# Connecting Arterial Blood Flow to Tissue Perfusion for In Silico Trials of Acute Ischaemic Stroke

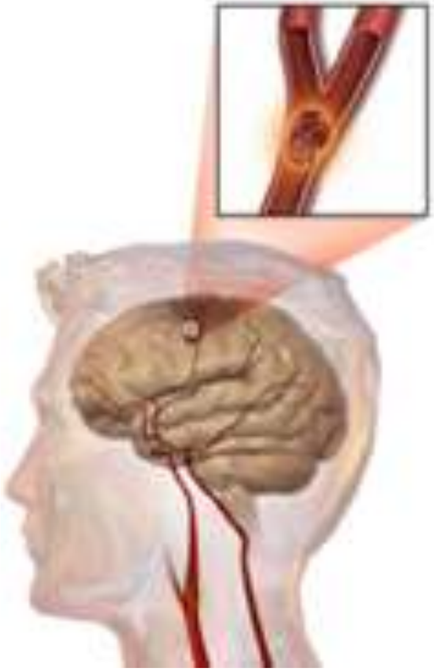
September 27th, 2019

Raymond Padmos

This project (INSIST; www.insist-h2020.eu) has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 777072.

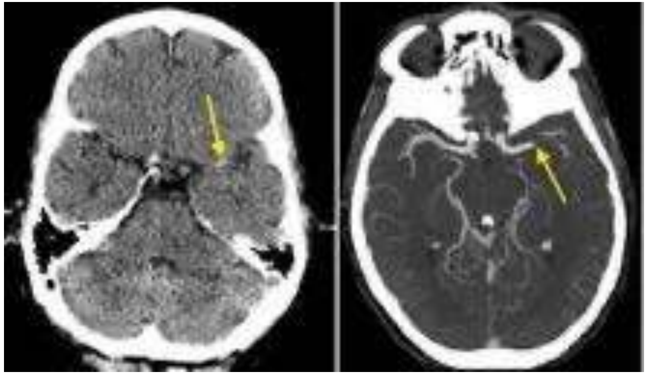
# Acute Ischaemic stroke

- Most common type of stroke: $\simeq$87%
- 3 million deaths per year
- “Time is brain”



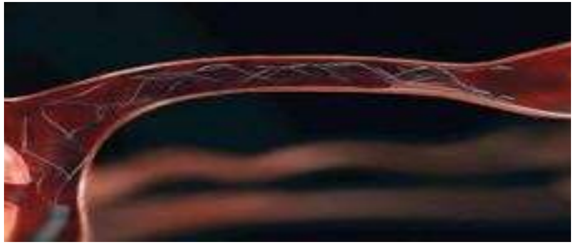

See https://en.wikipedia.org/wiki/Stroke

# Acute Ischaemic stroke


Patient enters the hospital

Treatment is given

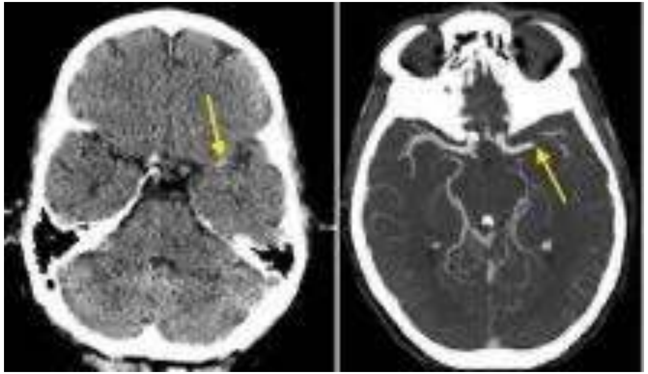

Thrombolysis


Thrombectomy

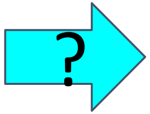

Follow-up
6 months later

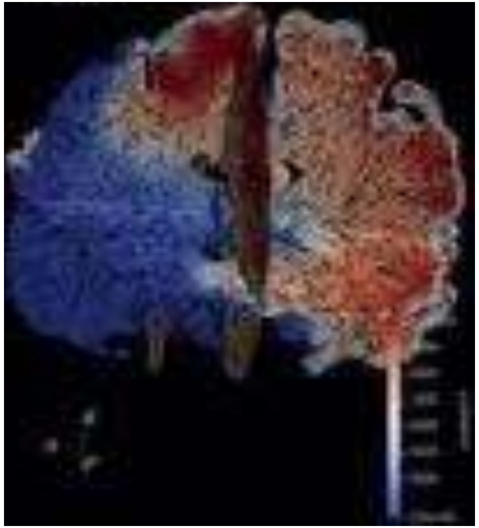
See http://www.svuhradiology.ie/case-study/occluded-middle-cerebral-artery-ct-angiography/
https://en.wikipedia.org/wiki/Stroke

# Predicting Infarct volume



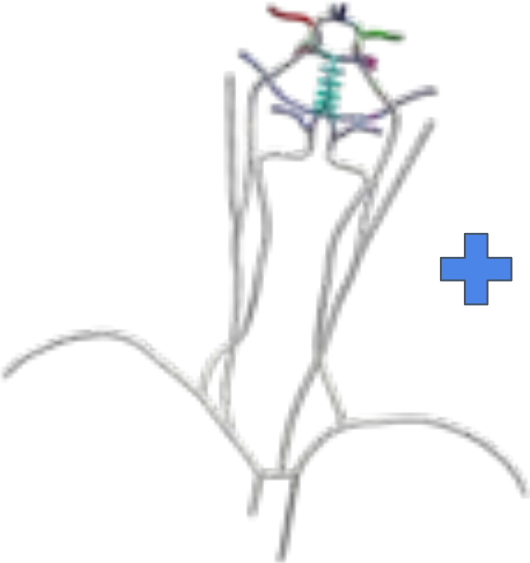
Patient enters the hospital



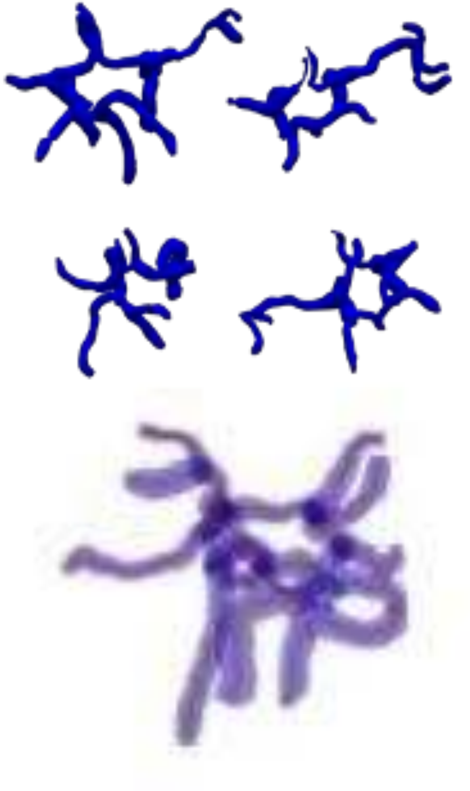



See http://www.svuhradiology.ie/case-study/occluded-middle-cerebral-artery-ct-angiography/

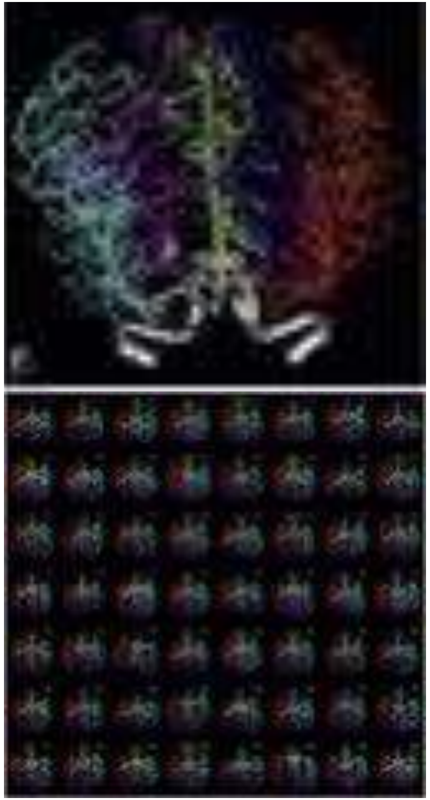
# Extending the Vasculature



Large Arteries



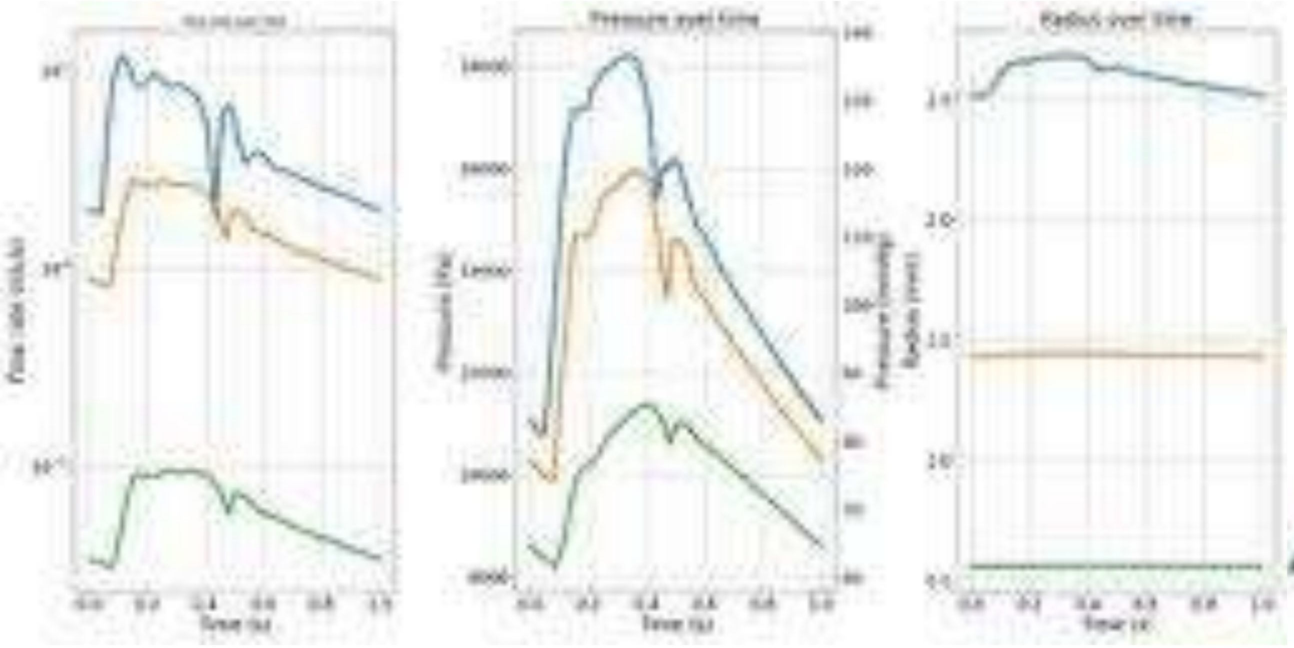
Major Cerebral Arteries

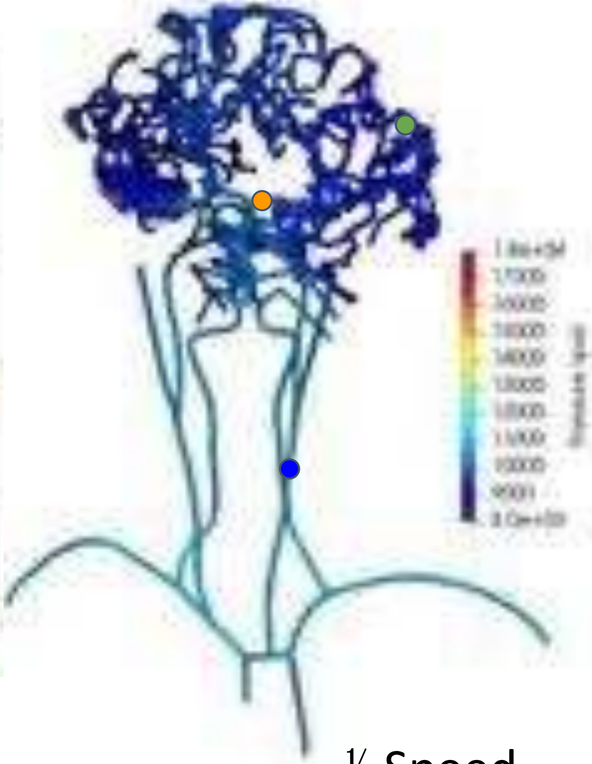


Small Arteries
See Wright2013

# Blood Flow Simulations

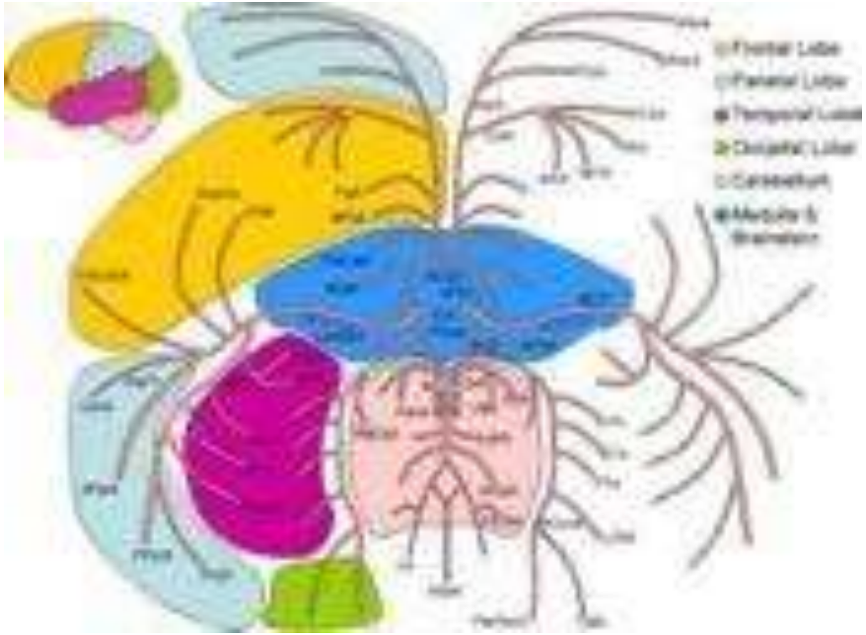
## 1-D Blood flow simulation





⅕ Speed

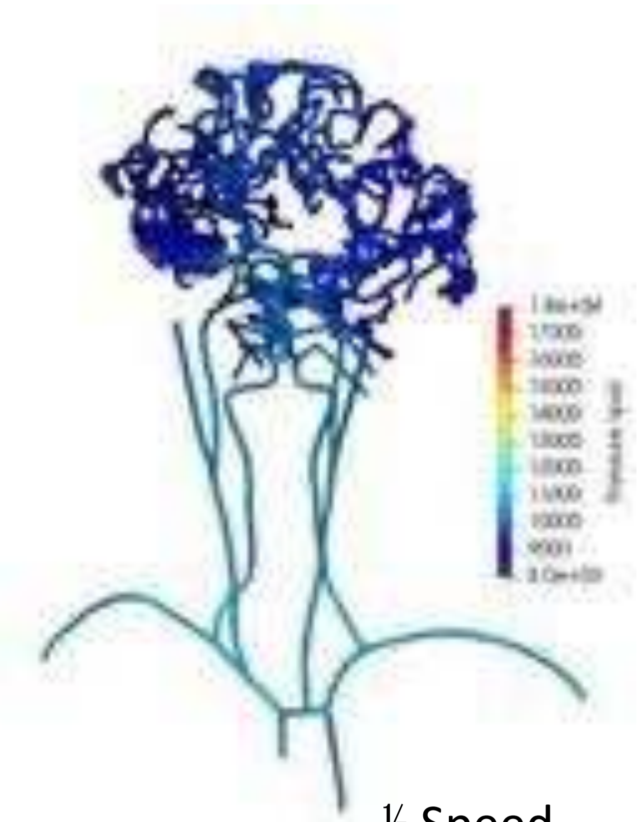
# Perfusion territories



?

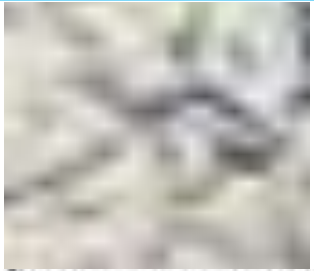
See David2008

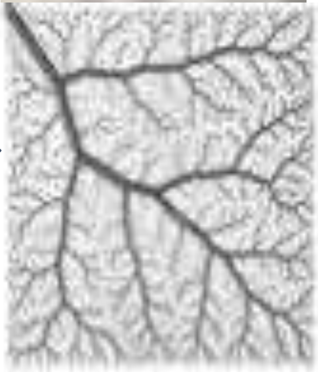
# Estimating Perfusion Territories

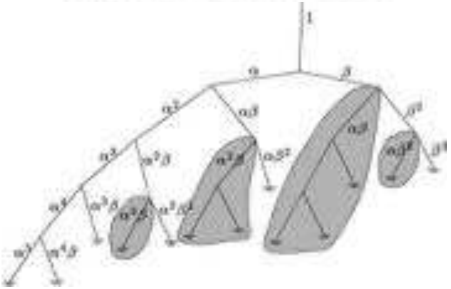


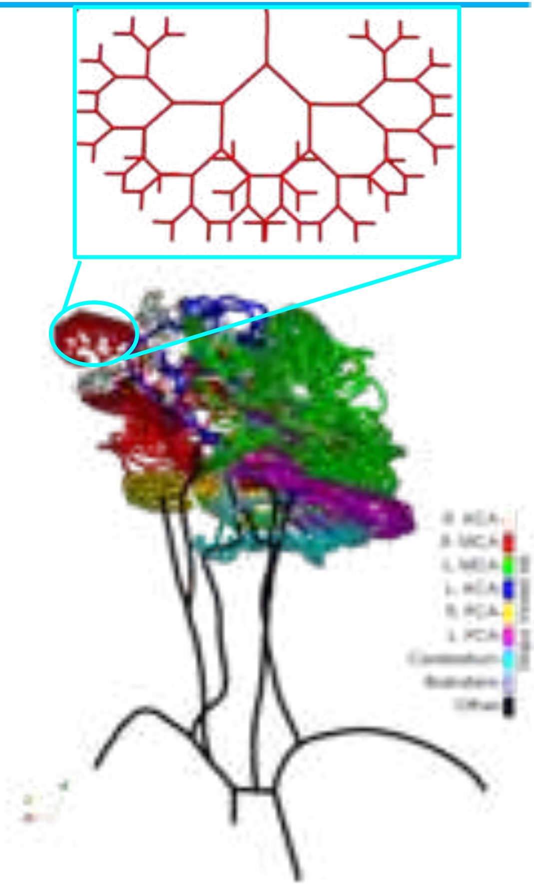
⅕ Speed

See Karch2000, Olufsen1999







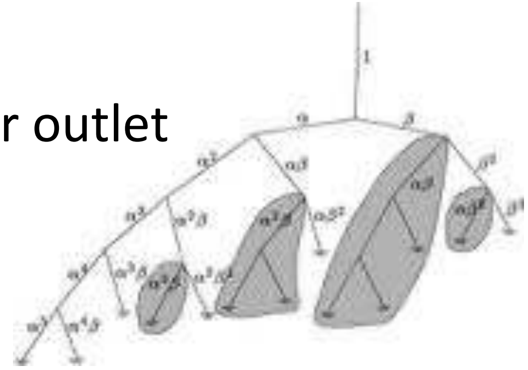


Bifurcating trees

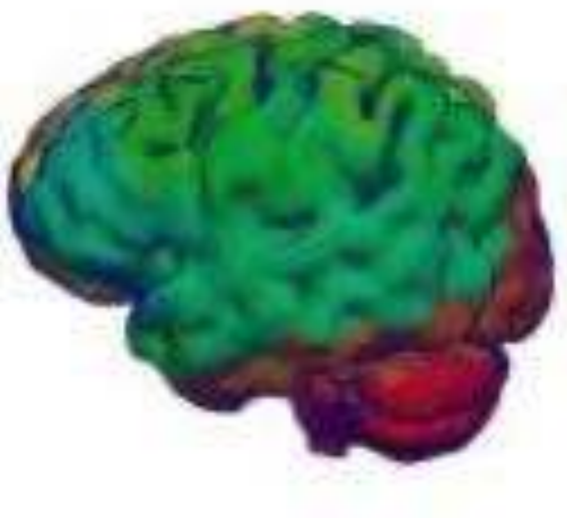
# Estimating Perfusion Territories

Based on the k-means clustering algorithm

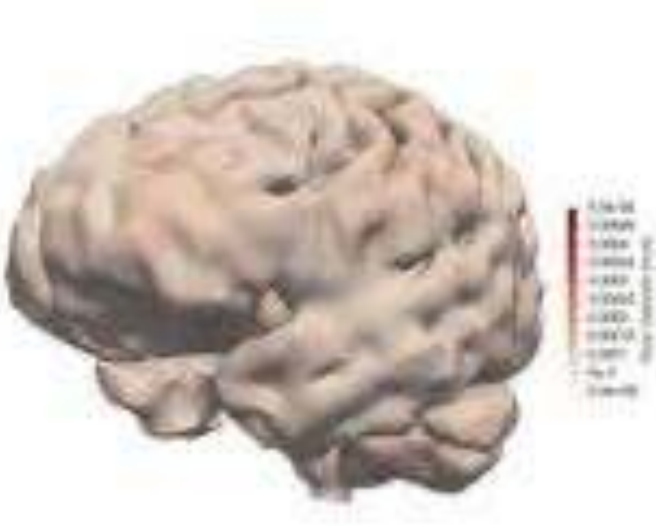
1. Generate a bifurcating tree at each outlet.
2. Cut-off radius sets the number of coupling points per outlet
3. Project outlet to the pial surface -> root
4. Find the closest set of points to the root -> cluster
5. Minimize the root-point distance within the clusters
6. Update the root
7. Convergence or max iteration reached?
   a. Yes -> done
   b. No -> go to step 4
8. Repeat for each major region.



# Input to the perfusion model



Estimated Perfusion territories



1-D blood flow simulation

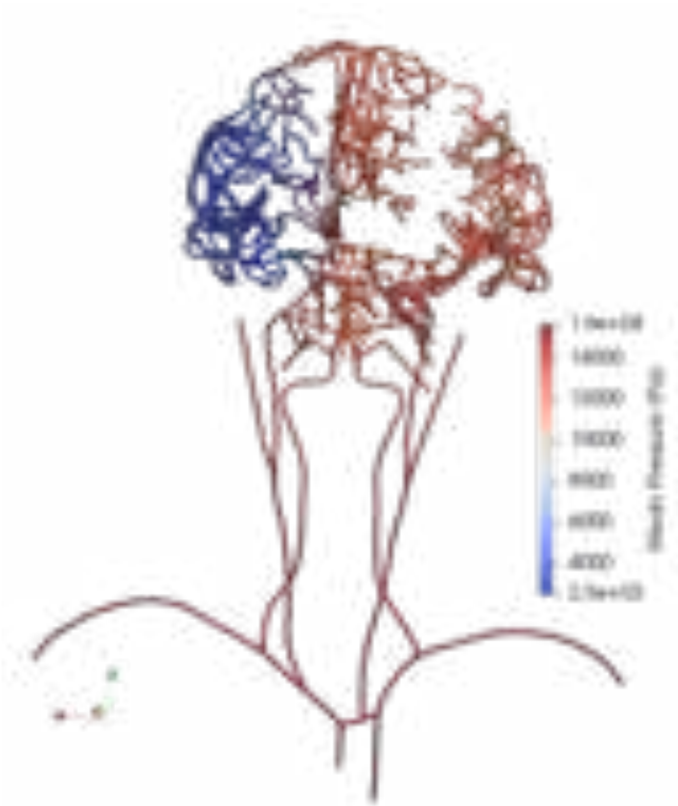
Perfusion model

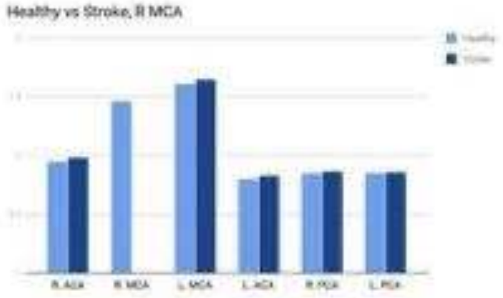
Work By Tamás Jozsa et al.

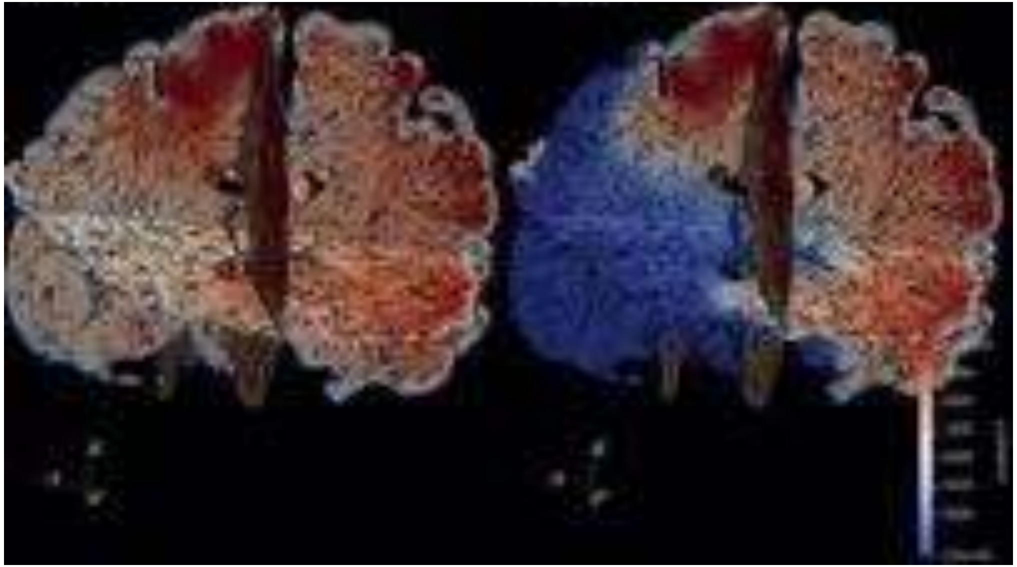
A cerebral circulation model for in silico clinical trials of ischaemic stroke

Presented 25th September at 11:35.

# Stroke modelling

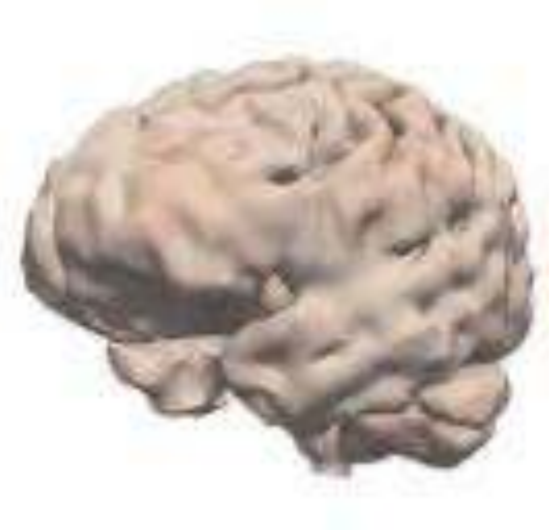


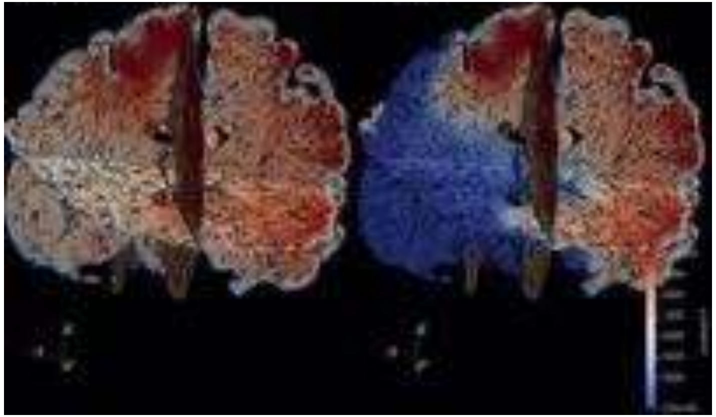


# Summary

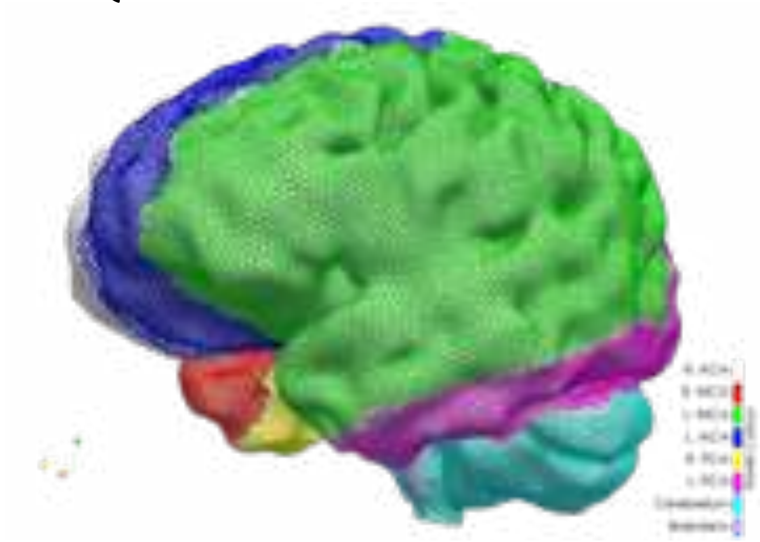
- Multiscale patient-specific model
- Estimating perfusion territories
- Stroke and infarct volume modelling

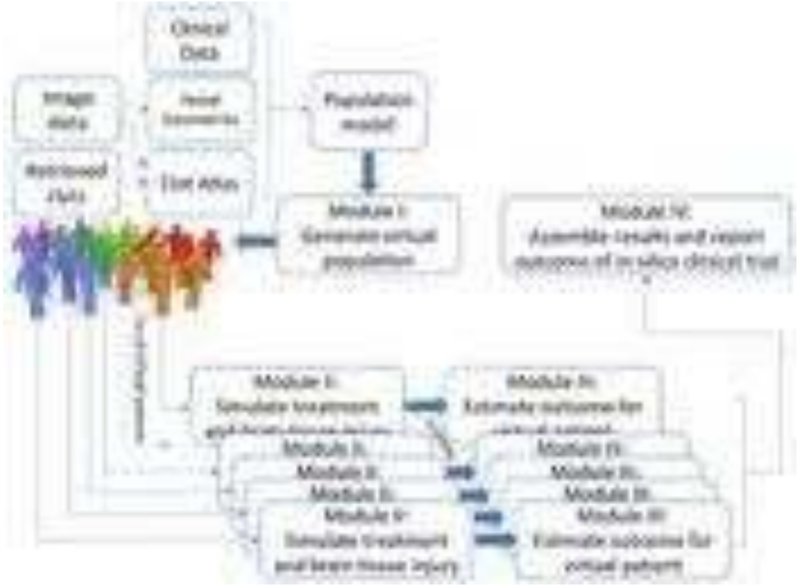




# Future plans

- Two-way coupling
- *In Silico* trial integration
- Pial surface network
- VVUQ





Thanks for listening!

Questions?

# Computational Science Lab

INSIST

UNIVERSITY OF AMSTERDAM

Computational Science Lab

# In Silico Clinical Trials for Treatment of Acute Ischemic Stroke (INSIST)

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# References

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**Sobotta**, J., Atlas and Text-book of Human Anatomy Volume III Vascular System, Lymphatic system, Nervous system and Sense Organs

**David**, T., & Moore, S. (2008). Modeling perfusion in the cerebral vasculature. Medical Engineering and Physics, 30(10), 1227–1245. https://doi.org/10.1016/j.medengphy.2008.09.008

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**Hirsch**, S., Reichold, J., Schneider, M., Székely, G., & Weber, B. (2012). Topology and Hemodynamics of the Cortical Cerebrovascular System. Journal of Cerebral Blood Flow & Metabolism, 32(6), 952–967. https://doi.org/10.1038/jcbfm.2012.39

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**Olufsen**, M. S. (1999). Structured tree outflow condition for blood flow in larger systemic arteries. American Journal of Physiology-Heart and Circulatory Physiology, 276(1), H257–H268. https://doi.org/10.1152/ajpheart.1999.276.1.H257

http://www.svuhradiology.ie/case-study/occluded-middle-cerebral-artery-ct-angiography/

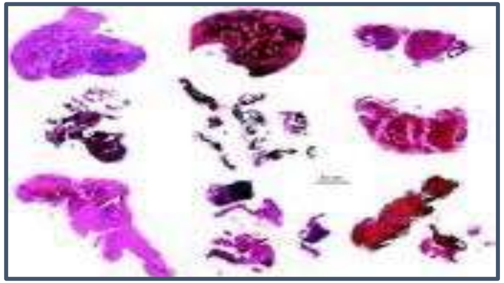
https://en.wikipedia.org/wiki/Stroke

https://radiopaedia.org/

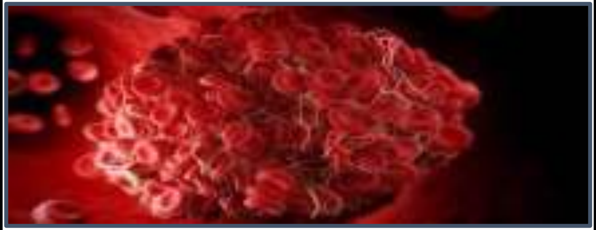
# INSIST Research Projects

## Population Model

## Clot properties



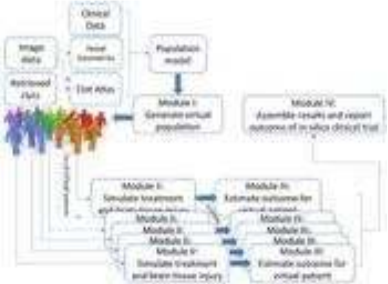
## Thrombosis and thrombolysis



## Thrombectomy

## Blood flow and perfusion

## Integration



# Blood Flow Simulations

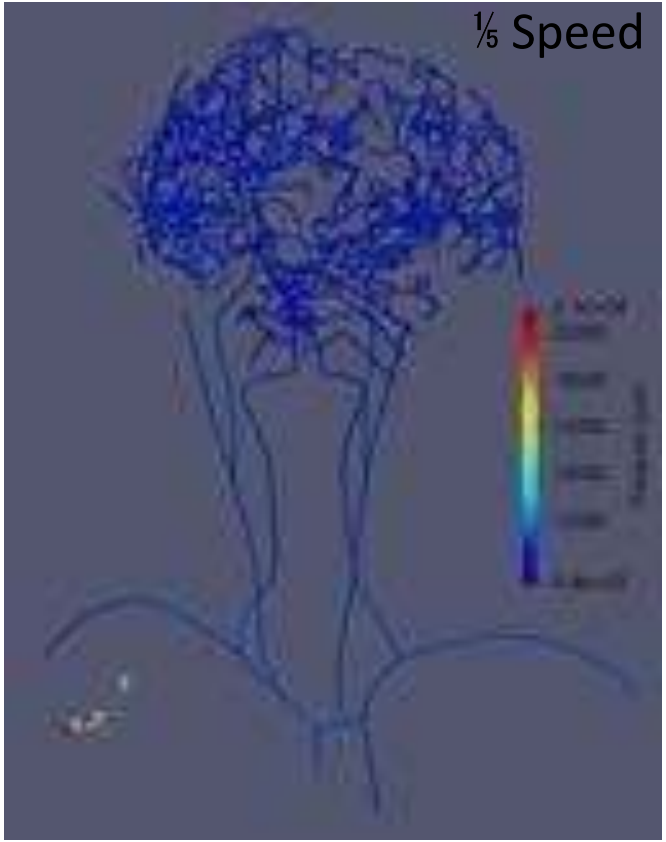
1-D Blood flow simulation

- Elastic tubes
- Incompressible fluid
- Detailed flow profiles
- Computational inexpensive

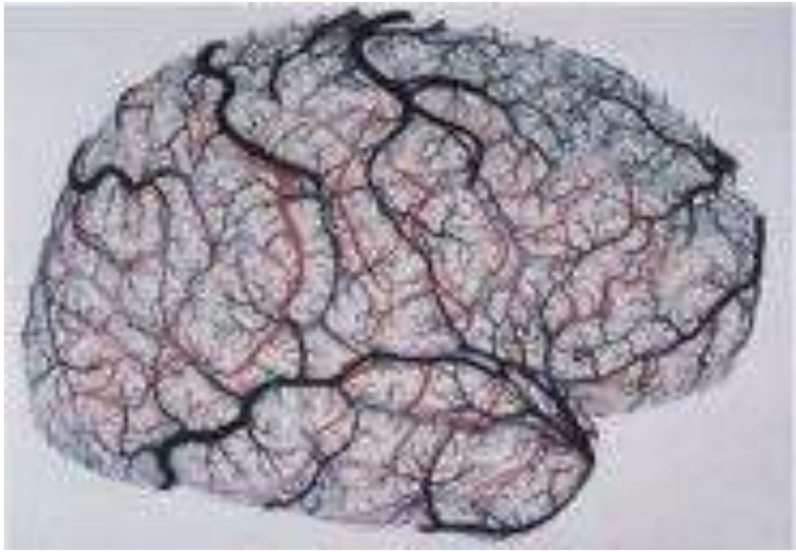
$$\frac{\partial \bar{v}_x}{\partial t} + (2\alpha - 1)\bar{v}_x \frac{\partial \bar{v}_x}{\partial x} + (\alpha - 1)\frac{\bar{v}_x^2}{A}\frac{\partial A}{\partial x} + \frac{1}{\rho}\frac{\partial p}{\partial x} = -2\frac{\alpha}{\alpha - 1}\nu\pi\frac{\bar{v}_x}{A}$$

$$\frac{\partial A}{\partial t} + \frac{\partial(\bar{v}_x A)}{\partial x} = 0$$

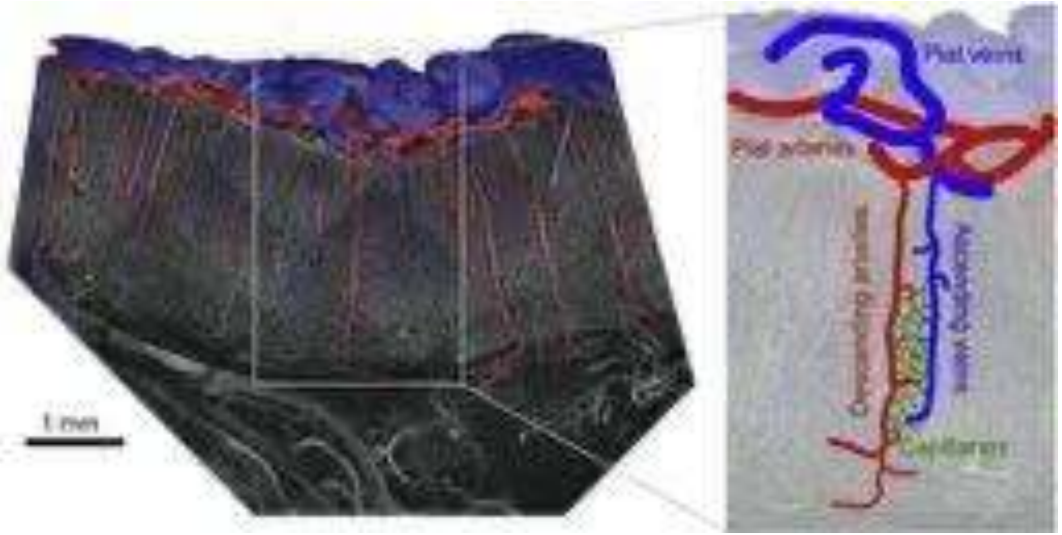
$$p = p_{ext} + \frac{\beta}{A_0}(\sqrt{A} - \sqrt{A_0})$$



# Pial Surface



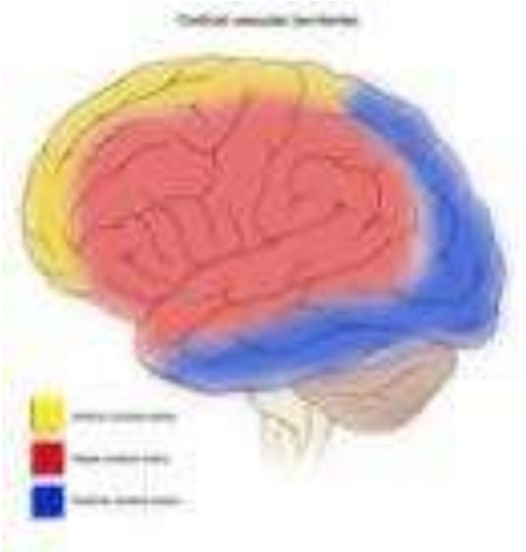
Pial surface vessels

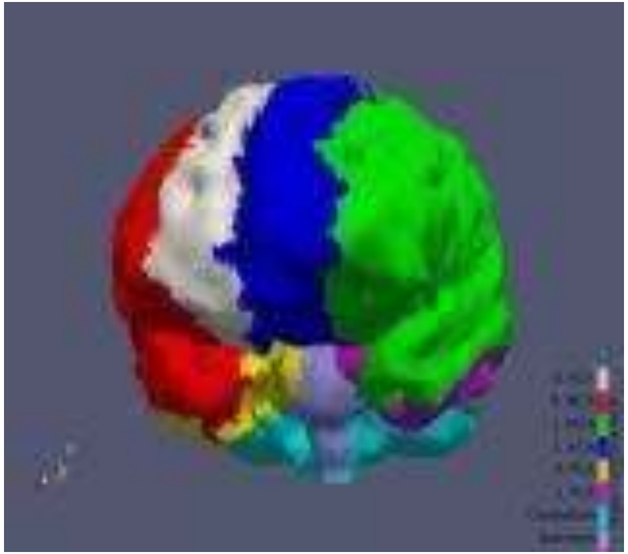


Penetrating vessels

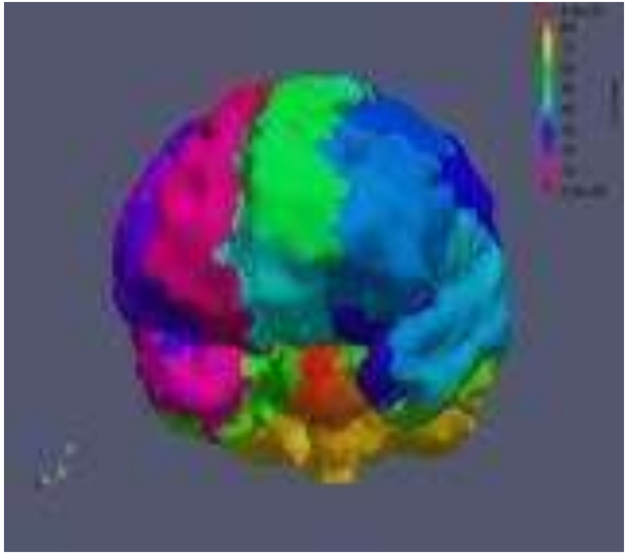
See Duvernoy1981, Hirsch2012, Schmid2019

# Estimating Perfusion Territories





Major Regions



Detailed Regions

Frank Gaillard, see radiopaedia.org

# Estimating Perfusion Territories

Based on the k-means clustering algorithm

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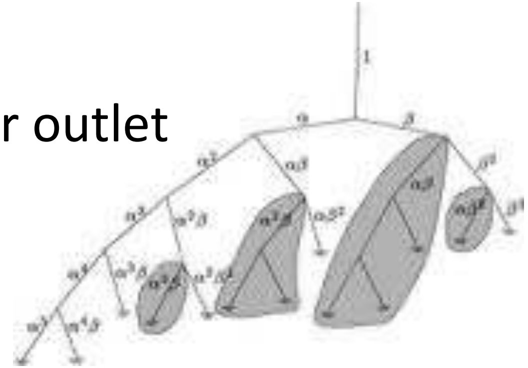
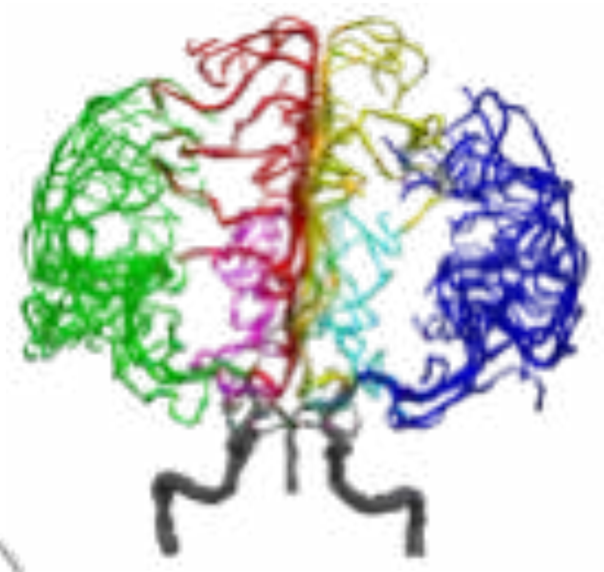
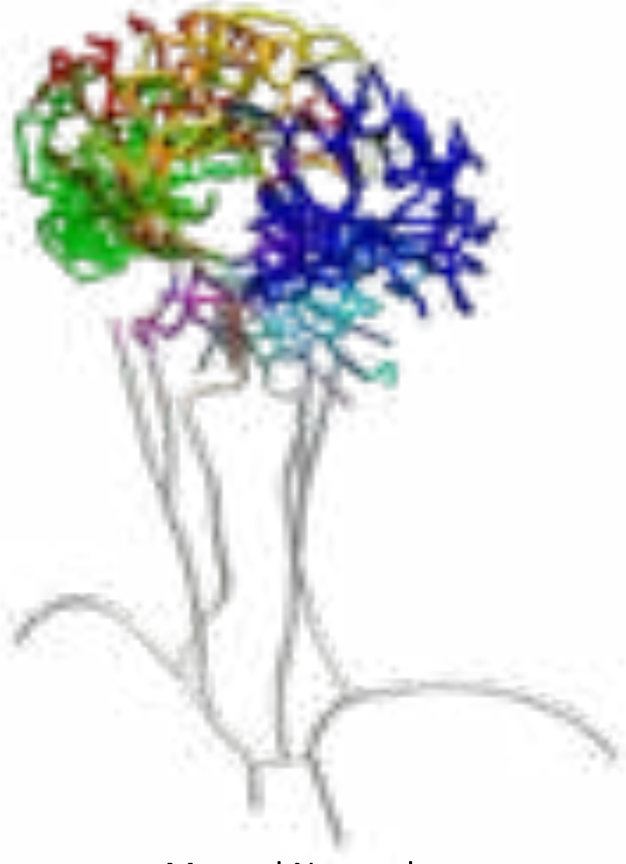


# Patient Vasculature

Large Arteries



Cerebral Arteries

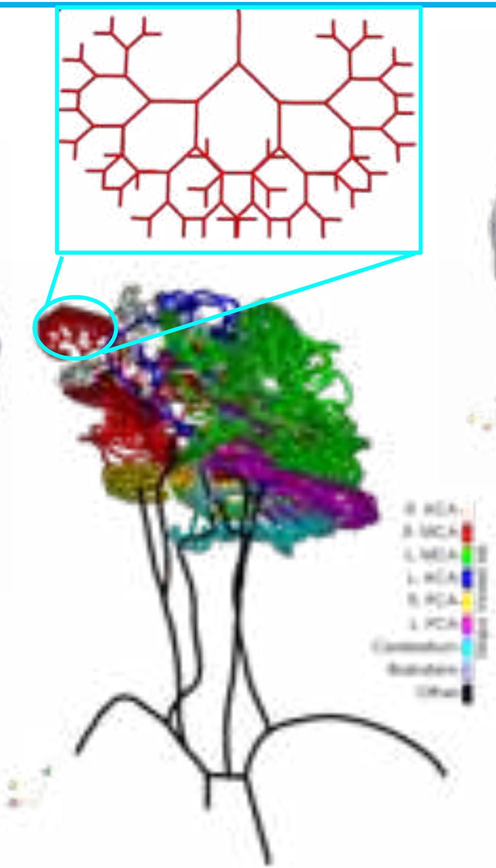


Merged Network

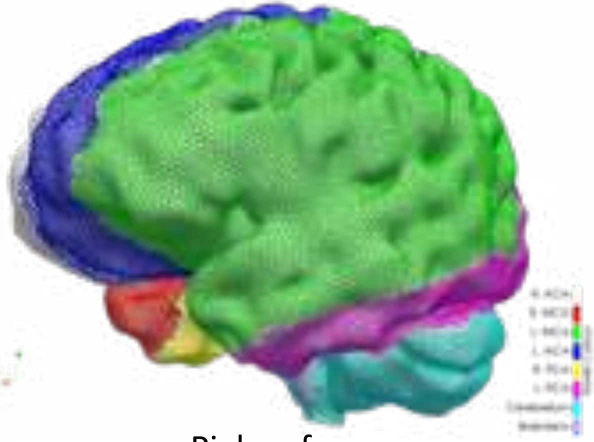
# Model Scales

Large Arteries

Cerebral Arteries



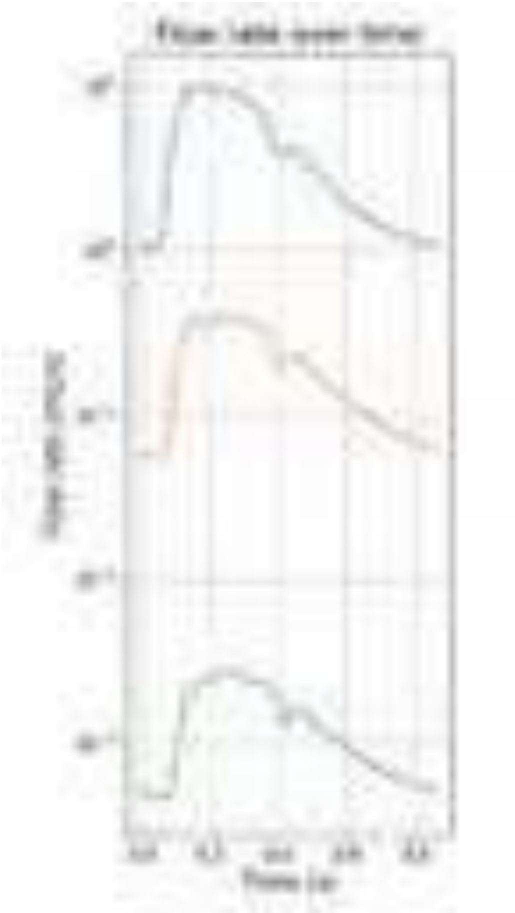
Bifurcating trees

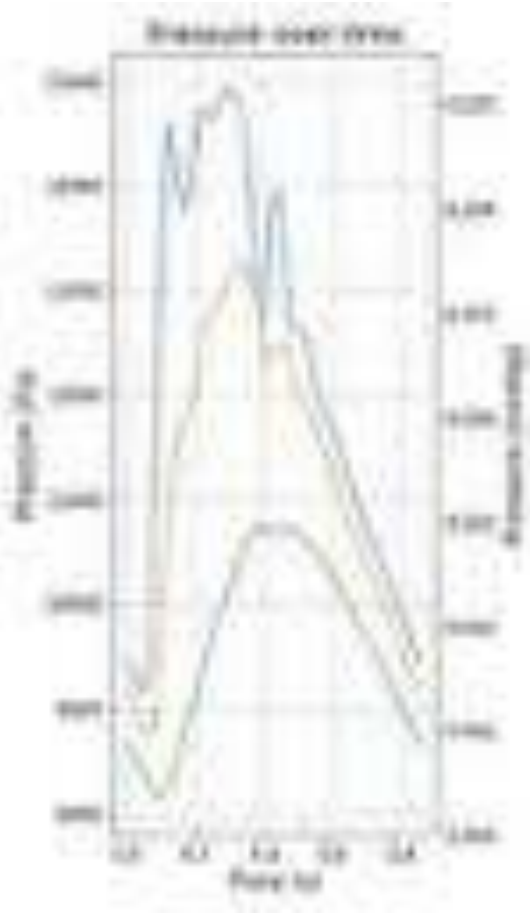


Pial surface

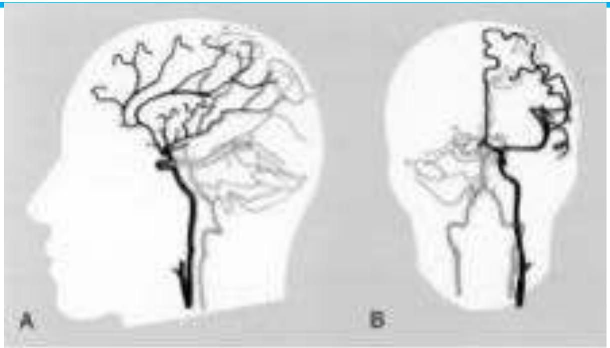
Penetrating arteries

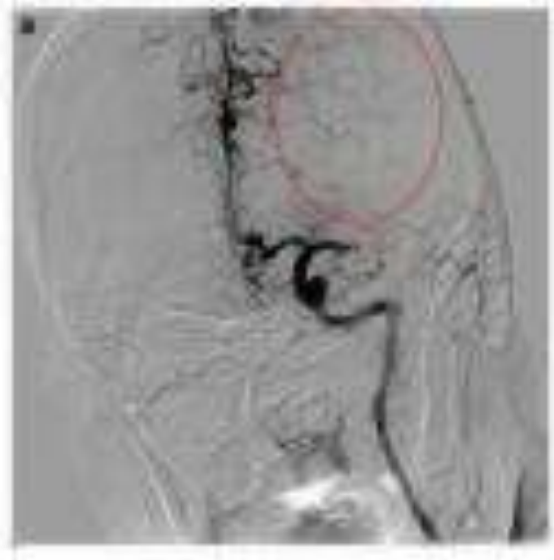
# 1-D blood flow results

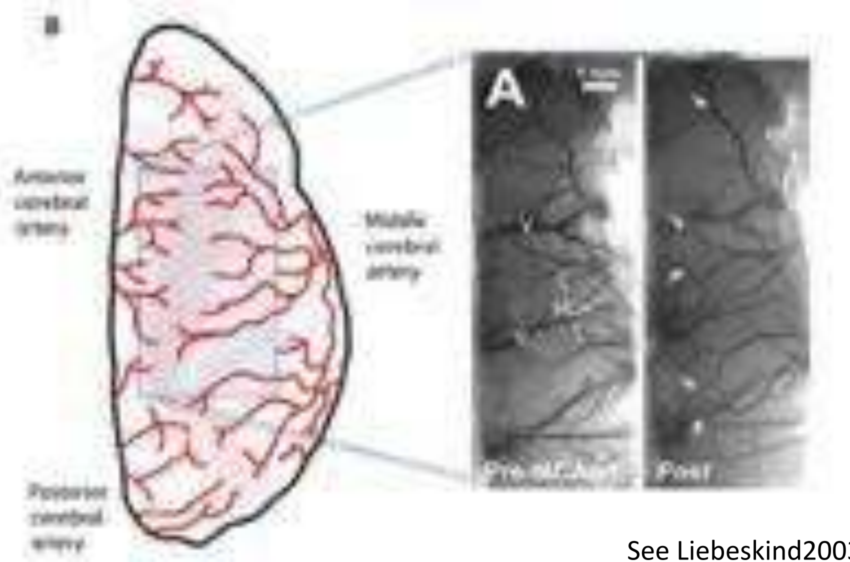




# Collaterals

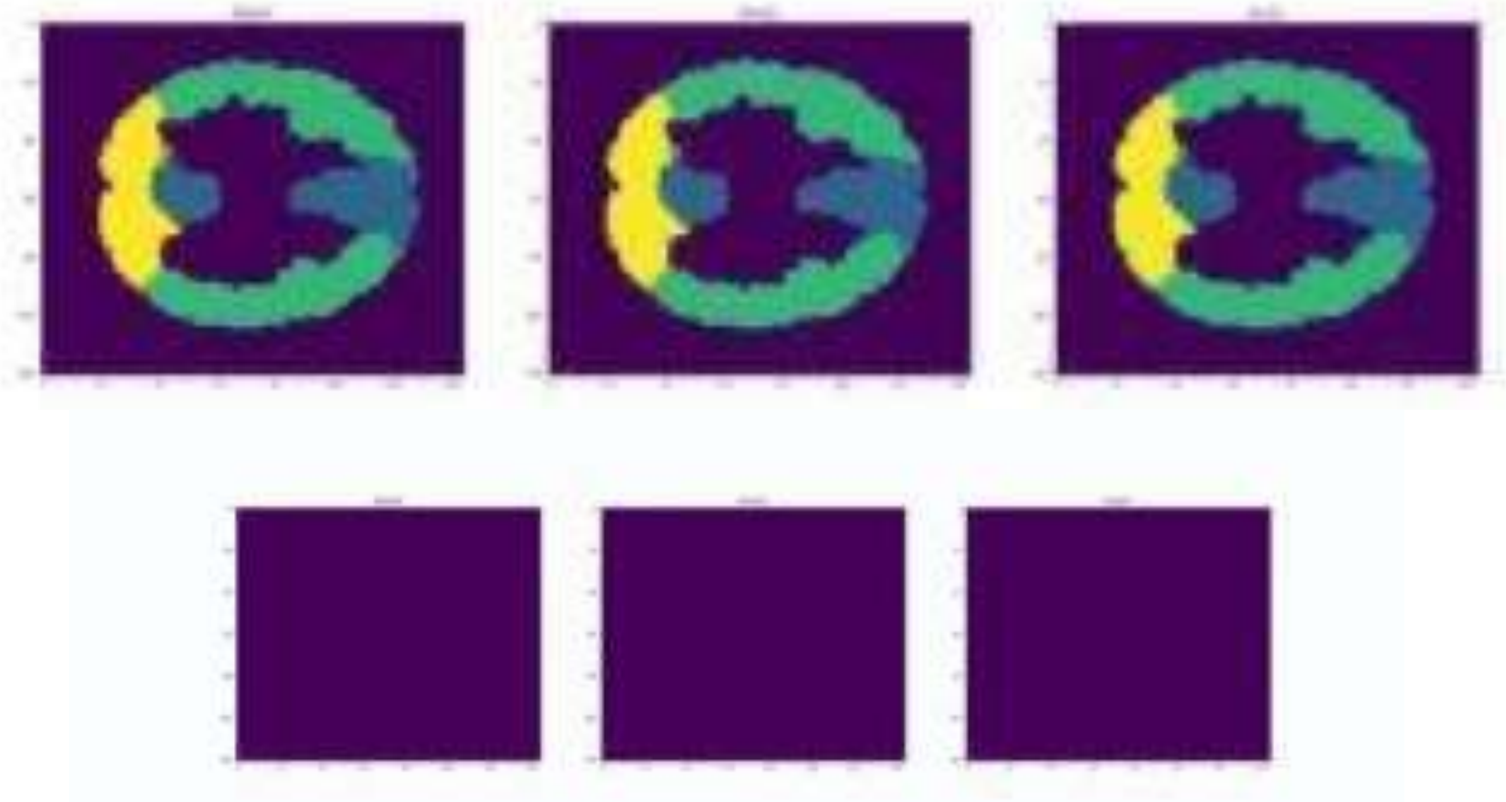


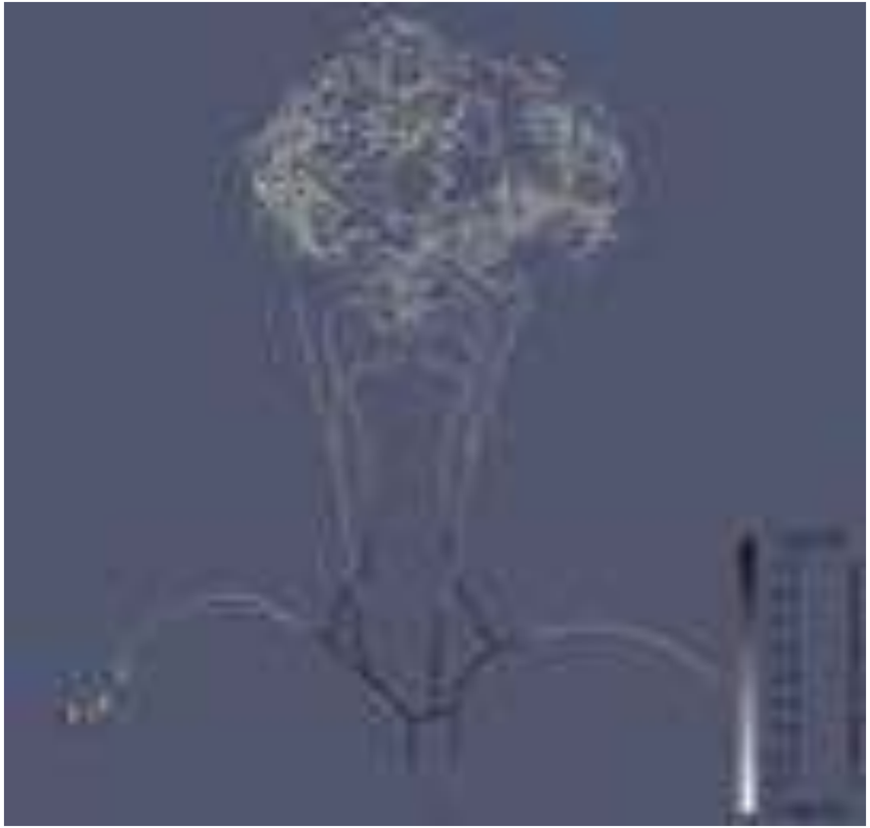


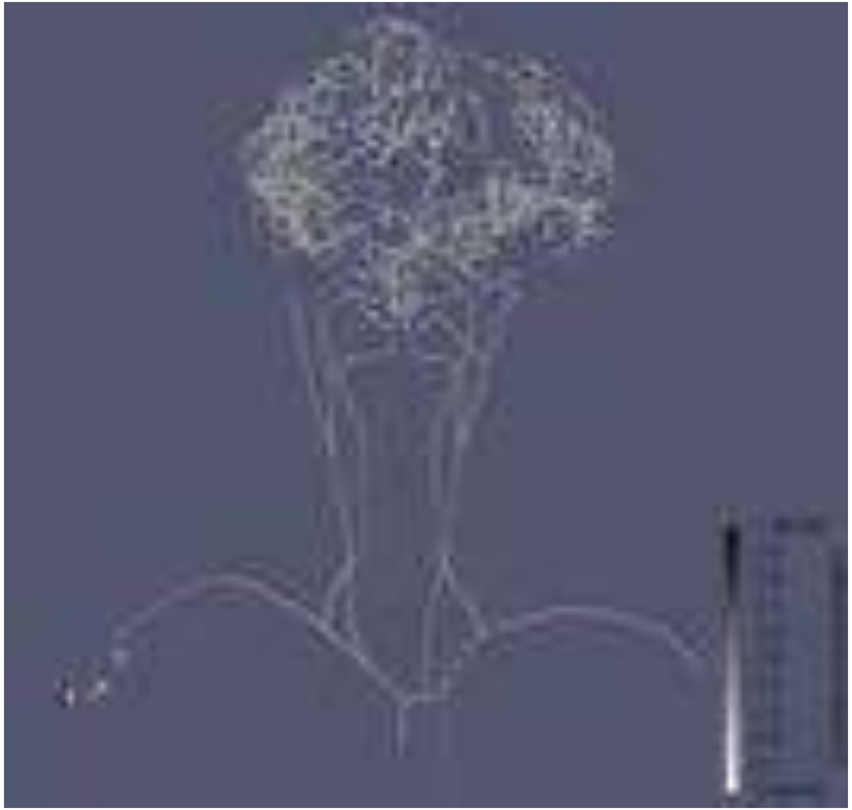

See Liebeskind2003, Winship2014

# Arterial Spin labelling data

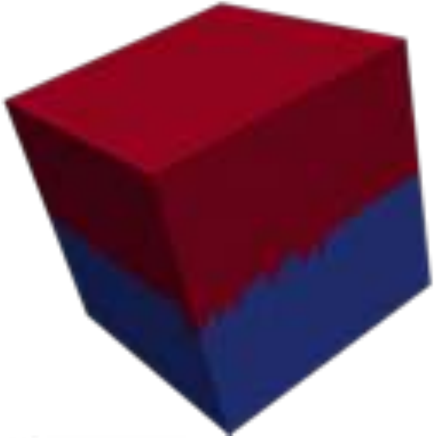


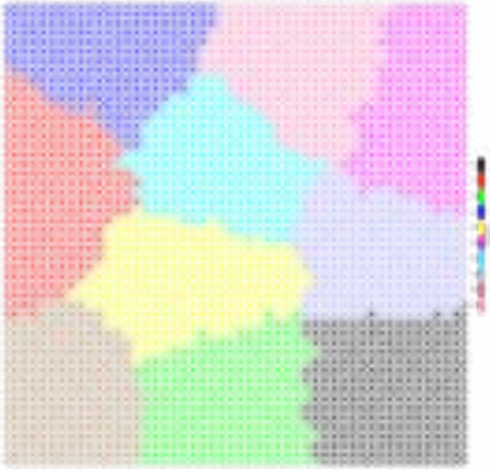
# Contrast advection model



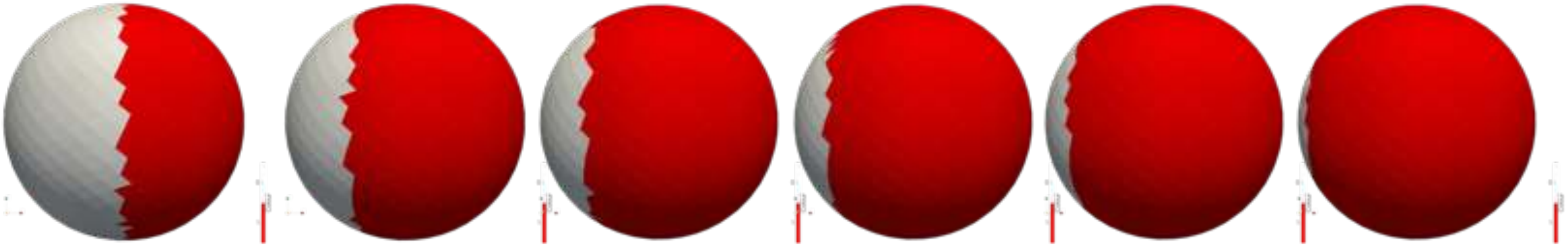


# Verification

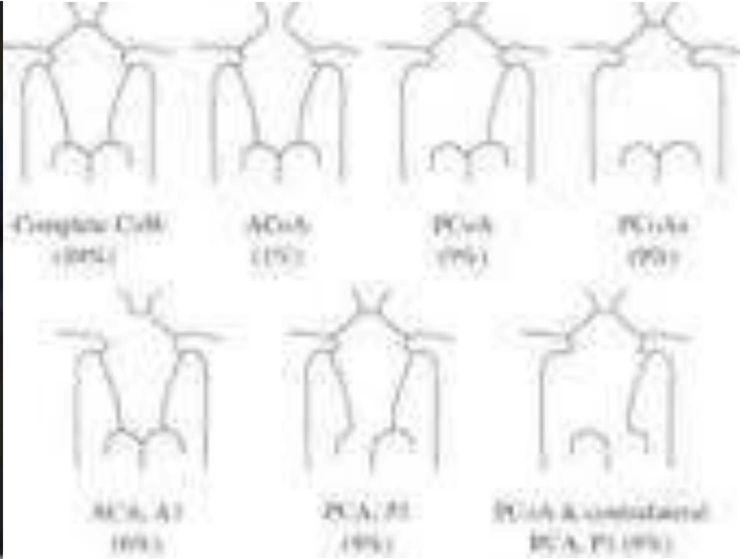




# Clustering on a sphere with different ratios



# Cerebral Circulation



See Alastruey2007, Wright2013