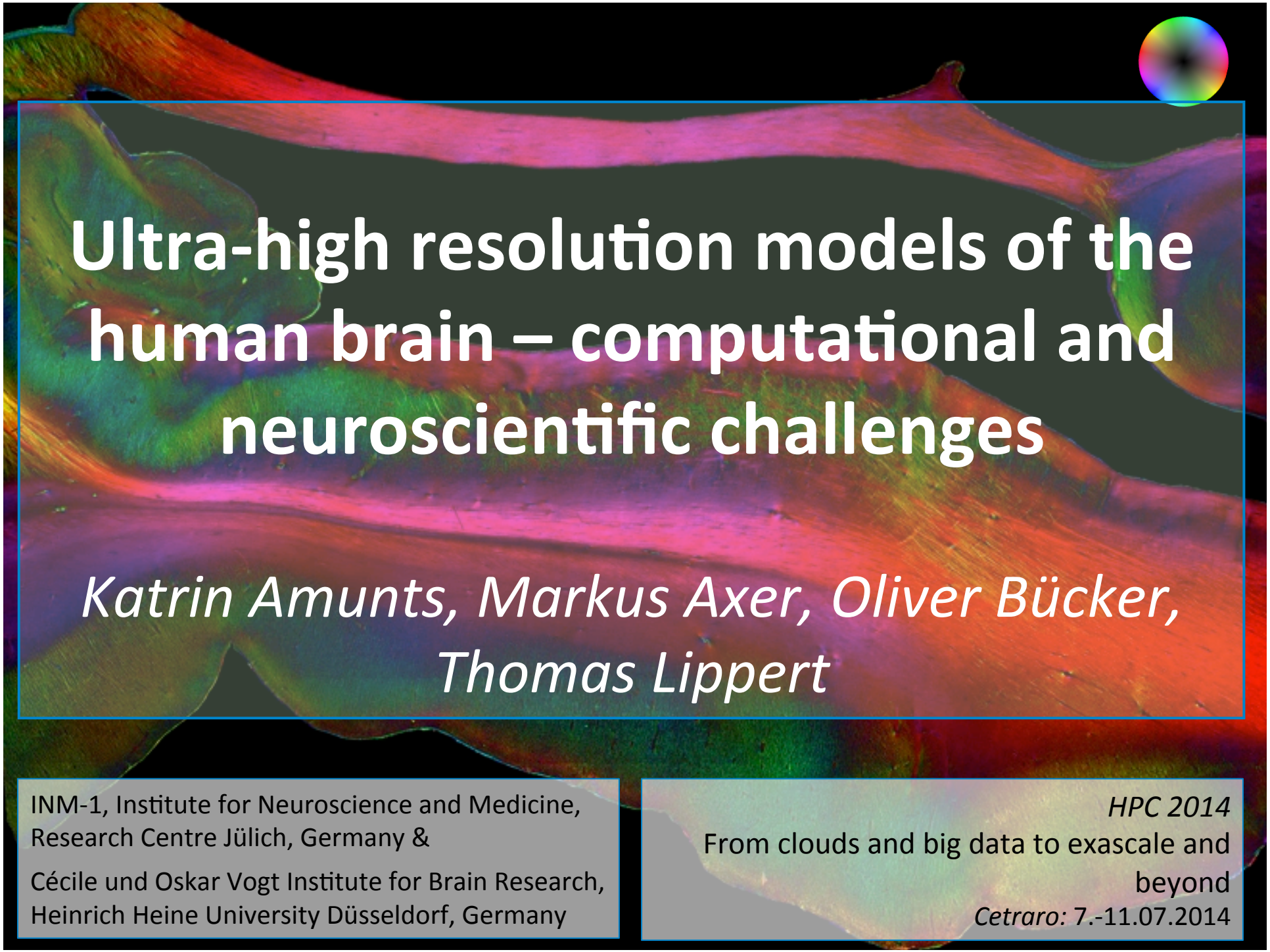


# Ultra-high resolution models of the human brain – computational and neuroscientific challenges

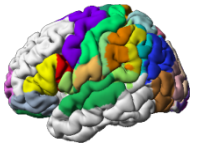
*Katrin Amunts, Markus Axer, Oliver Bücker, Thomas Lippert*

INM-1, Institute for Neuroscience and Medicine, Research Centre Jülich, Germany &

Cécile und Oskar Vogt Institute for Brain Research, Heinrich Heine University Düsseldorf, Germany

*HPC 2014*
From clouds and big data to exascale and beyond
*Cetraro:* 7.-11.07.2014

# Challenge: Brain Complexity



≈100 billion nerve cells
each with $10^4$ synapses
2 states for each synapse

$= 2^{10^{15}}$

**Complexity and size**

Multiscale organization
*(nm – cm, ms – years)*

Multimodal organization
*(from molecules, cells, circuits, to large cognitive systems)*

Intersubject variability

Genome

Environmental factors

Activity and learning

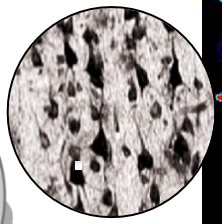
Development and aging

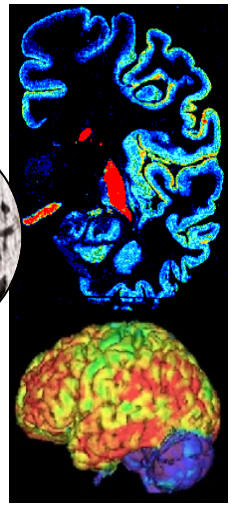
Plasticity and disease

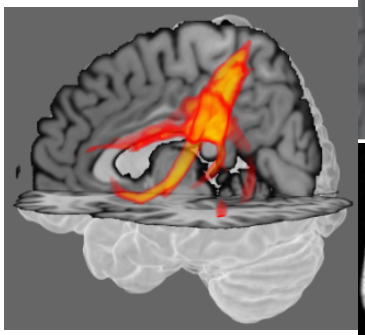
# Multilevel organization

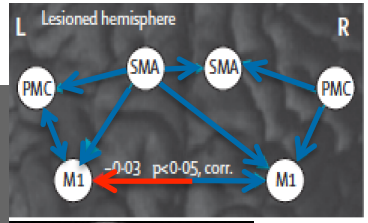

*Simulation-Lab*
*Jülich supercomputers*
*Visualization*
*BigData*
*Neuroinformatics*

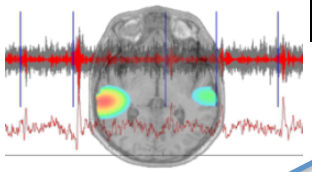
**BIG DATA ANALYTICS & SIMULATION**

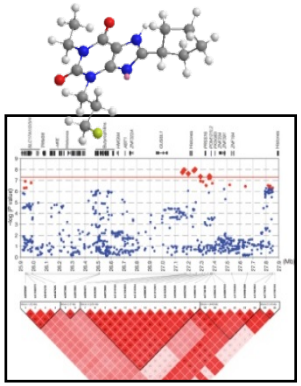


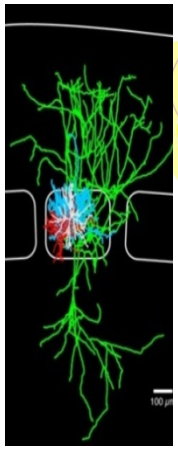


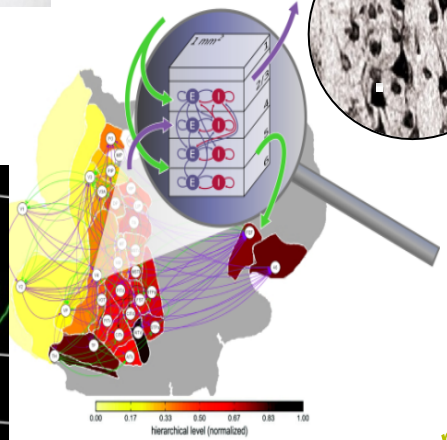




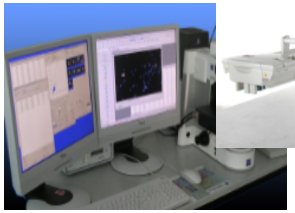


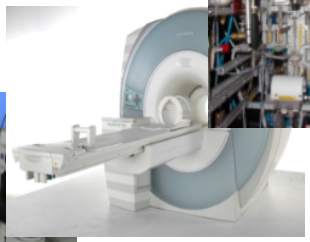


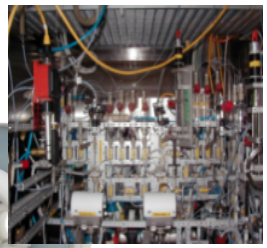



*Multiscale in space and time, multimodal*

**NEUROIMAGING**

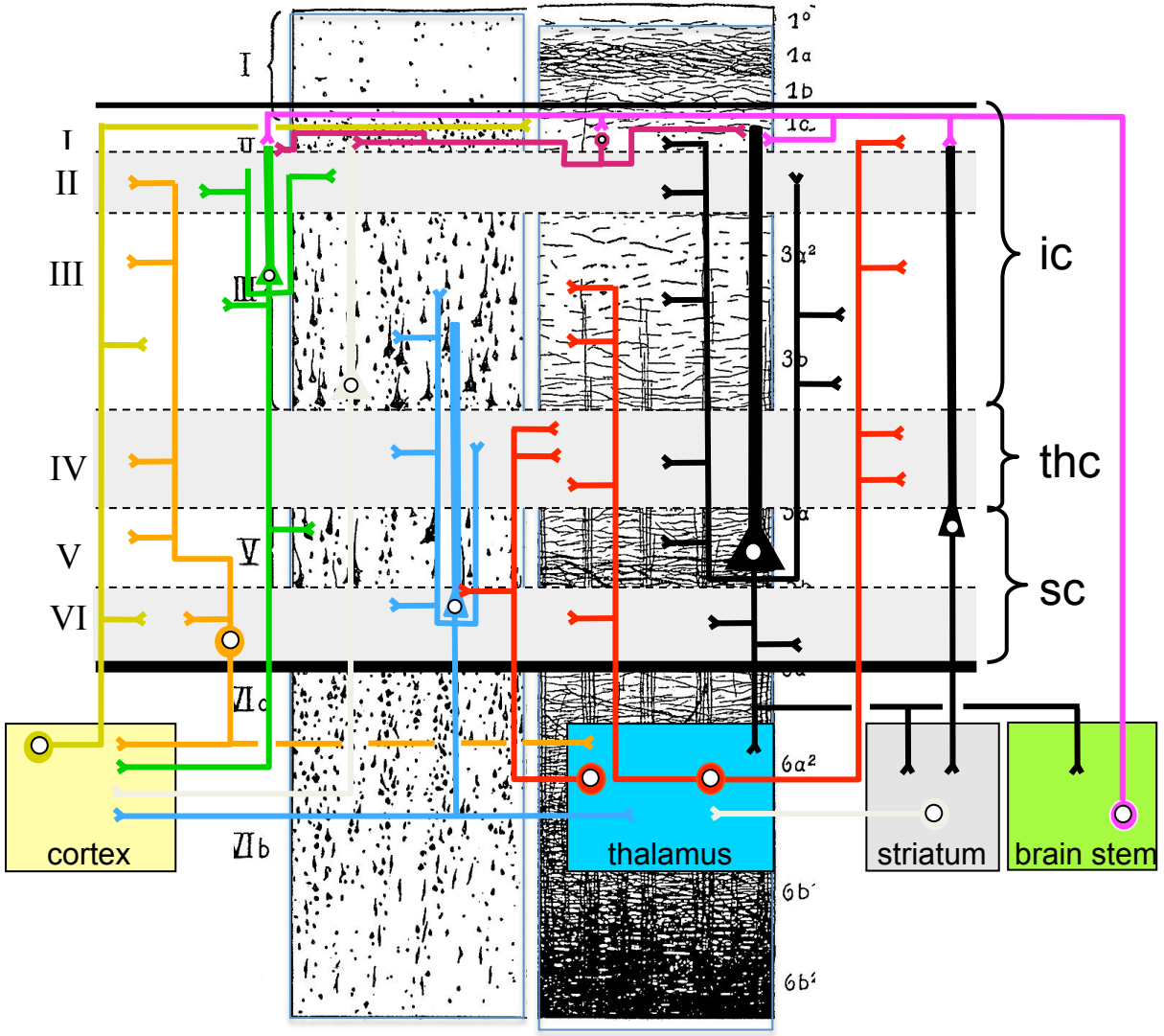






*3T MR*
*9.4 MR-PET*
*3T MR-PET*
*Electron microscopy*
*Image analysis*
*9.4 T animal MR*
*Tracer development*
*Radiopharmacology*
*High-throughput microscopical imaging*

# Cellular and fiber architecture

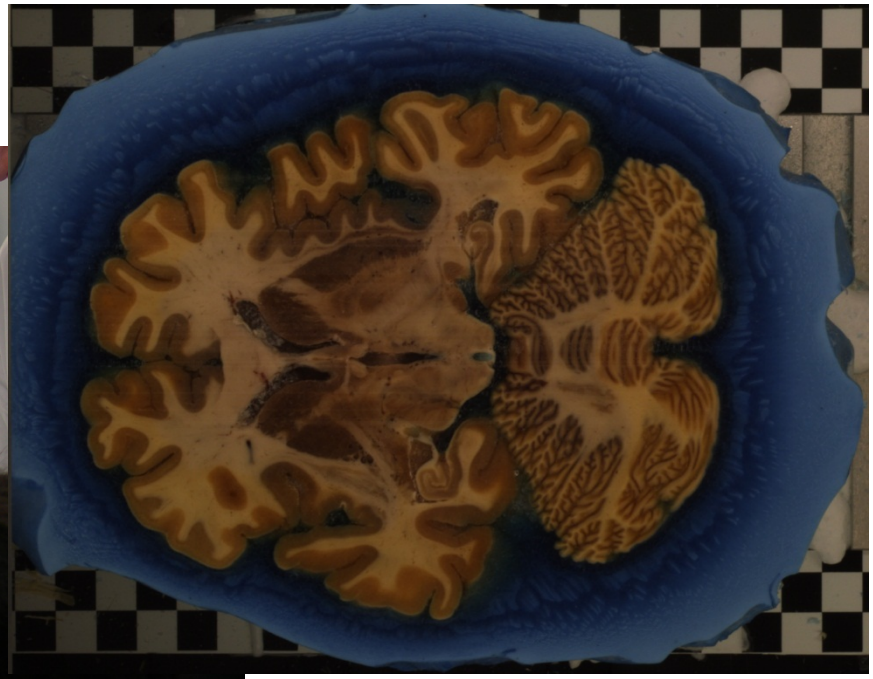



Vogt, 1927

Zilles and Amunts, in press

Vogt, 1927

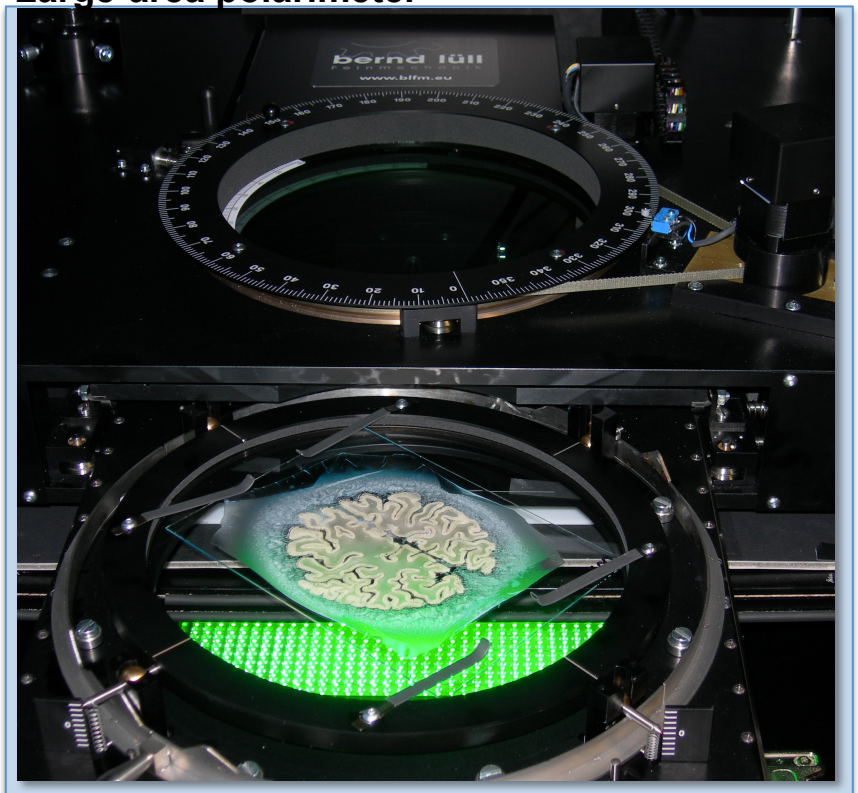
# *Analysis of fiber tracts with Polarized Light Imaging (PLI)*



Blockface of a brain
0.06- 0.1 mm
thickness of sections

# Data acquisition for PLI on 2 spatial scales

**Large-area polarimeter**




**Data traffic:**

single-shot image

Size: 3.000×3.000 pixel

**Resolution: 60µm × 60µm**

Scan time: 15min/section

4.4 GByte per section ➡ 11TByte per brain

**PLI microscope**

**Data traffic:**

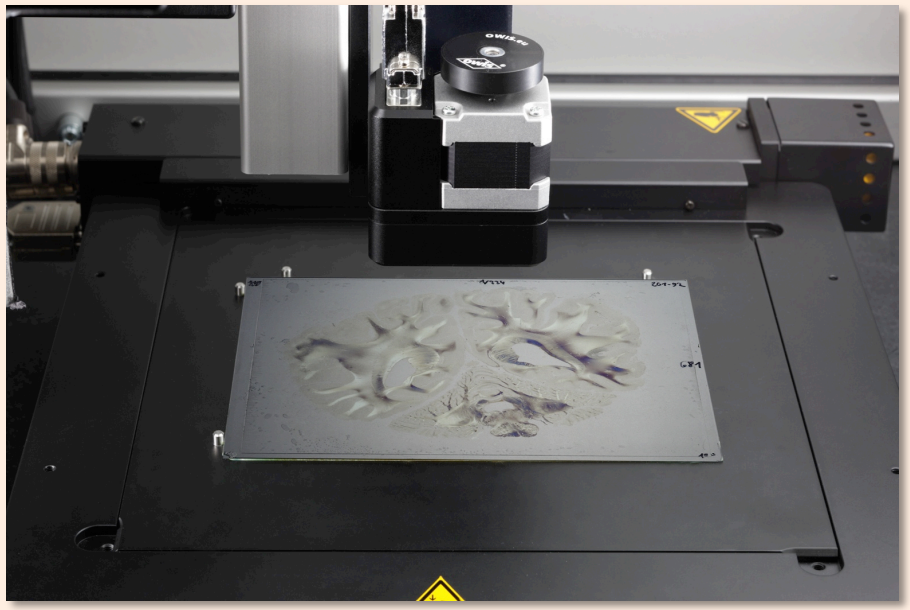
Tiled image acquisition

Total size: 100.000×100.000 pixel

**Resolution: 1,6µm × 1,6µm**

Scan time: 6h/section

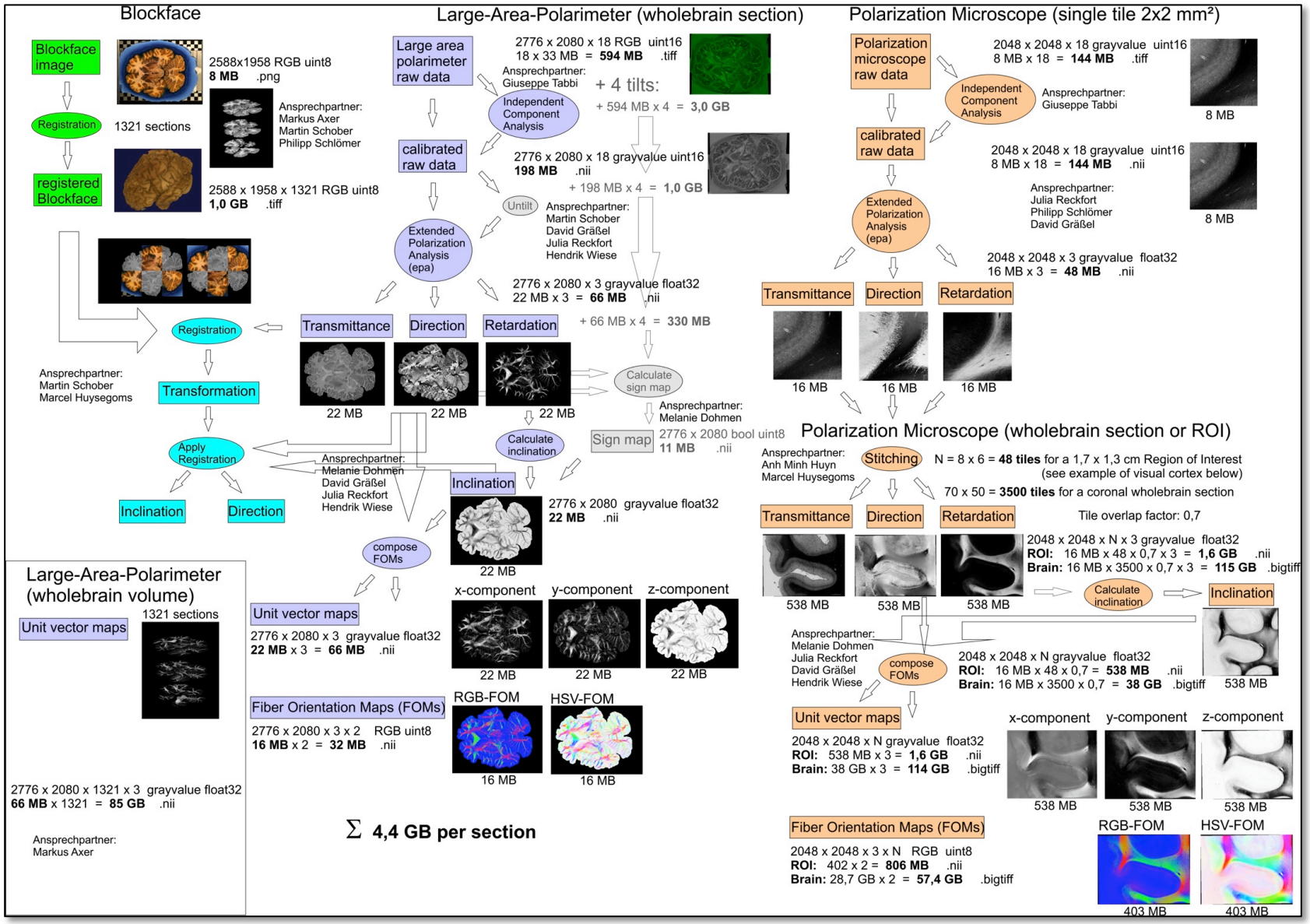
1.5 TByte per section ➡ 3.8 PByte per brain



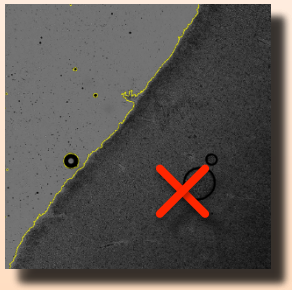
single tile 2mm x 2mm

*Axer et al. (2011) NeuroImage 54: 1091-1101 & (2011) Frontiers Neuroinformatics 5:34*

# Workflow for 3D-PLI

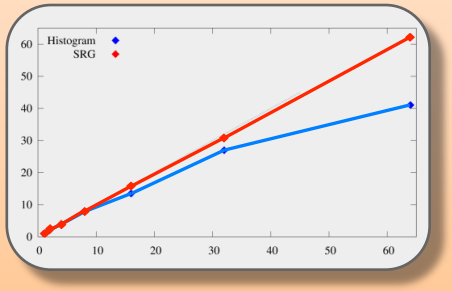


## Segmentation



**How to automate the segmentation of thousands of tiles ?**

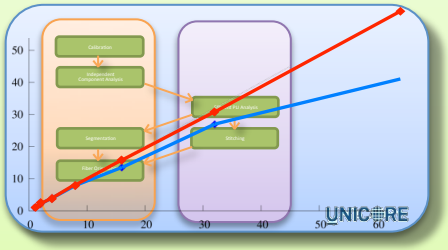
**Are we able to speed up the segmentation by parallelization?**



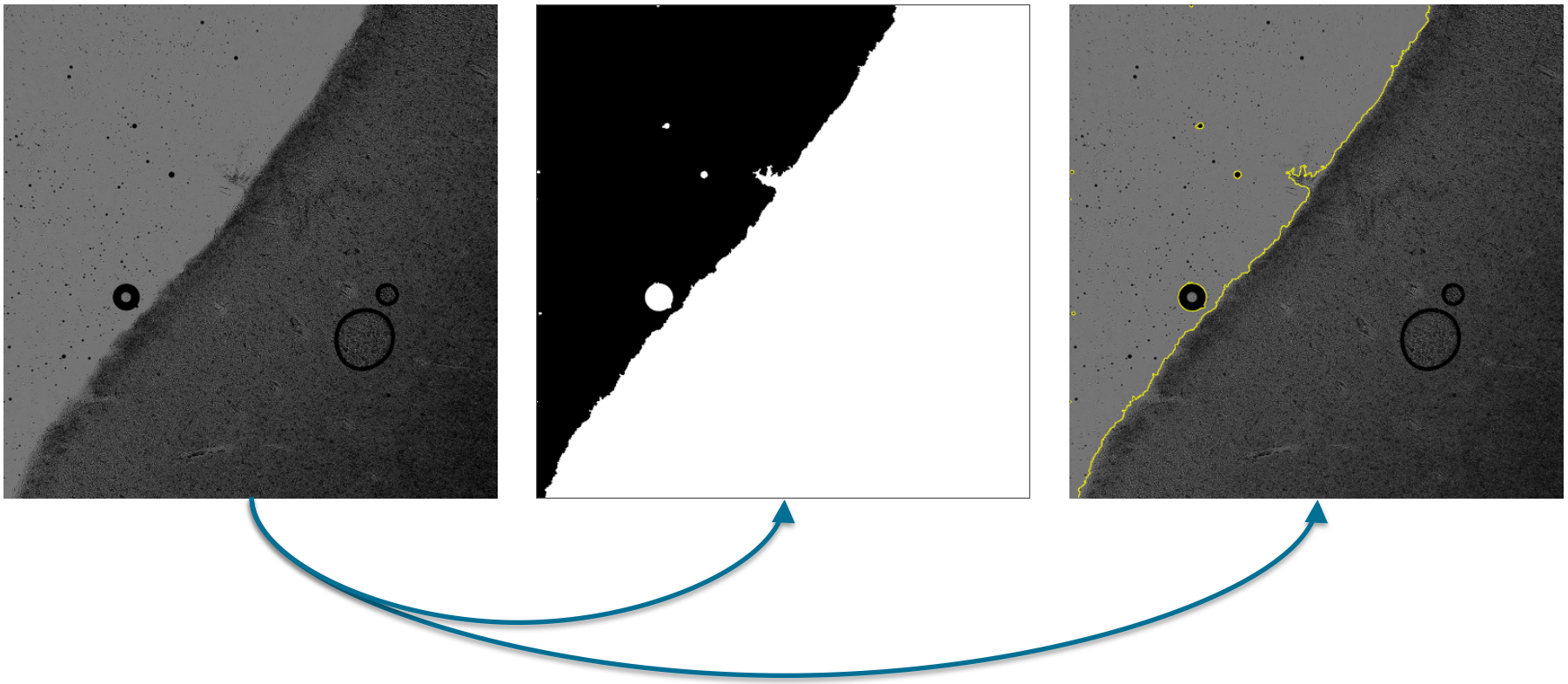

## Workflow


**How to automate the workflow tools, which build on one another?**

**Are we able to speed up the workflow by parallelization?**

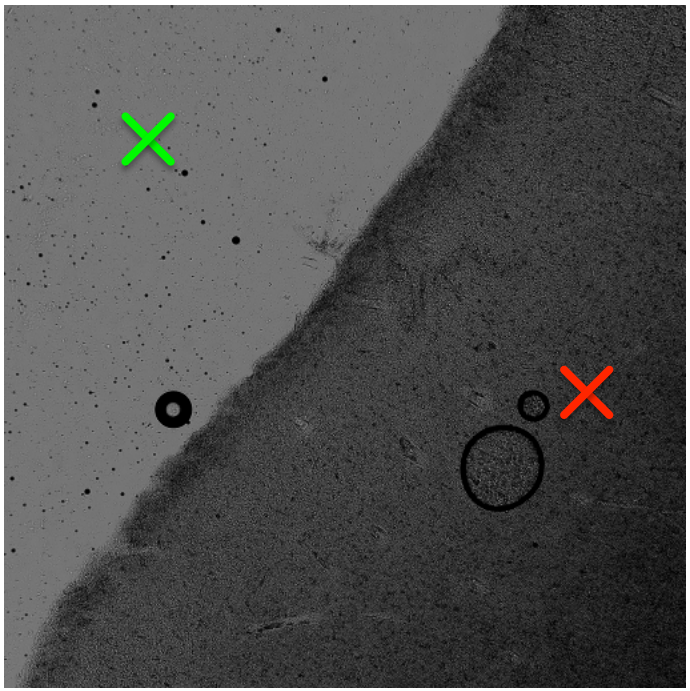


# Segmentation



# Seeded Region Growing – basic algorithm

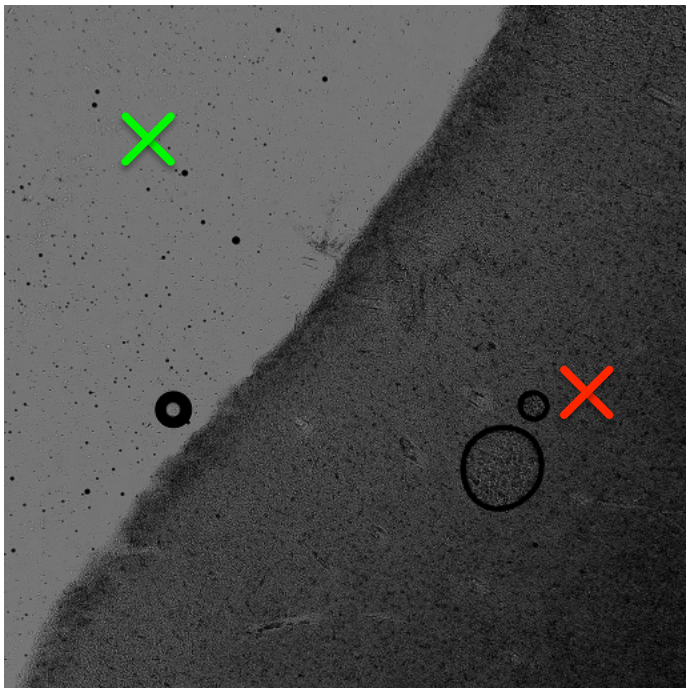
- Set seeds for every image region

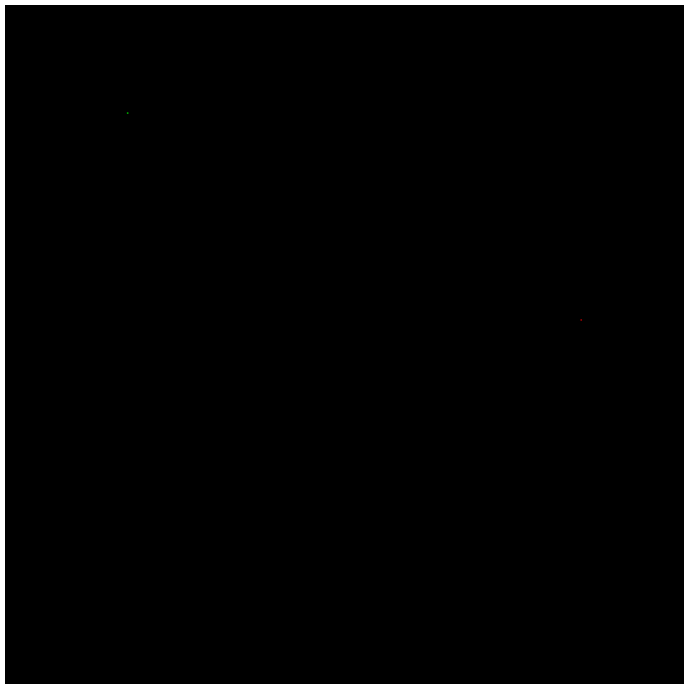


# Seeded Region Growing – basic al

How to set seeds for 1,125,000 images/brain?!

- Set seeds for every image region
- Growing of the regions until the whole image is covered



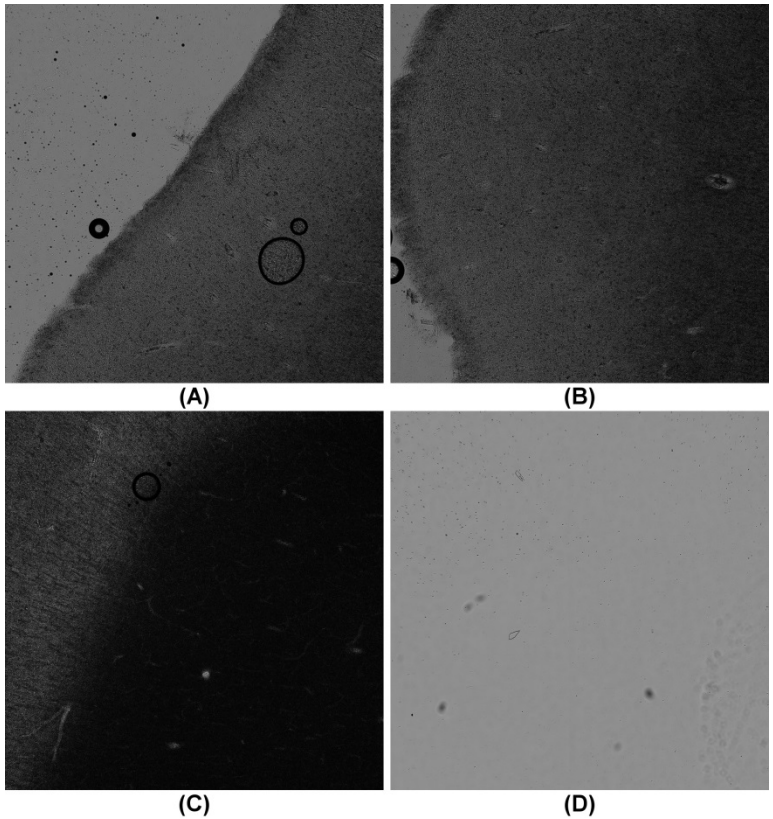


# Automating the choice of seeds

- Tiles may show
  - brain
  - background
  - both
- Brain darker than background

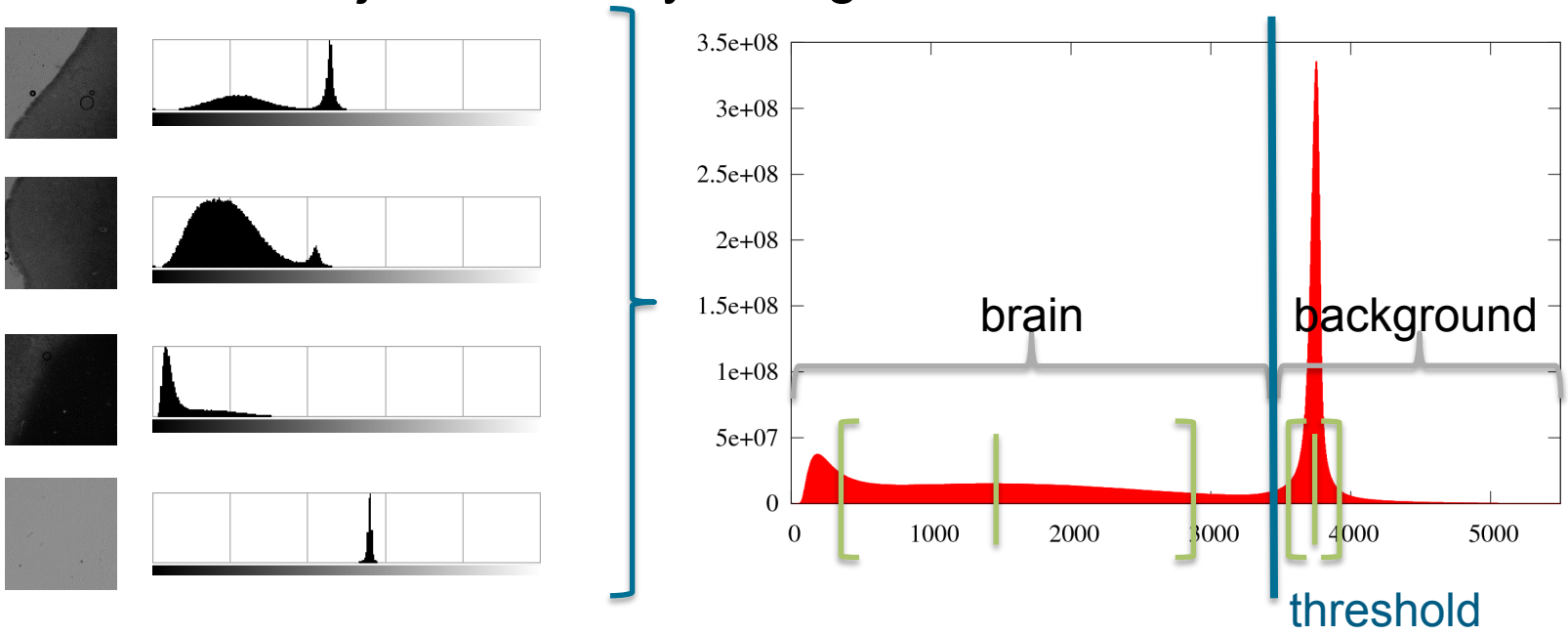
→ Intensity histogram based choice of seeds

→ Must take into account the different image contents



# Automating the choice of seeds

- Calculate the joint intensity histogram of all tiles

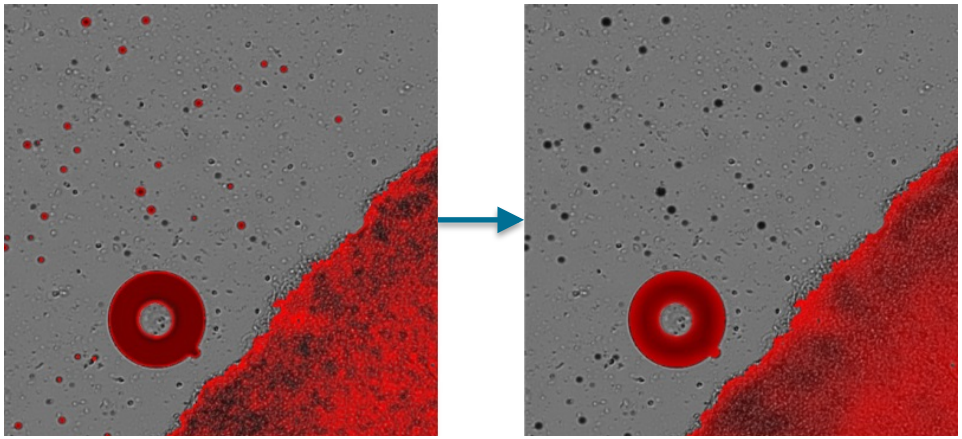


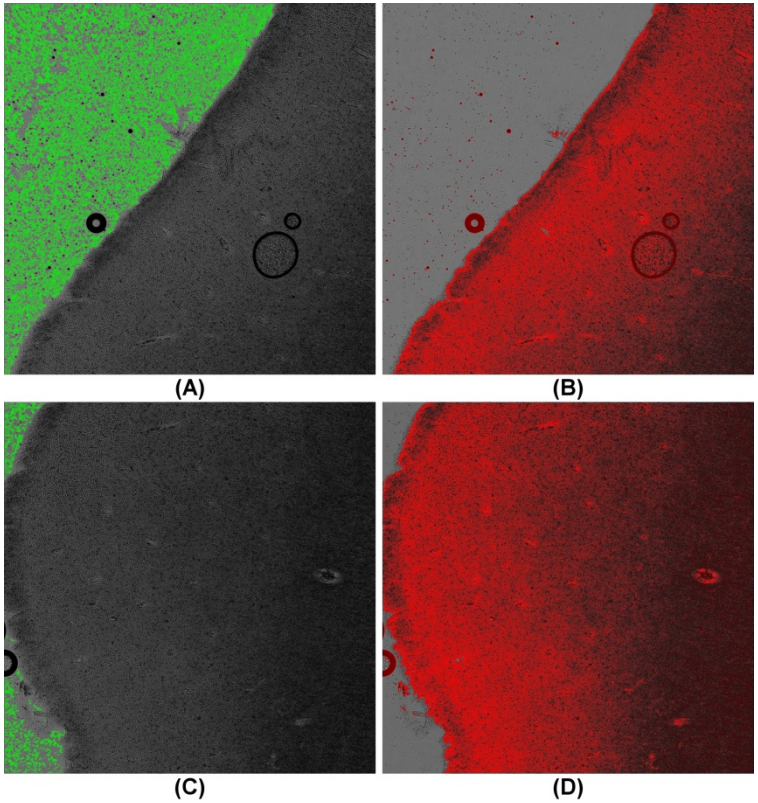

- Calculate measure $m\downarrow final$:

$$m\downarrow final\,(x,y)=\sum l=-m\uparrow m \sum k=-n\uparrow n\, w(x+l,y+k)\cdot \max(i(x+l,y+k)-q\downarrow 0{,}5\ /q\downarrow\alpha-q\downarrow 0{,}5\ ,q\downarrow 0{,}5\ -i(x+l,y+k)/q\downarrow 1-\alpha-q\downarrow 0{,}5\ )$$

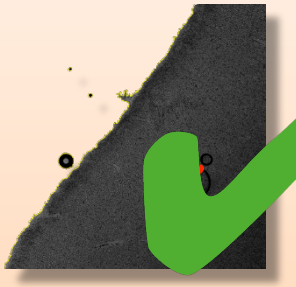
# Automating the choice of seeds

- Dirt particles in the background marked as seeds
- Eliminate these seeds
- → Basically another sum of a defined neighborhood



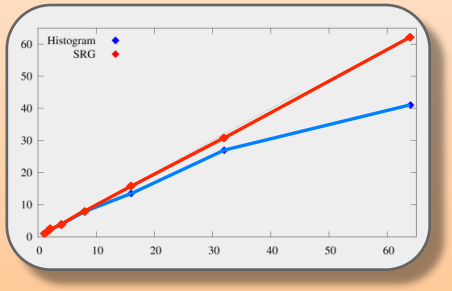


## Segmentation



**How to automate the segmentation of thousands of tiles ?**

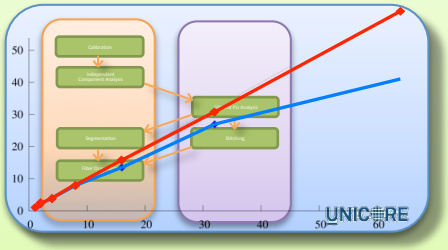
**Are we able to speed up the segmentation by parallelization?**




## Workflow

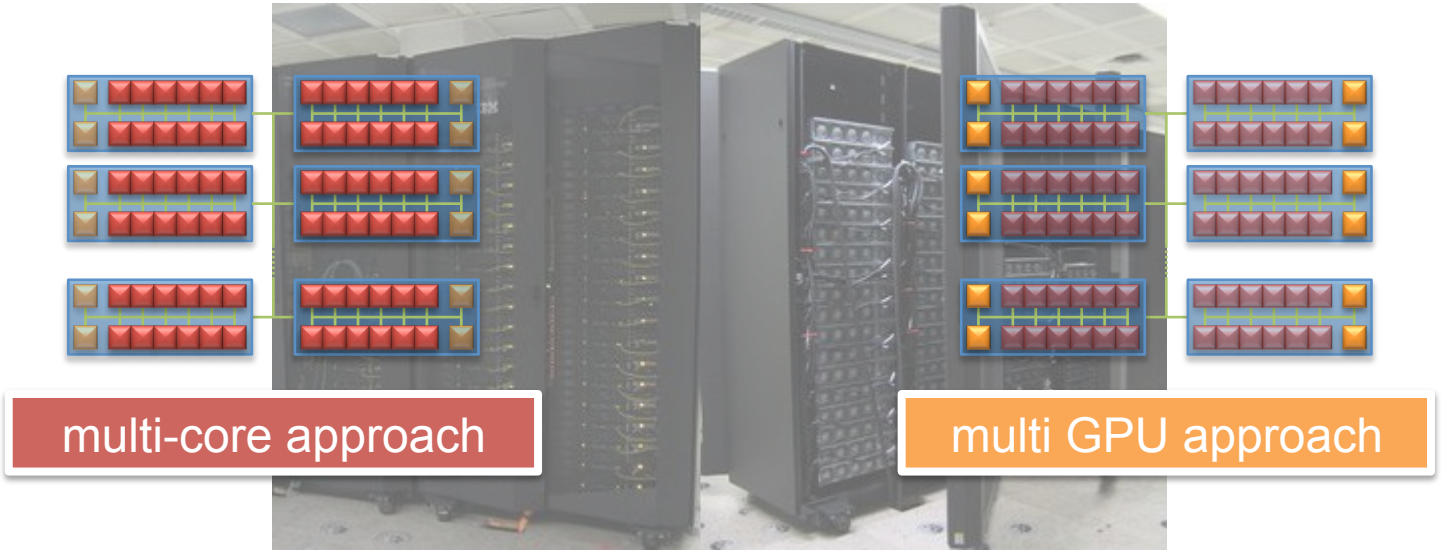

**How to automate the workflow tools, which build on one another?**

**Are we able to speed up the workflow by parallelization?**

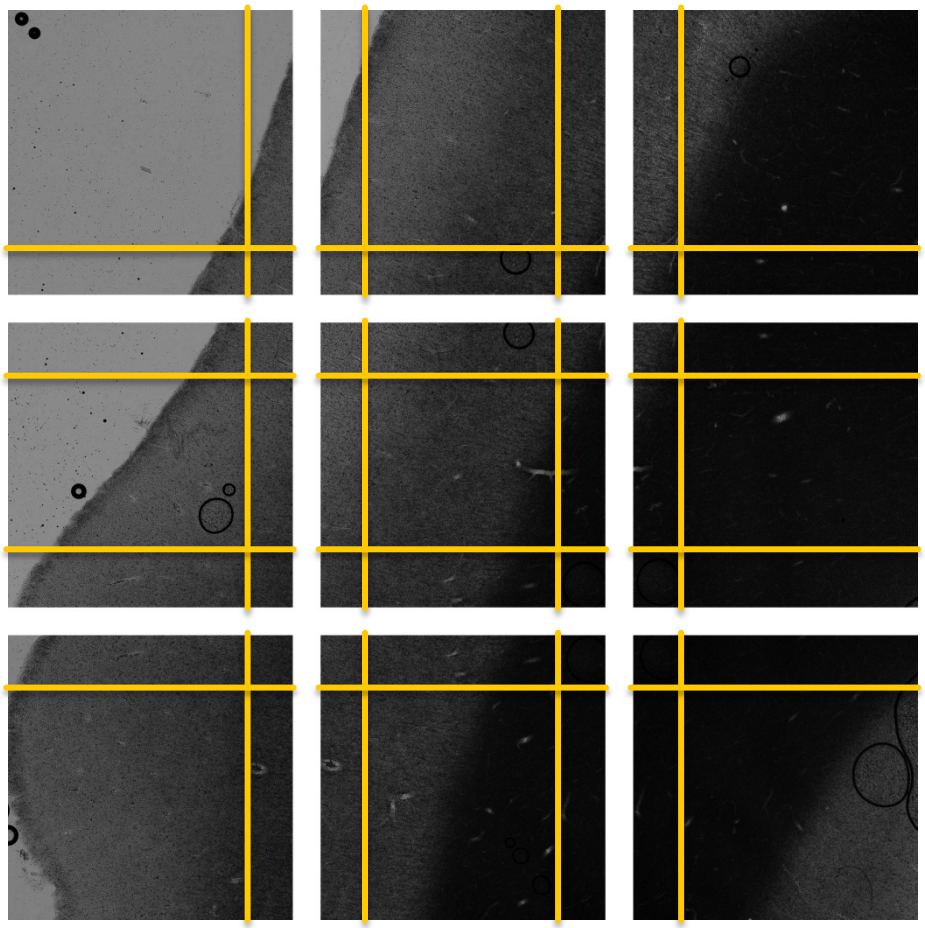


# Hybrid parallelization

- Exploit the architecture of JUDGE
- 2 levels of parallelism

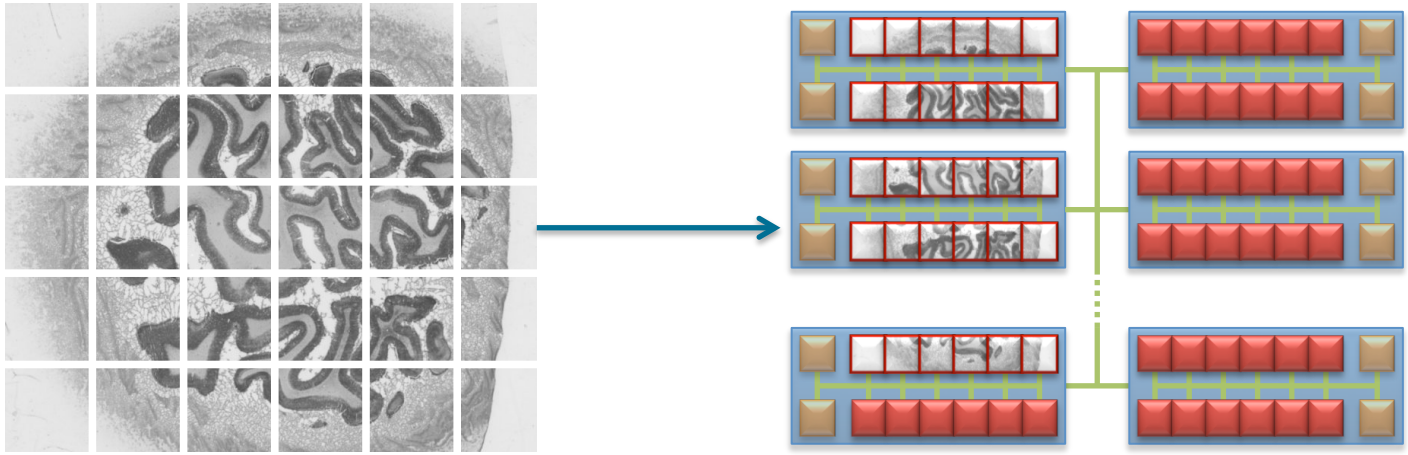


# Multi-core approach

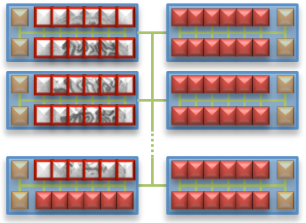


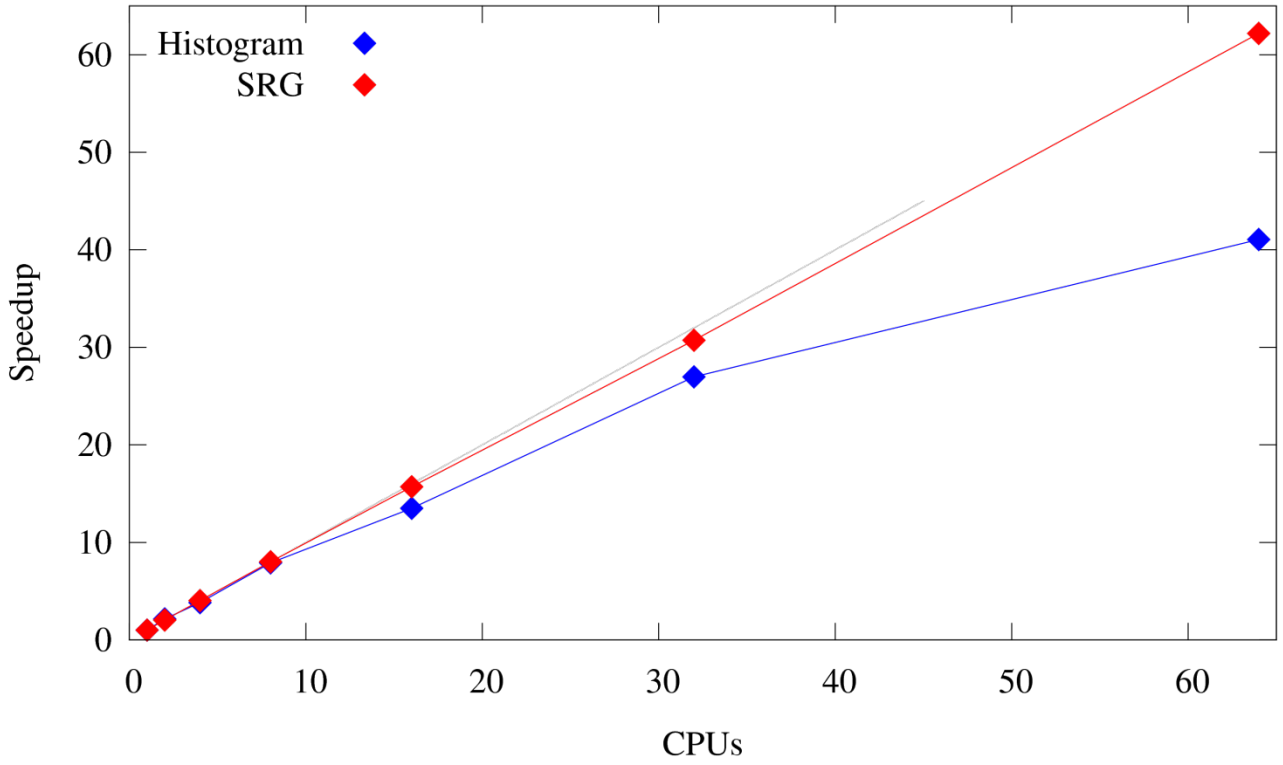
# Multi-core approach

- Overlapping of the tiles → independently processible
- Joint histogram: Collecting of distributed histograms with `MPI_Reduce`
- Seeded region growing: no communication

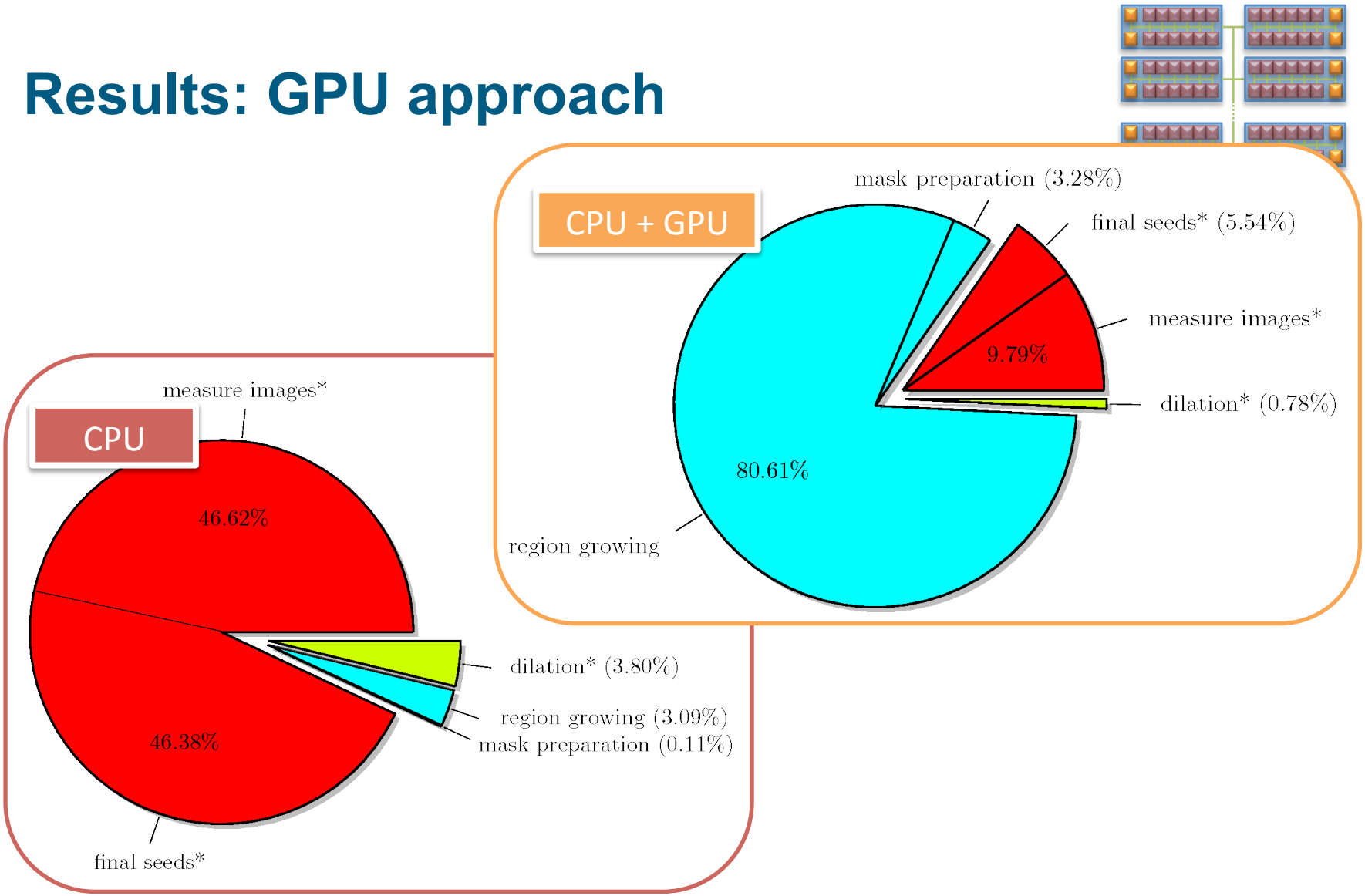


# Results: multi-core approach



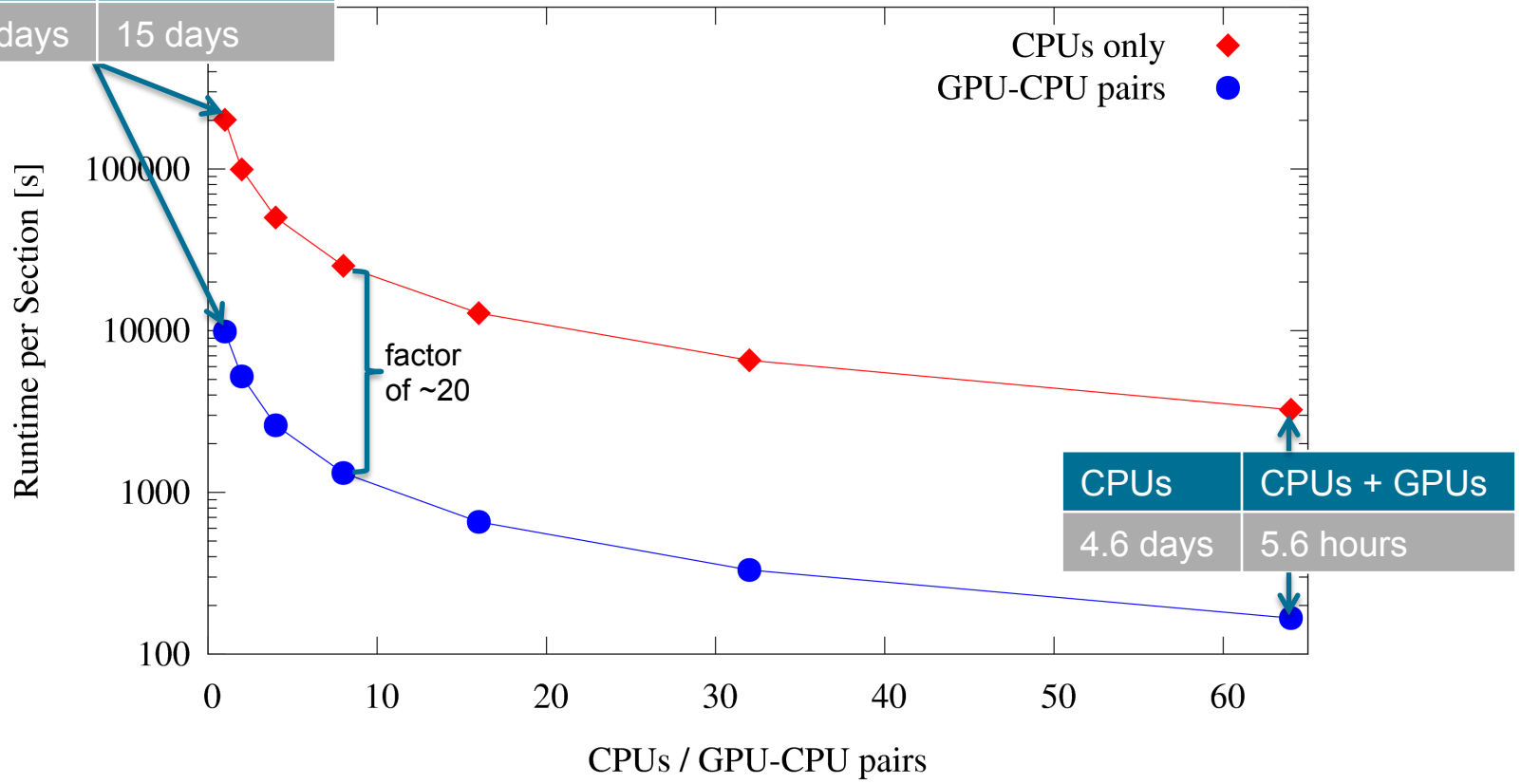


# Results: GPU approach



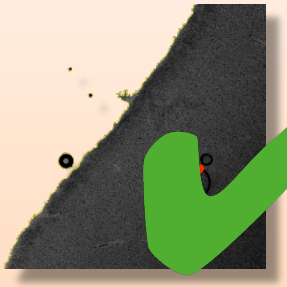
# Results: Hybrid approach

| CPU | CPU + GPU |
|---|---|
| 295 days | 15 days |



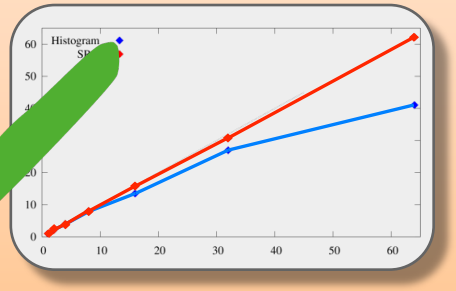

| CPUs | CPUs + GPUs |
|---|---|
| 4.6 days | 5.6 hours |

## Segmentation



How to automate the segmentation of thousands of tiles ?

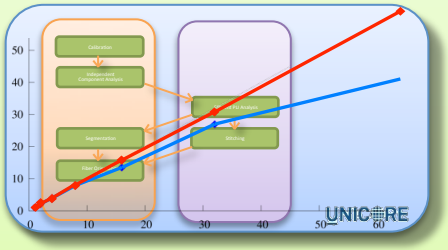
Are we able to speed up the segmentation by parallelization ?



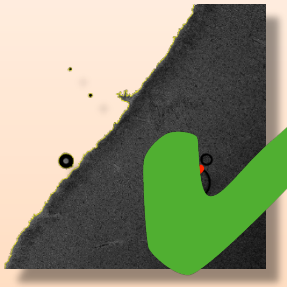

## Workflow


How to automate the workflow tools, which build on one another?

Are we able to speed up the workflow by parallelization?



Segmentation



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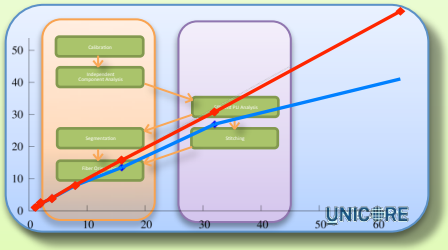
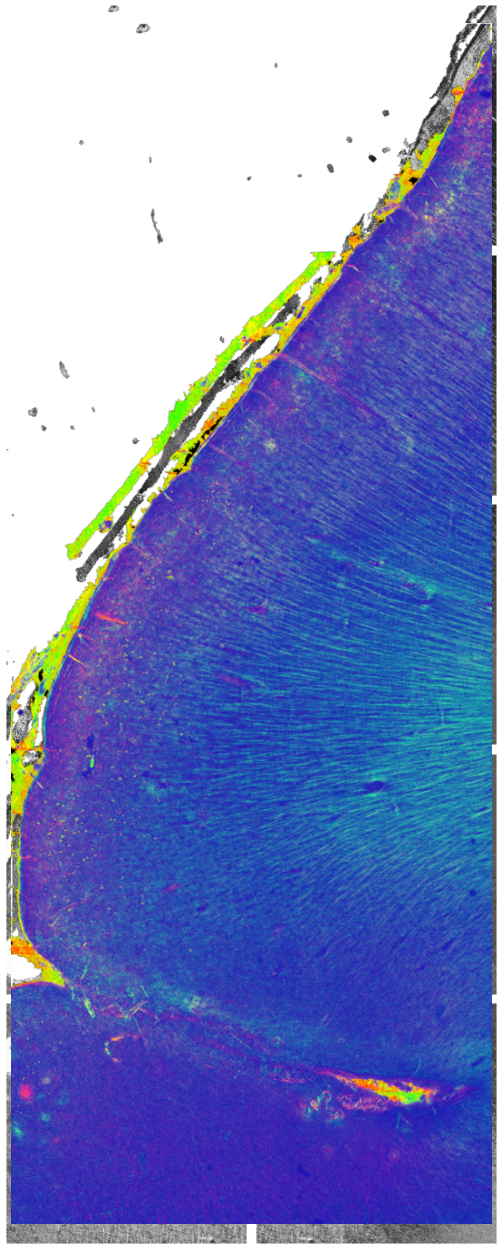
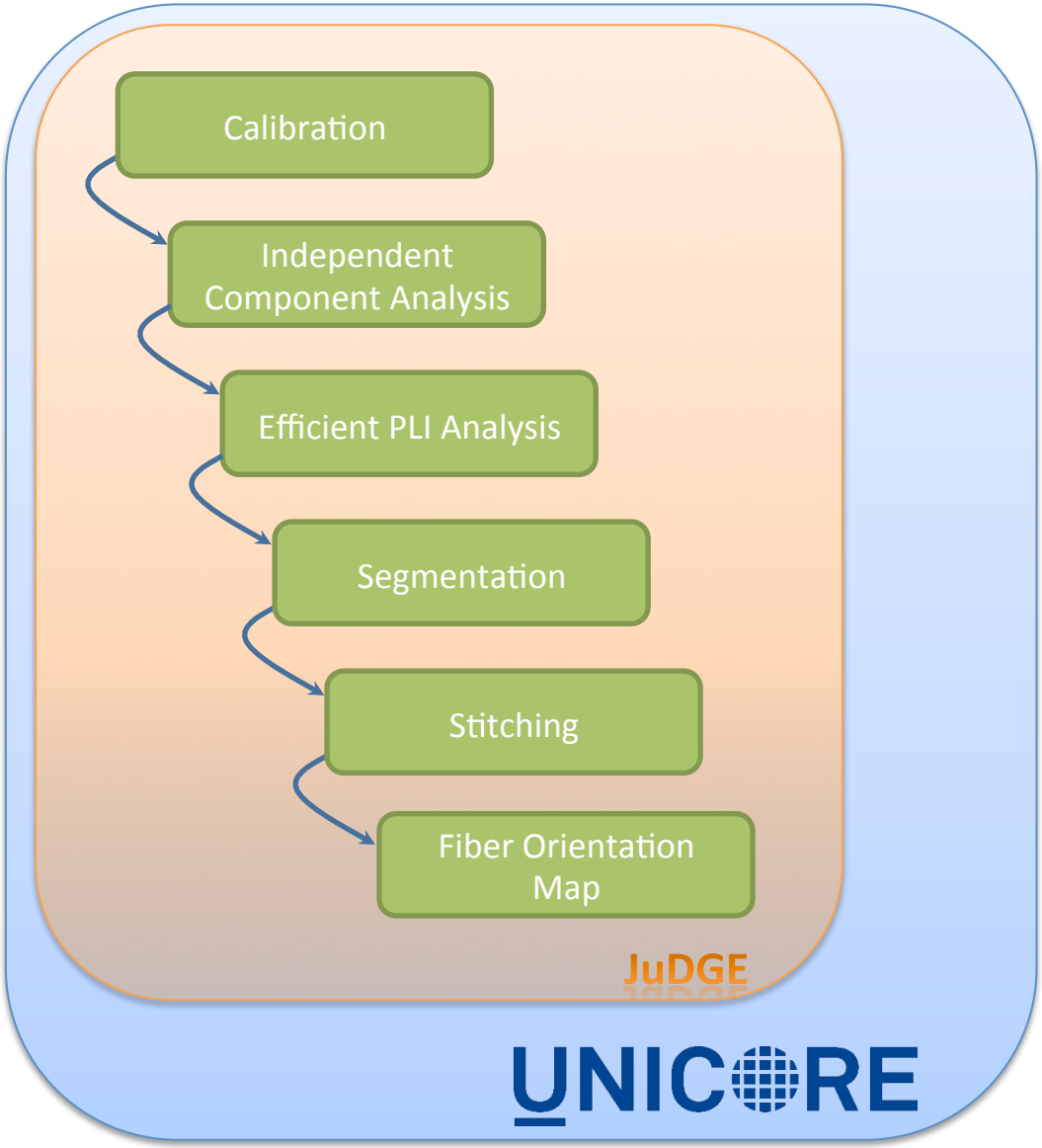
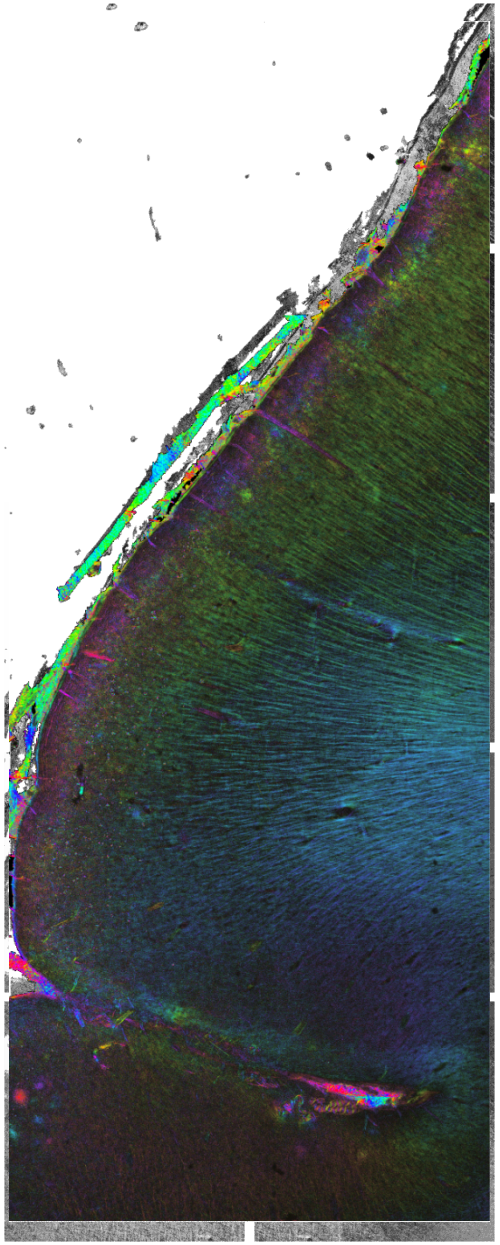


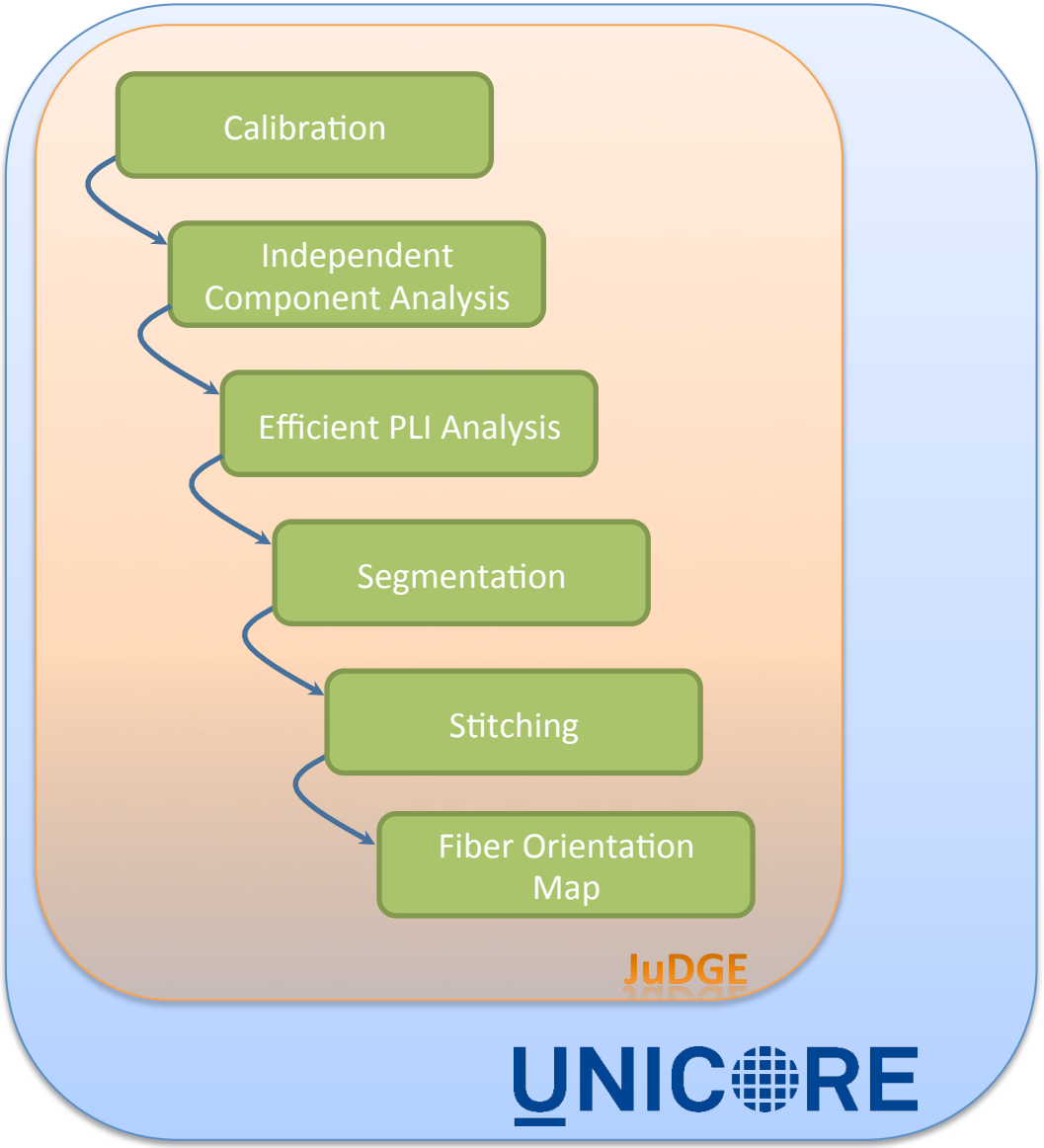


# PLI - Workflow





# PLI - Workflow



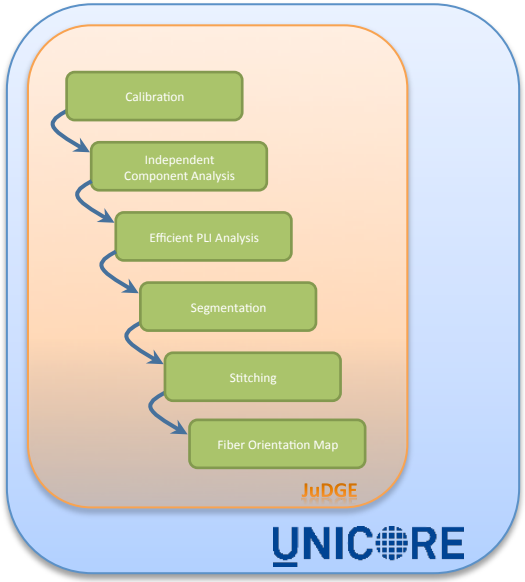
# Automation of workflow

1) Minimizing source of errors caused by no manually interaction between single tools

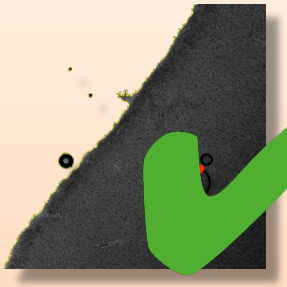
2) Speedup the overall execution

3) Parameter studies are easy to implement

4) Users can initiate a workflow calculation without knowing all tools in the entire process



Segmentation



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Are we able to speed up the segmentation by parallelization?


Workflow

How to automate the workflow tools, which build on one another?

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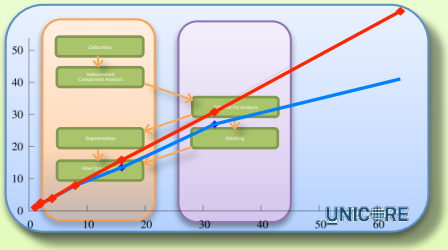
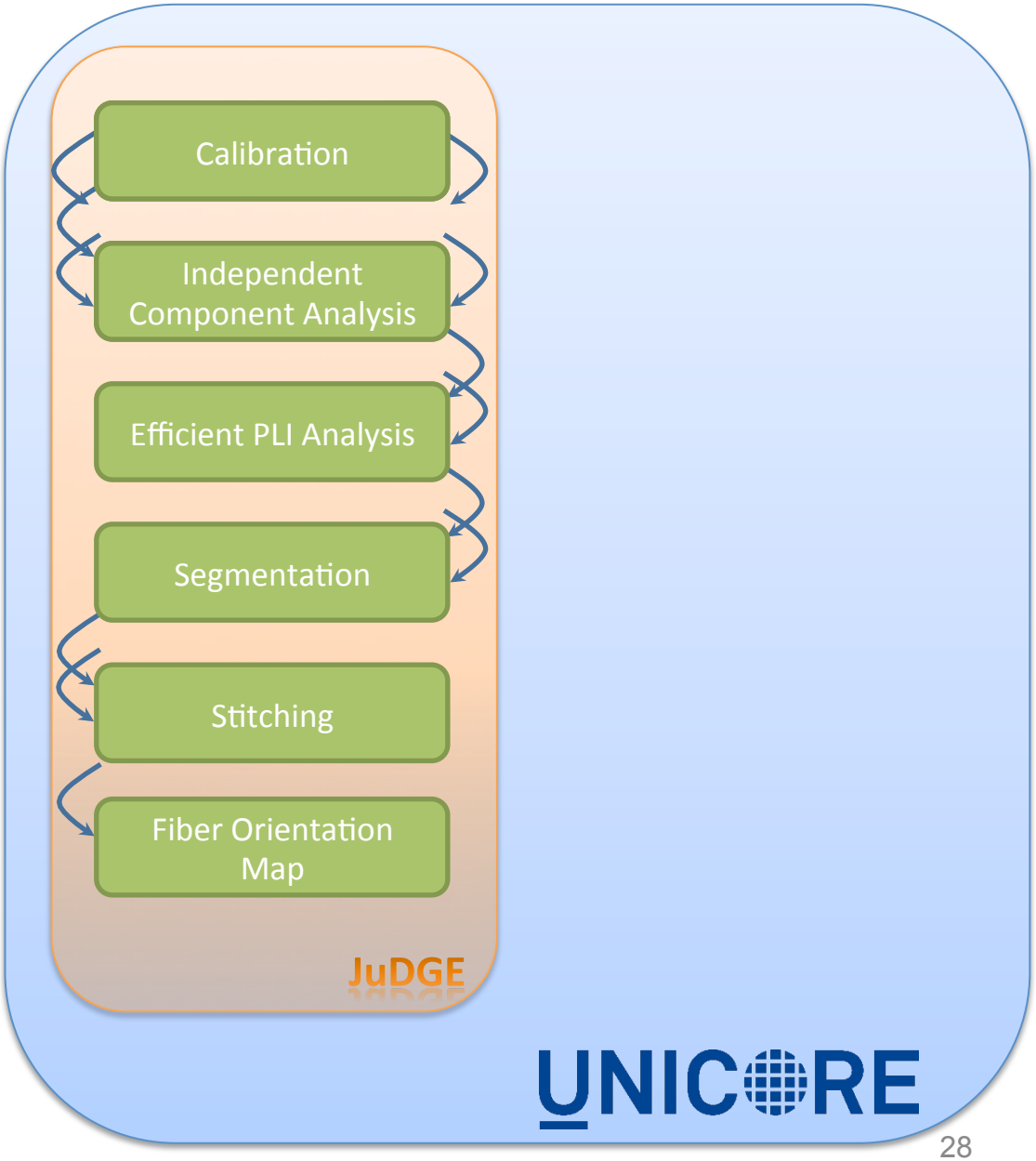


# Parallel execution of PLI - tools

1) Farming sequential executions on several cores

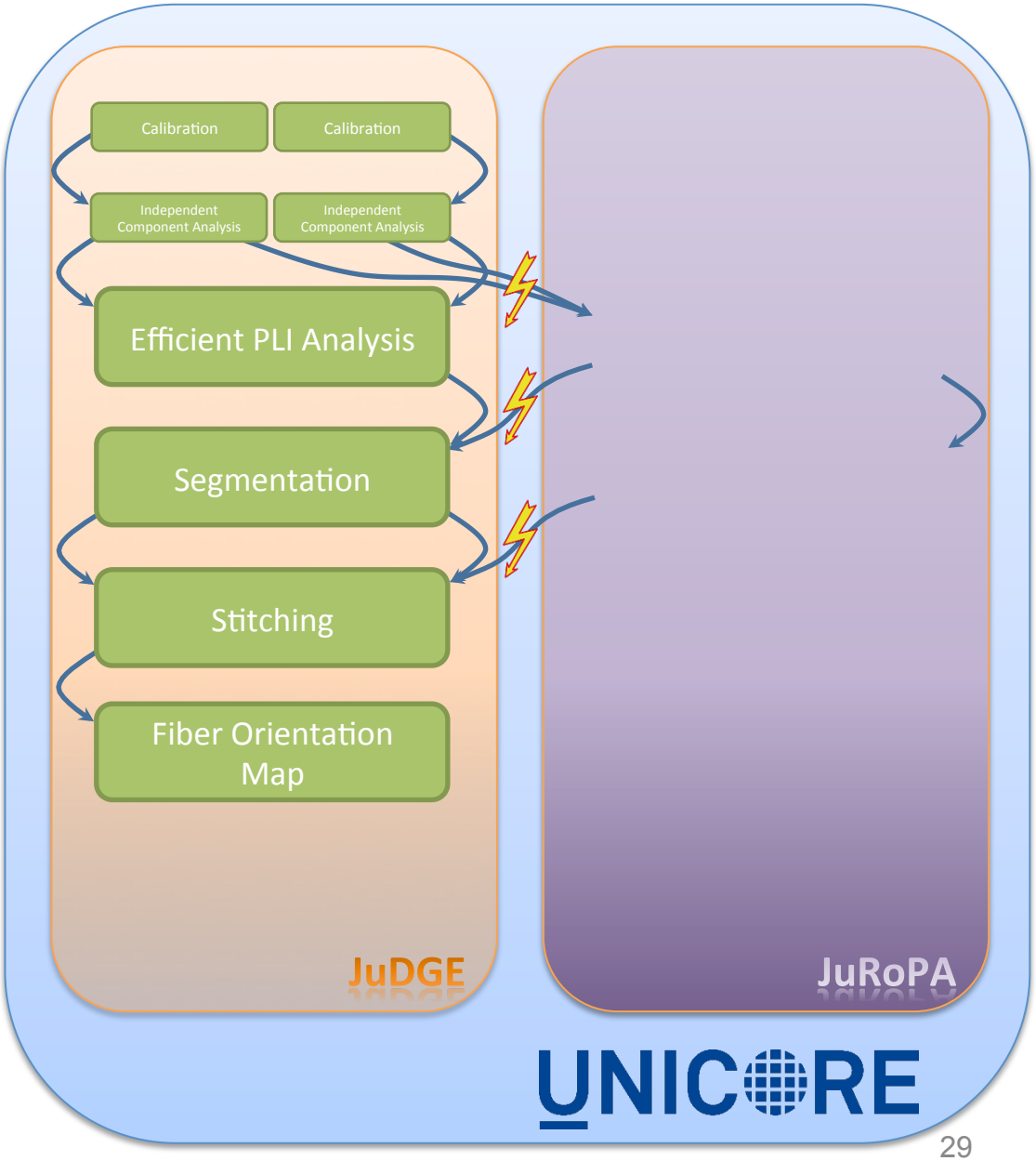


# Parallel execution of PLI - tools

1) Farming sequential executions on several cores

2) Enabling an automated data flow between different supercomputers

**Attention:** Data transfer can nullify the speed up

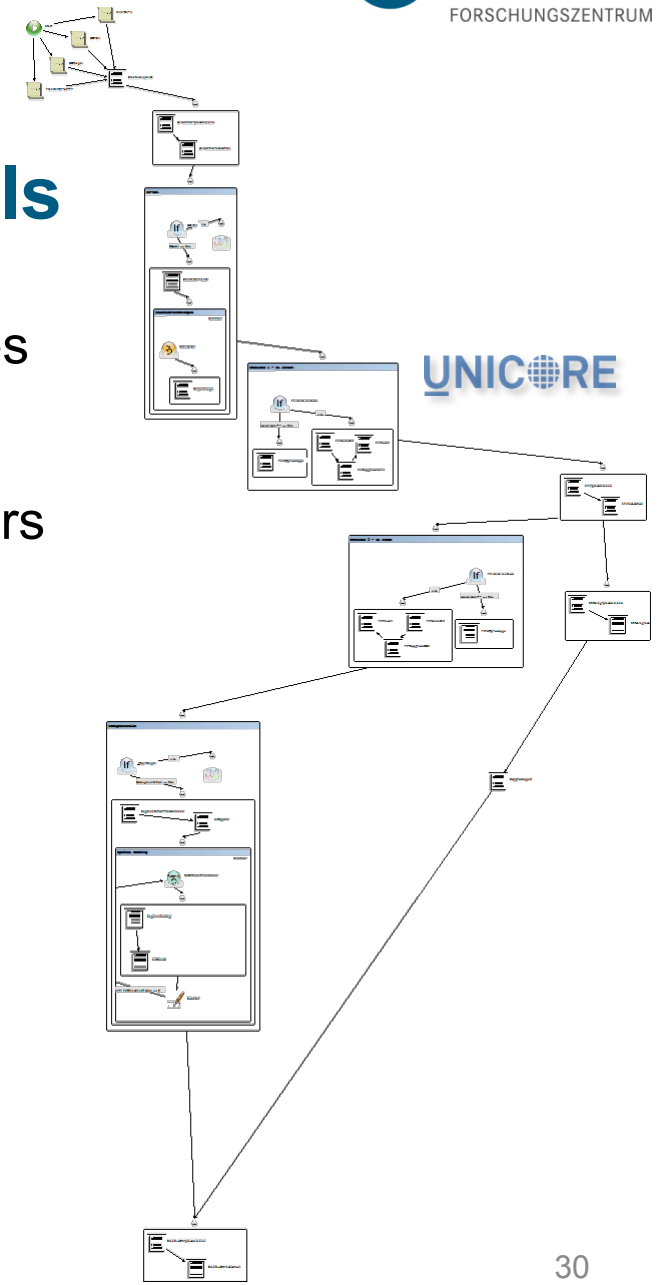


# Parallel execution of PLI - tools

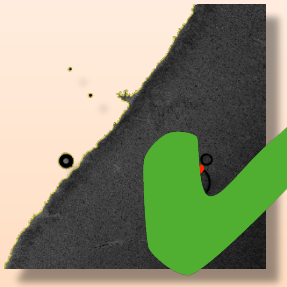
1) The different features of UNICORE makes distributed computing available

2) No knowledge of the used supercomputers (here Judge and JuRoPA) is needed

3) Speedup of the entire process

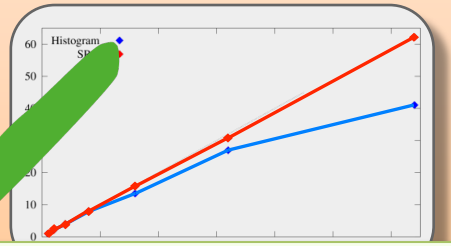


Segmentation



How to automate the segmentation of thousands of tiles ?

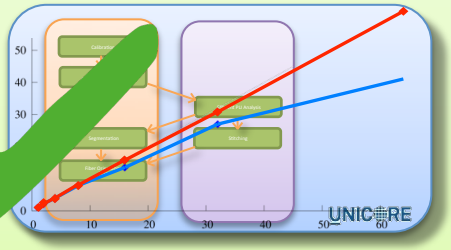
Are we able to speed up the segmentation by parallelization



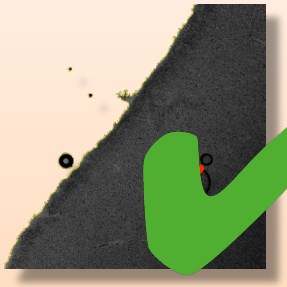

Workflow

How to automate the workflow tools, which build on one another?

Are we able to speed up the workflow by parallelization



Segmentation



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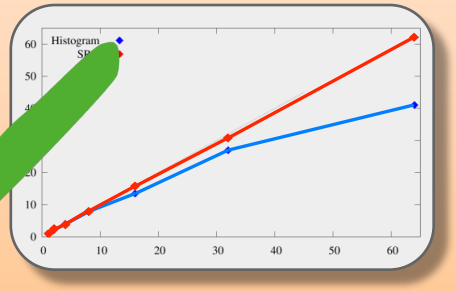


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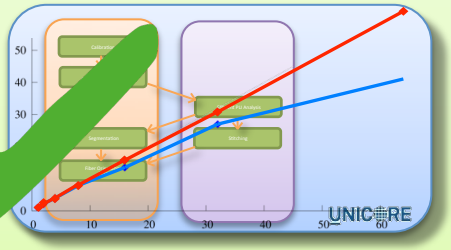
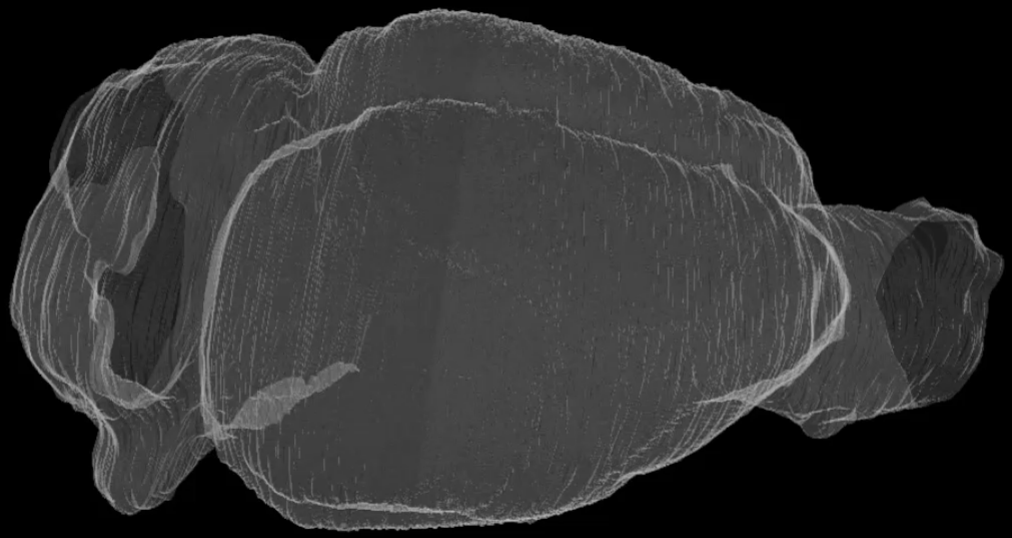


# *3D fiber architecture of the rat brain*

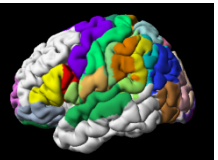


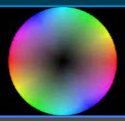
# *3D fiber architecture of the human brain*

***Talk: Markus Axer, Tuesday, 10.30***

*Hippocampal mapping: Zeineh al., Poster 3914 (Wed), OHBM 2014*

# *Thanks to …*





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