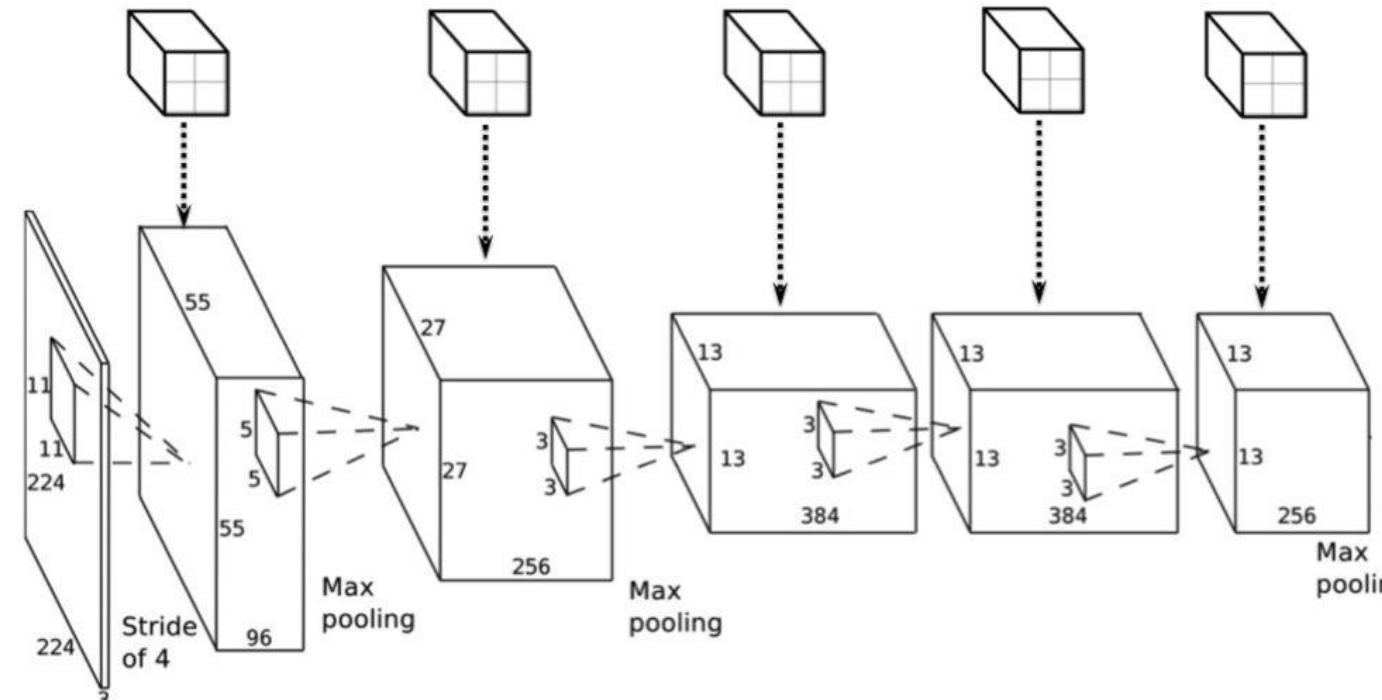
Kirillov, A., He, K., Girshick, R., Rother, C. & Dollár, P. Panoptic Segmentation. *arXiv:1801.00868 [cs]* (2019).

Approaches for Segmentation

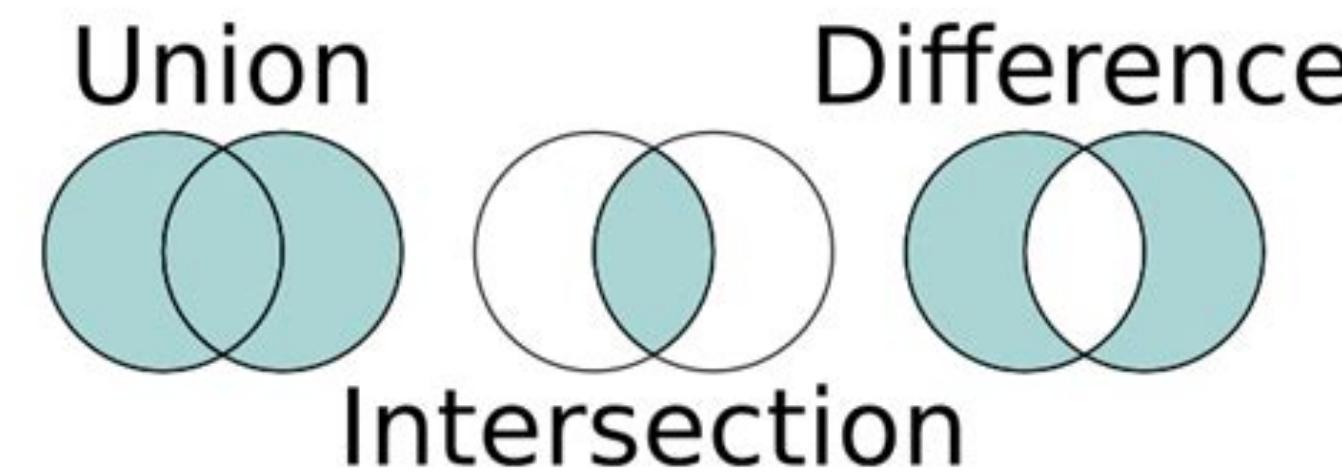
Classical Approaches



Deep Learning based Approaches using Convolutional Neural Networks



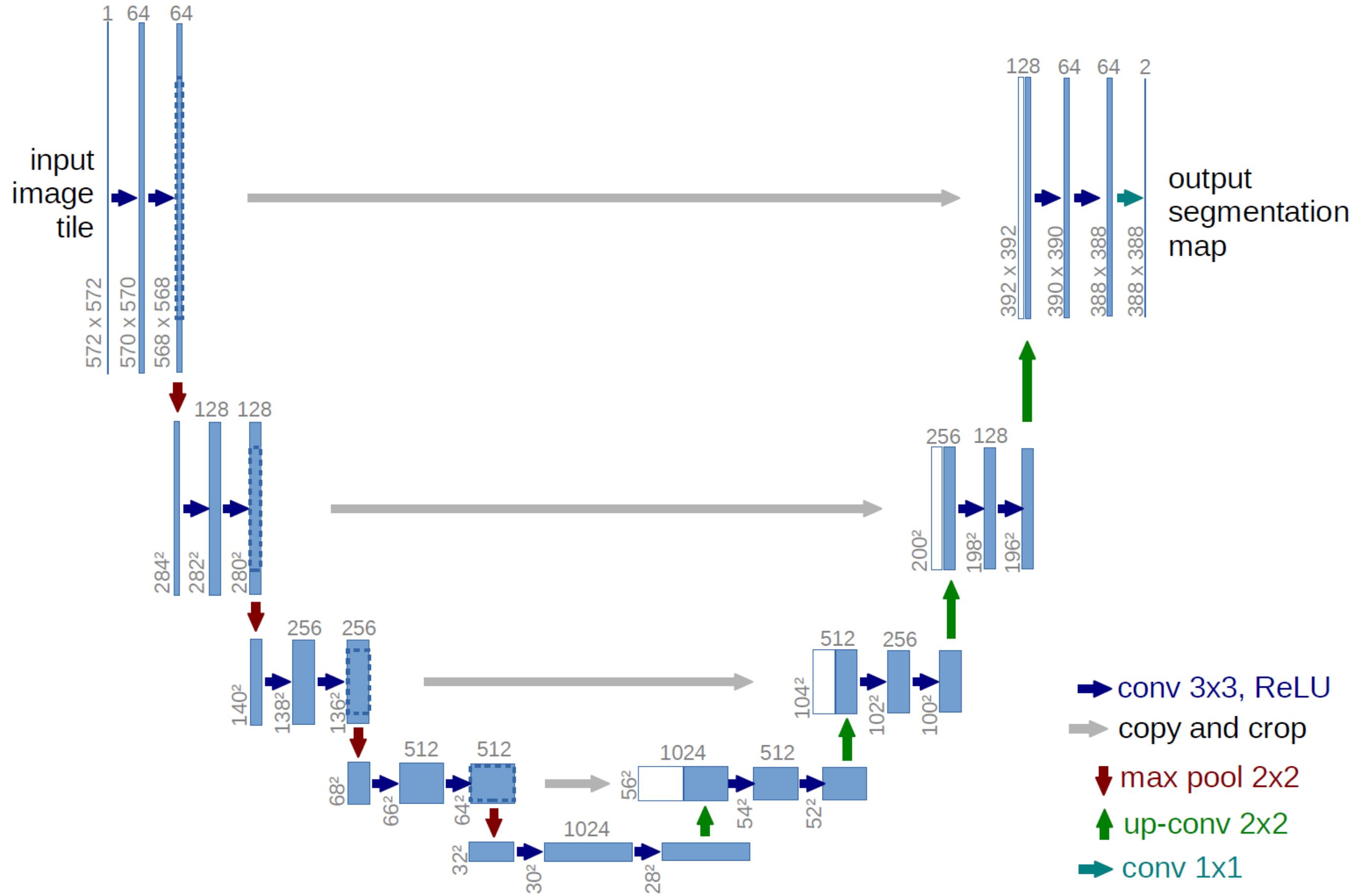
- Trained with differentiable Loss functions in a pipeline
- Loss Functions: Cross-Entropy (BCE), DICE (Soft), IoU Loss
 $= 1 - \text{IoU}$



<https://www.v7labs.com/blog/image-segmentation-guide>

<https://stackoverflow.com/questions/15102332/how-to-intersect-multiple-ienumerable>

Introducing the U-Net



- Architecture
 - Fully Convolutional Architecture
 - Skip Connections
- Designed for Biomedical problems

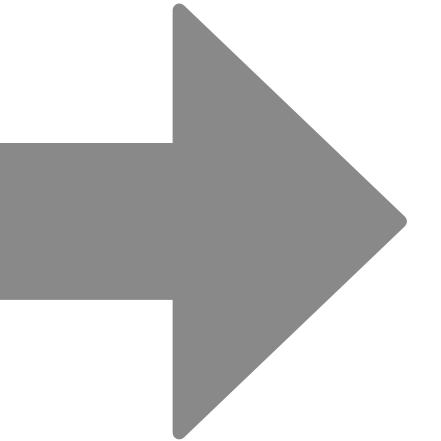
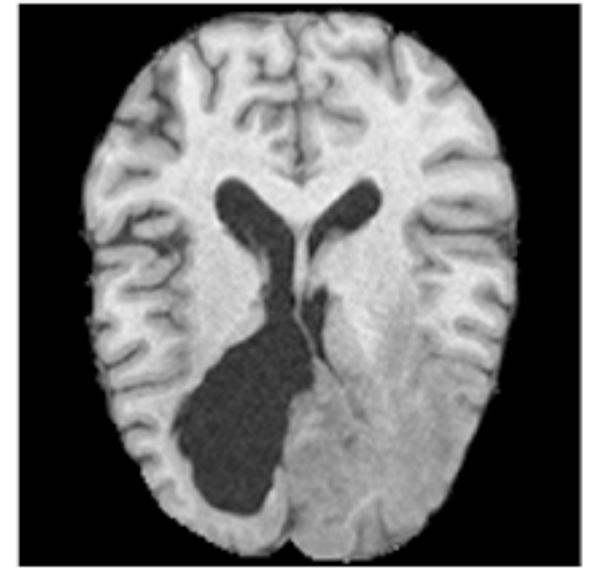
Ronneberger, O., Fischer, P. & Brox, T. U-Net: Convolutional Networks for Biomedical Image Segmentation. *arXiv:1505.04597 [cs]* (2015).

Milletari, F., Navab, N. & Ahmadi, S.-A. V-Net: Fully Convolutional Neural Networks for Volumetric Medical Image Segmentation. *arXiv:1606.04797 [cs]* (2016).

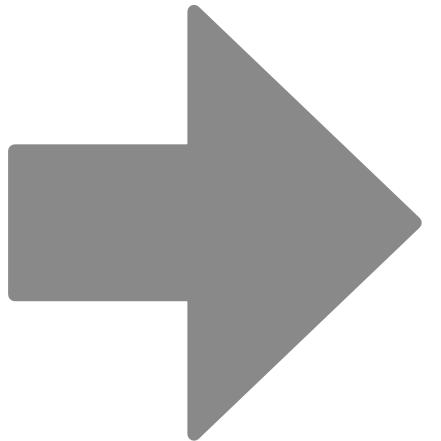
How to use the U-Net



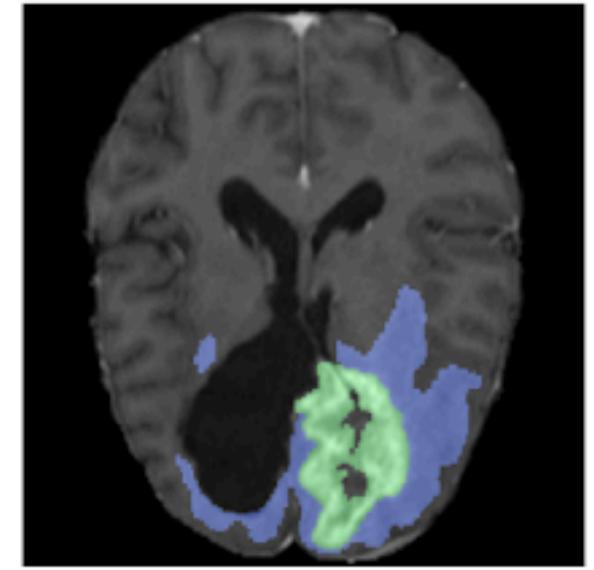
Train Data



U-Net



Downstream Task



Volume of a Tumor?

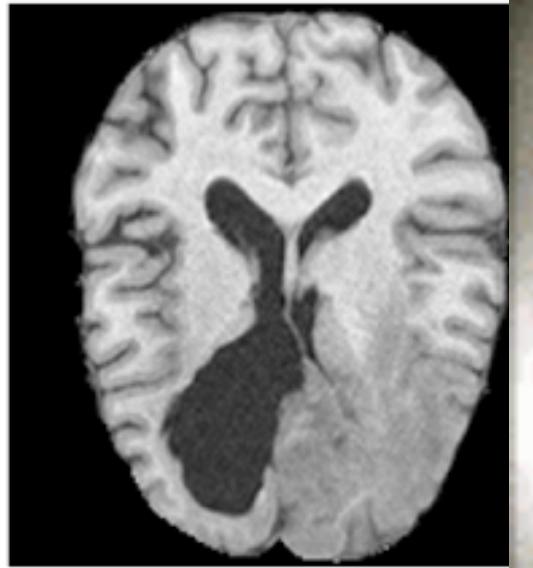
[Slide is Property of Fabian Jaeger & Fabian Isensee]

How to use the U-Net

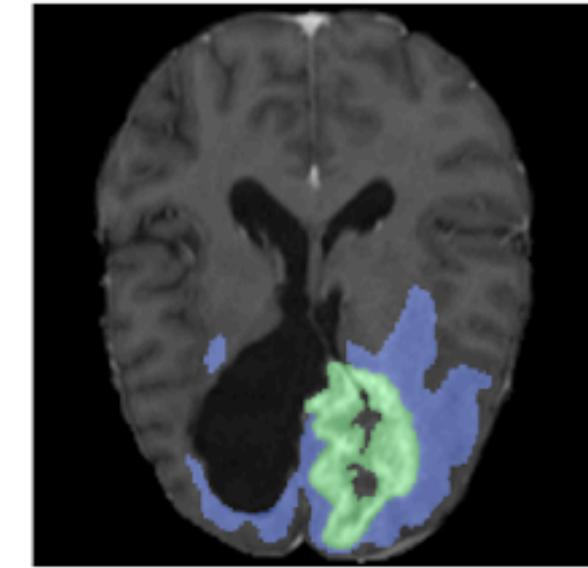
Confrontation with Reality



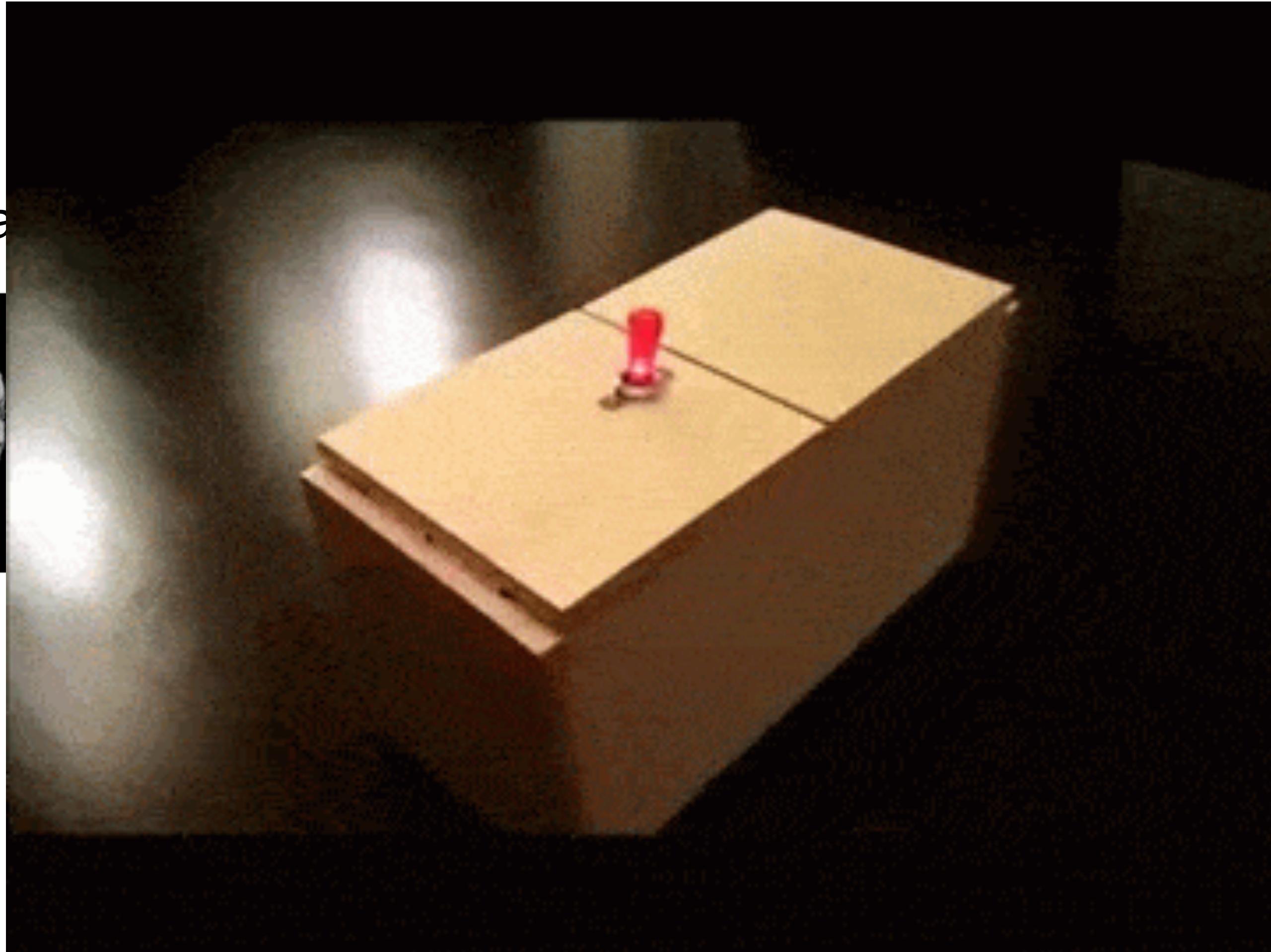
Train Data



Downstream Task



Volume of a Tumor?

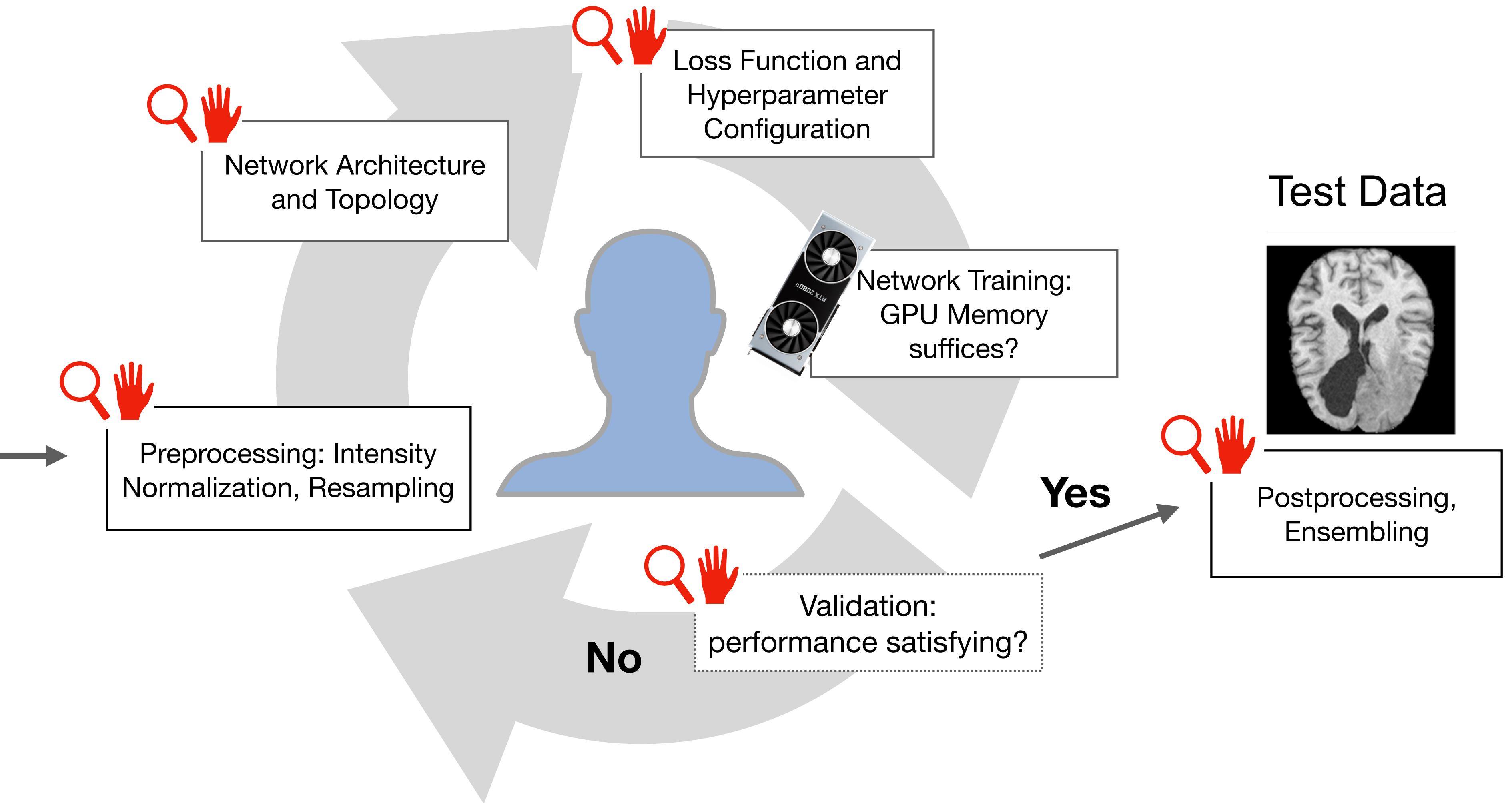
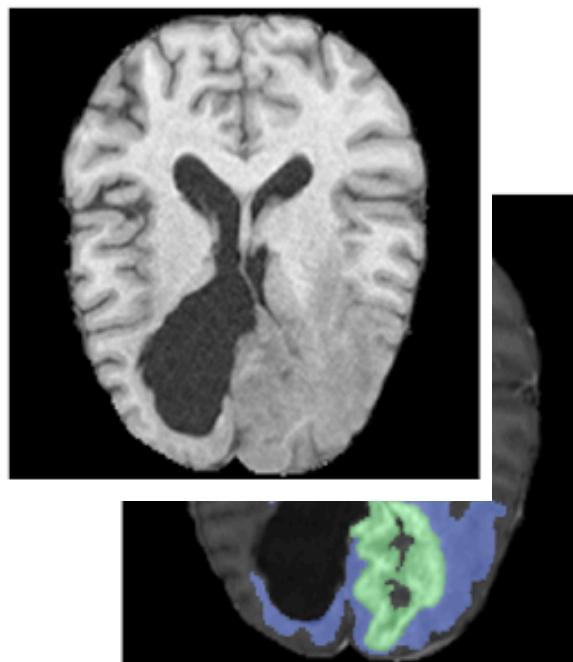


[Slide is Property of Fabian Jaeger & Fabian Isensee]

What do ML Engineers spend a lot of time on?

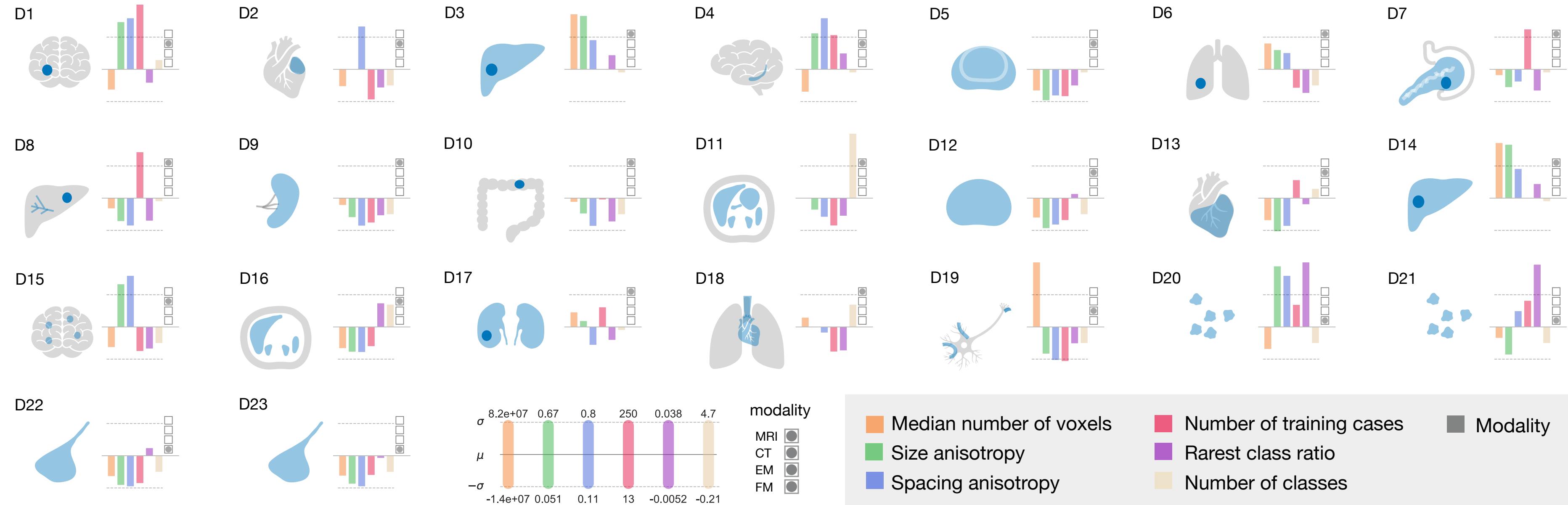
Reality

Train Data



[Slide is Property of Fabian Jaeger & Fabian Isensee]

Problem: Diversity of Biomedical Images



D1 MSD - Brain Tumor (edema, necrosis, enhancing tumor)
 D2 MSD - Heart (left atrium)
 D3 MSD - Liver (liver, liver tumor)
 D4 MSD - Hippocampus (anterior h., posterior h.)
 D5 MSD - Prostate (peripheral zone, transition zone)
 D6 MSD - Lung (lung nodules)
 D7 MSD - Pancreas (pancreas, pancreas tumor)
 D8 MSD - Hepatic Vessel (hepatic vessels, liver tumors)

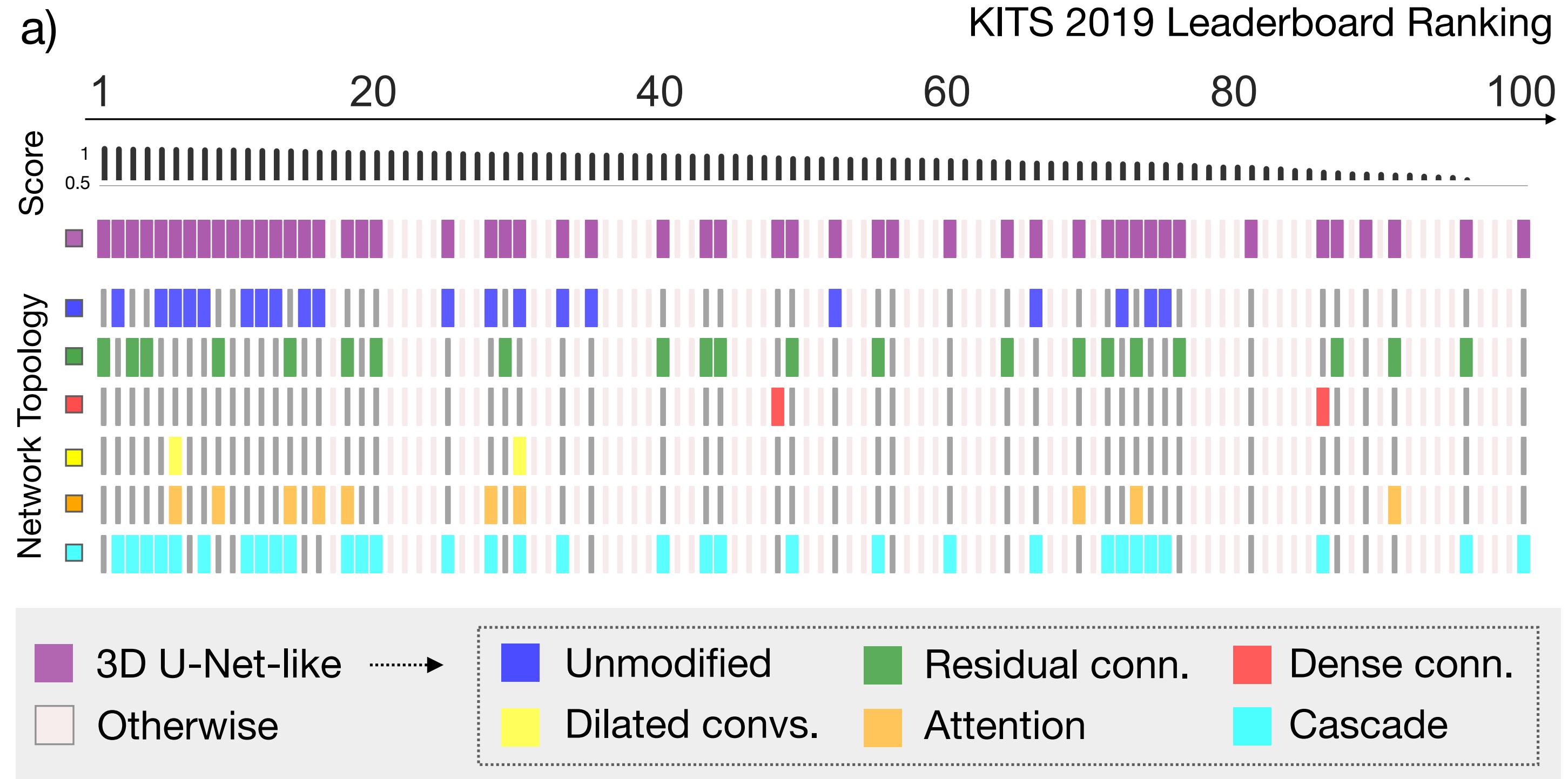
D9 MSD - Spleen (spleen)
 D10 MSD - Colon (colon cancer)
 D11 BCV-Abdomen (13 abdominal organs)
 D12 Promise12 (prostate)
 D13 ACDC (left ventricle, right ventr., myocard.)
 D14 LiTS (liver, liver tumor)
 D15 MSLes (ms lesions)
 D16 CHAOS (liver, spleen, l/r kidney)

D17 KiTS (kidneys, kidney tumor)
 D18 SegTHOR (heart, aorta, esophagus, trachea)
 D19 CREMI (synaptic cleft)
 D20 CTC - Fluo-N2DH-SIM+ (HL60 nuclei)
 D21 CTC - Fluo-N3DH-SIM+ (HL60 nuclei)
 D22 CTC - Fluo-C3DH-A549 (A549 cell)
 D23 CTC - Fluo-C3DH-A549-SIM (A549 cell)

MSD = Medical Segmentation Decathlon; CTC = Cell Tracking Challenge

[Slide is Property of Fabian Jaeger & Fabian Isensee]

From U-Net to nnU-Net



- Finding: The U-Net Architecture does not guarantee good results - neither do their modifications
- There is much more to Deep Learning than just the Architectural Design s.a.
 - Ensembling
 - Understanding the task
 - Validation
 - Data Handling
- But why do we not automate this with learned and known rules?
 - The idea of nnU-Net

nnU-Net

A segmentation method that automatically configures itself for arbitrary biomedical datasets without requiring expert knowledge nor computing resources beyond standard network training.

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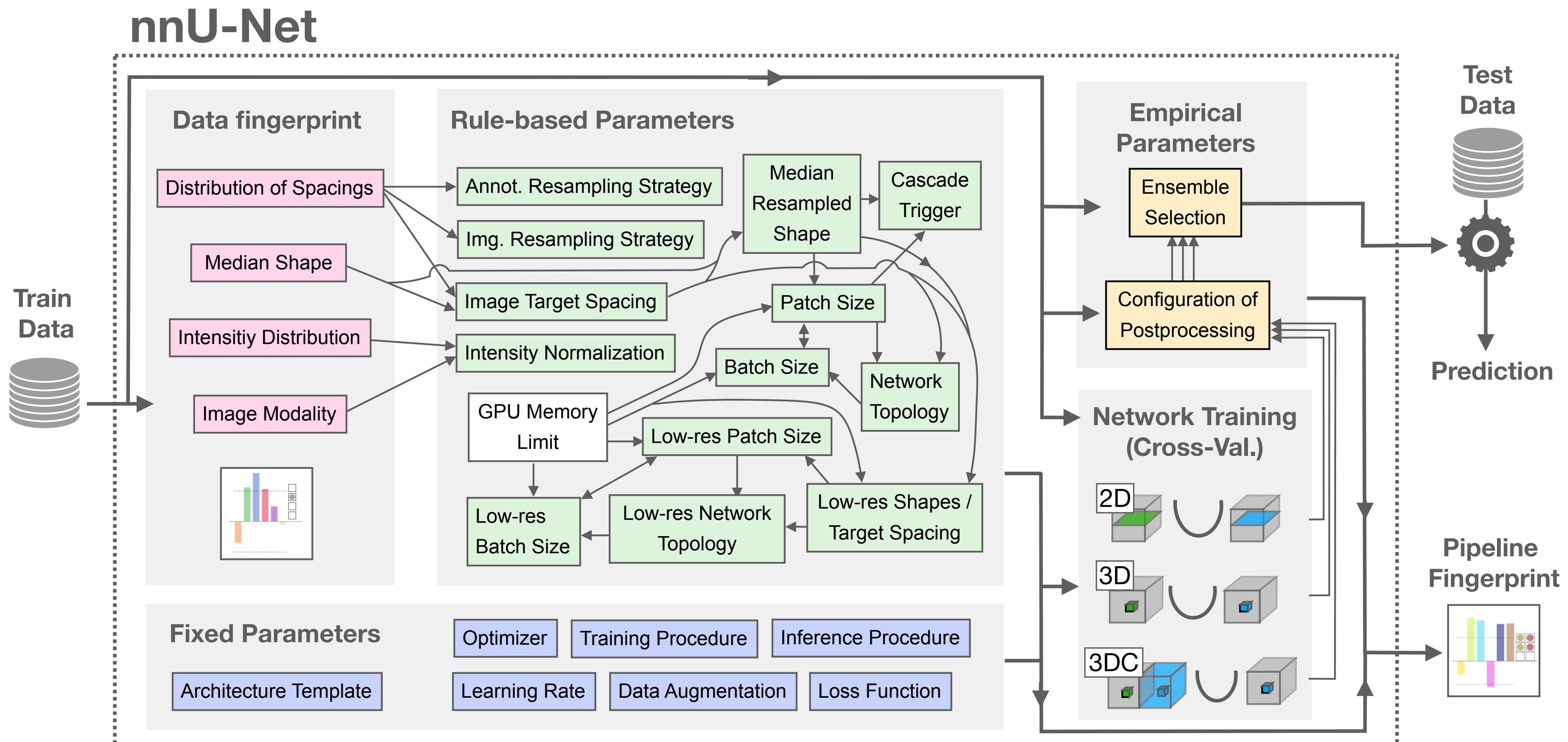
nnU-Net

A segmentation method that automatically configures itself for arbitrary biomedical datasets without requiring expert knowledge nor computing resources beyond standard network training.

In short: nnU-Net makes State-of-the-Art Segmentation results on a wide variety of (untested) datasets accessible to non-experts

[Slide is Property of Fabian Jaeger & Fabian Isensee]

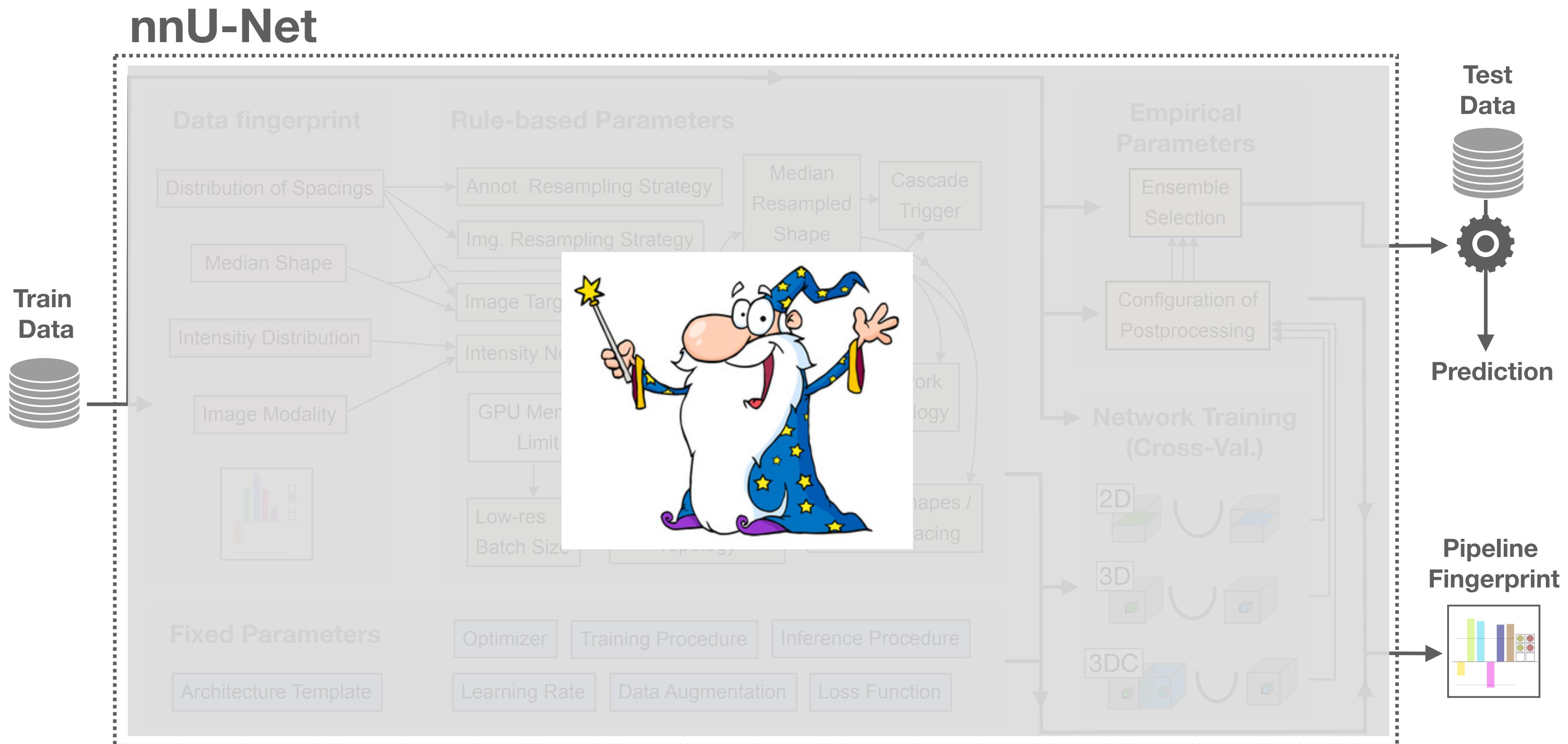
What does nnU-Net do for you?



[Slide is Property of Fabian Jaeger & Fabian Isensee]

Isensee, F., Jaeger, P. F., Kohl, S. A. A., Petersen, J. & Maier-Hein, K. H. nnU-Net: a self-configuring method for deep learning-based biomedical image segmentation. *Nat Methods* **18**, 203–211 (2021).

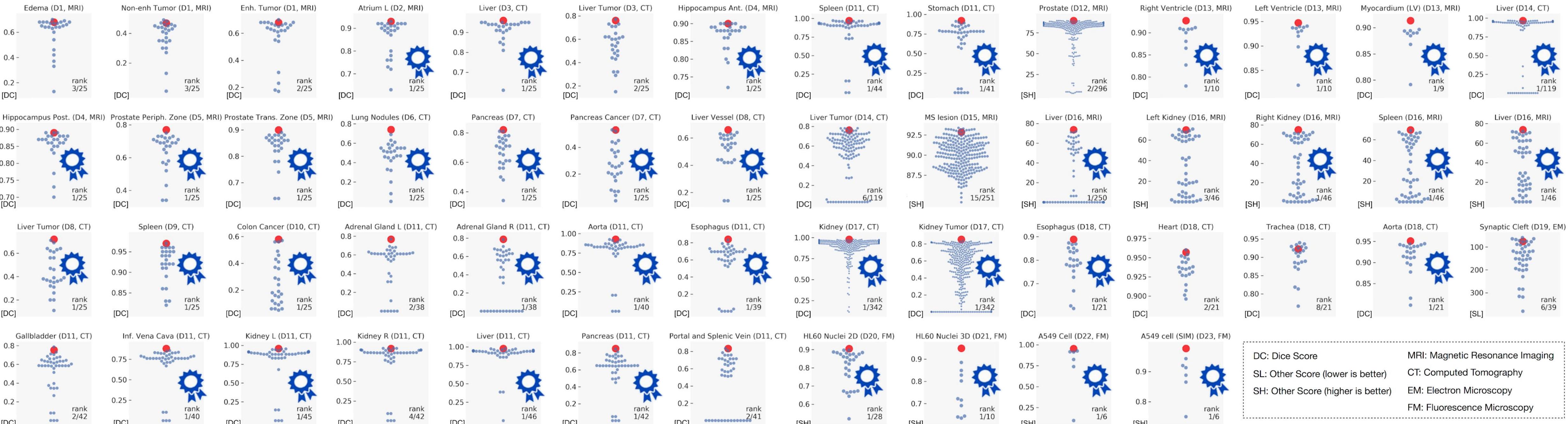
From U-Net to nnU-Net



[Slide is Property of Fabian Jaeger & Fabian Isensee]

Isensee, F., Jaeger, P. F., Kohl, S. A. A., Petersen, J. & Maier-Hein, K. H. nnU-Net: a self-configuring method for deep learning-based biomedical image segmentation. *Nat Methods* **18**, 203–211 (2021).

Quantitative Results on multiple Biomedical Benchmarks

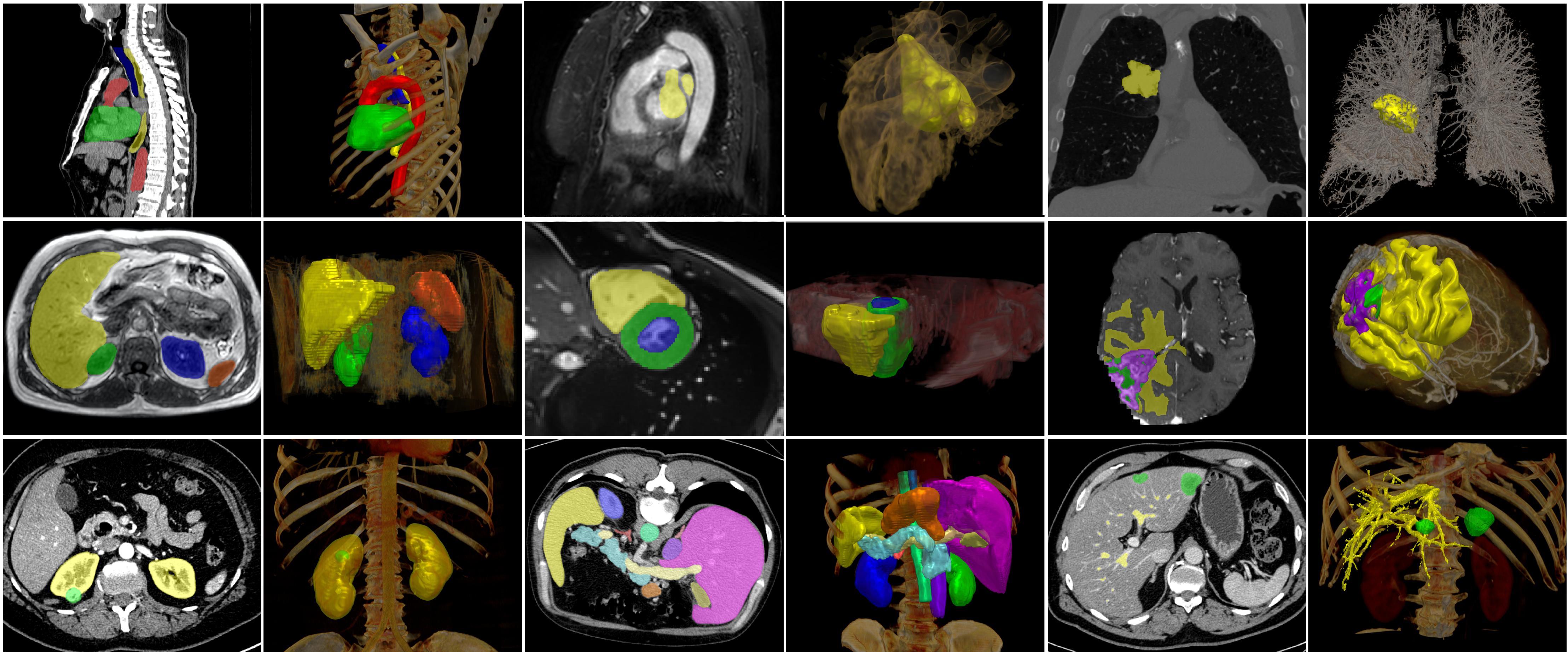


First rank in 33/53 Tasks!

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Visual Examples of the Results

Created with MITK

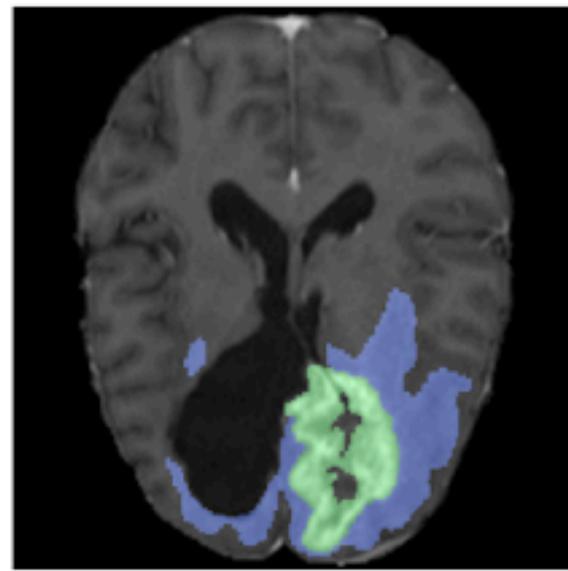
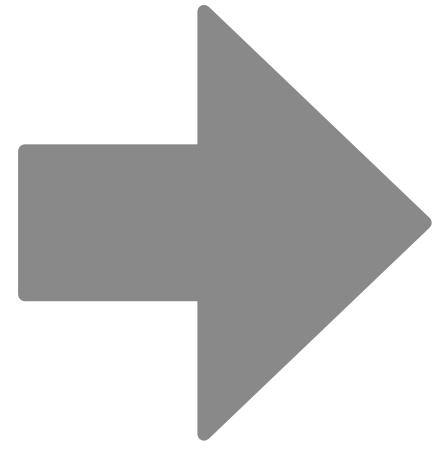
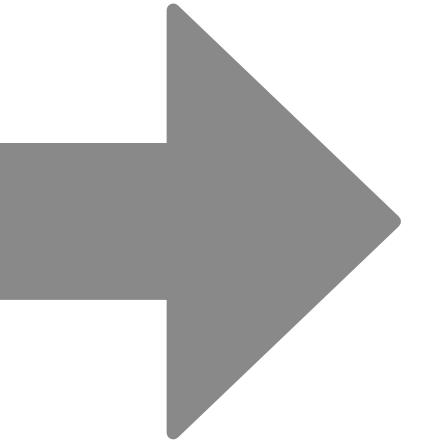
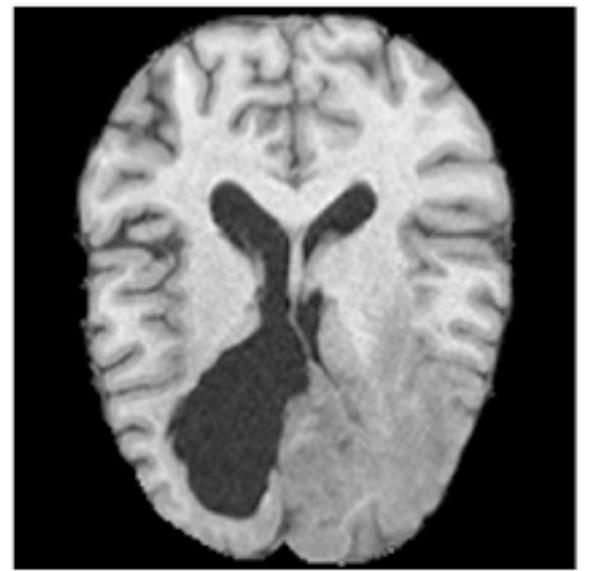


[Slide is Property of Fabian Jaeger & Fabian Isensee]

- Time consuming trial-and-error process
 - Success depends on experience of researcher
 - Inaccessible to non-experts
 - Needs to be repeated on own
- 1. Out-of-the-box tool**
- Reduces method evaluation to one or few datasets in practice
 - Causes non-standard baseline re-implementations
- 2. Experimental Framework**
- Standardised Baseline

[Slide is Property of Fabian Jaeger & Fabian Isensee]

nnU-Net



No more time consuming pipeline optimization

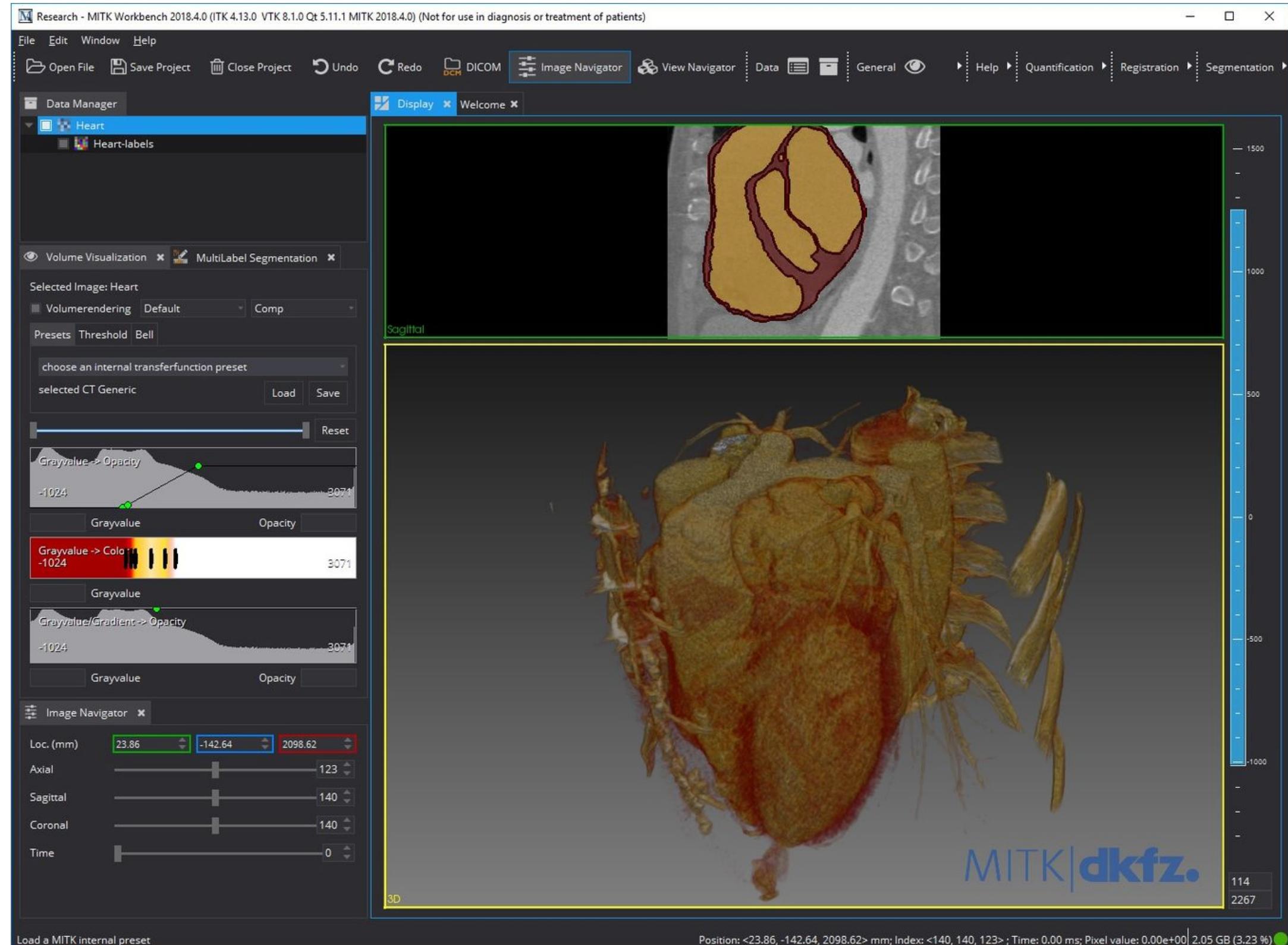
[Based on Slide by Fabian Jaeger & Fabian Isensee]

nnU-Net



How and for what purpose would you use it?

[Based on Slide by Fabian Jaeger & Fabian Isensee]



What is **MITK-Workbench**?

- application to view, process, and segment medical images

What to use it for?

- Analysis of medical imaging methods, both 3D and 2D
- Familiarisation with Data

What can you do with it?

- Create visualizations - read out metadata used for later tasks.
- Create Segmentations to use with nnU-Net

Where do you obtain it?

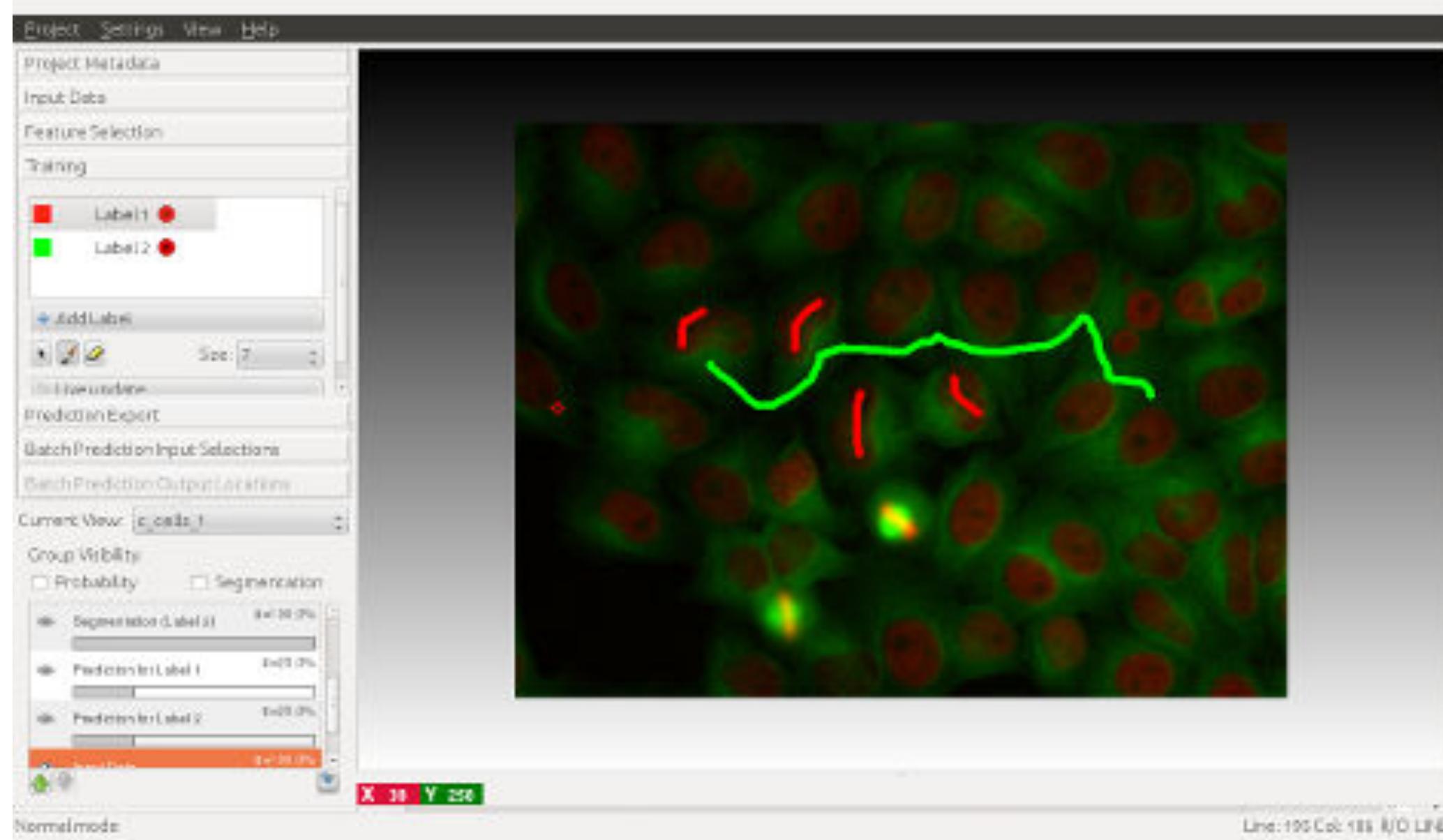
- <https://www.mitk.org/wiki/Downloads>

Developed by Medical Image Computing Research Group at the DKFZ

<https://www.mitk.org/wiki/MITK>



lastik



What is **ilastik**?

- The interactive learning and segmentation toolkit

What to use it for?

- Apply Machine Learning Algorithms on experimental biological data such as cells.

What can you do with it?

- Carving, Tracking, Counting, Pixel Classification, Object Classification

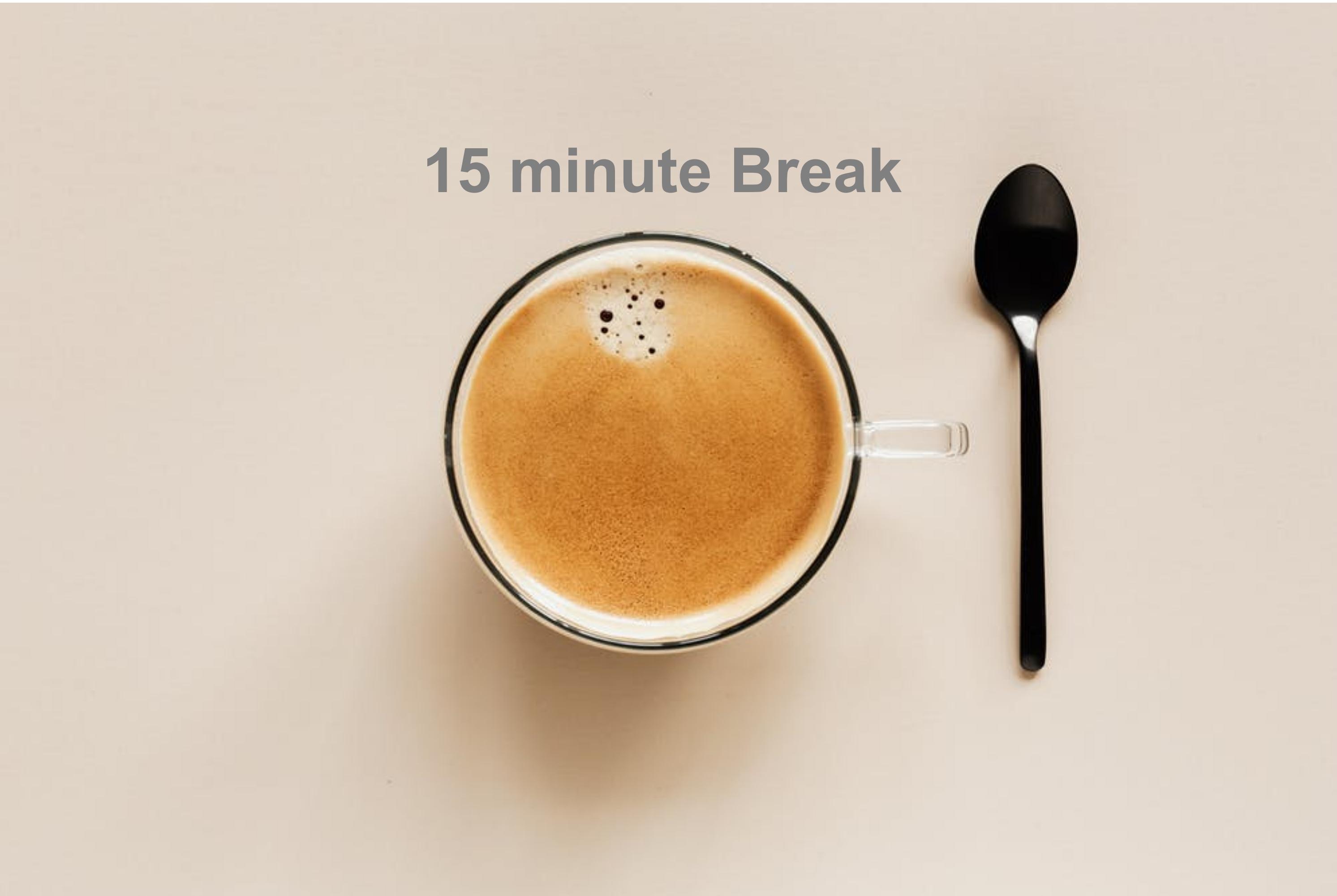
Where do you obtain it?

- <https://www.ilastik.org>
- Free & Open Source

Developed in Heidelberg

<https://www.ilastik.org/>

Break



[[pexels.com](https://www.pexels.com)]

Instructions for the Break - what to do?

- application to view, process, and segment medical images

What do we want to achieve?

- You being able to use the developments made at the DKFZ for your own projects!
 - nnU-Net
 - MITK-Workbench - installed on your local machine [best prepared during break]

What do you need?

- A Laptop for now (PC at home does the job too)
- Either:
 - A Google Account (for serious use Colab Pro) - [prepare during break] (at least 2Gb free on GoogleDrive)
 - A Computer with a 12GB VRAM Nvidia Graphics Card
- Optional: A working email-address for nice visualisations with [Weights&Biases](#)

Notes:

Due to time constraints I will host the data for the tutorial - If you want to share, or work with the notebook from the tutorial again, please keep in mind that You will have to download the data and put in the correct place yourself!

Link: https://colab.research.google.com/drive/12ZR6fOK0H8YAcIjn_4hHUeDgVaFjQjQC?usp=sharing

Thank you for your attention



[sten2lu.github.io](https://github.com/sten2lu)



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Further Information



Presentation about Instance and Semantic Segmentation

- <https://www.youtube.com/watch?v=LMZI8DDyltQ&t=3729s>

Presentation by Dr. Paul Jäger about nnU-Net

- <https://www.youtube.com/watch?v=3po8qVzz5Tc&t=2196s>

Presentation by Dr. Fabian Isensee about nnU-Net

- <https://www.youtube.com/watch?v=C6tpnJRpt90>

nnU-Net GitHub Page

- <https://github.com/MIC-DKFZ/nnUNet>

Backup

- Paper by Lena about metrics with examples

[Citation]