Numerical simulation of liver perfusion
from CT scans to FE model

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Introduction

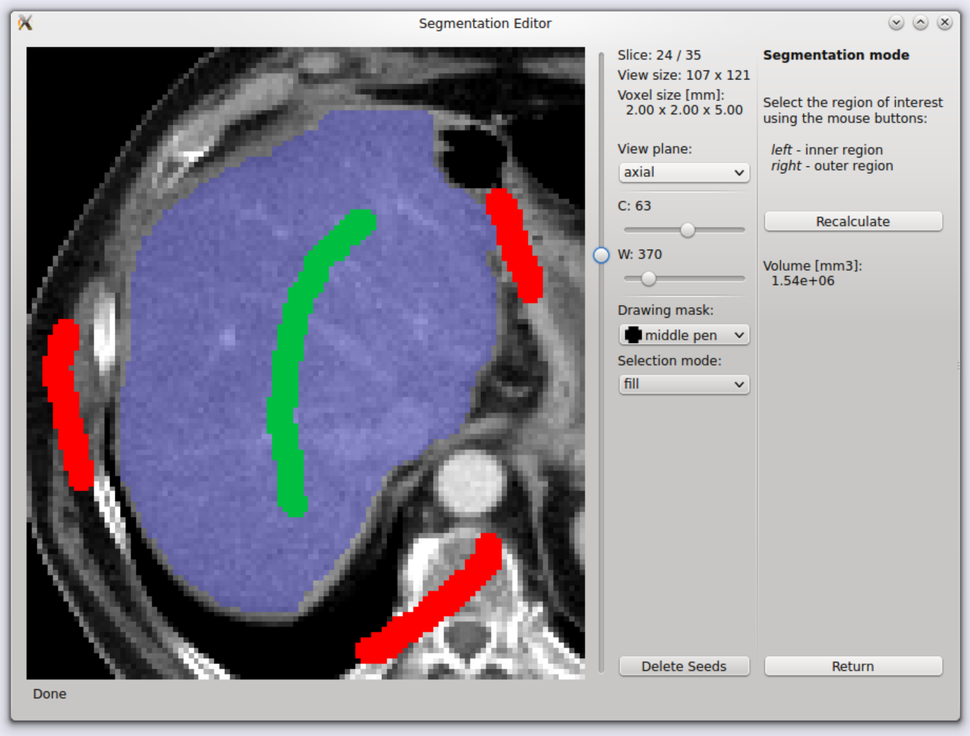
Patient specific numerical modelling of a human liver involves:

- identification of larger vascular structures and hepatic parenchyma from computed tomography (CT) or magnetic resonance (MR) data
- generation of a finite element (FE) mesh and vascular trees
- numerical simulations of liver perfusion using different mathematical models of blood flow at different spatial scales

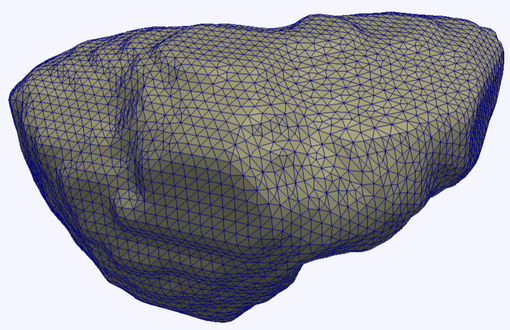
Volumetric model of liver parenchyma

DICOM2FEM: application for semi-automatic segmentation and generation of finite element meshes from CT scans

- DICOM files handled by *pydicom* library
- user interface build up using *PyQt*
- visualization and data storage: *PyVTK*
- segmentation of liver parenchyma based on the *Graph-Cut method*



- user interactively selects the liver tissue (green seeds) and the regions outside the liver (red seeds)
- FE mesh generated using the marching cube method and the Taubin smoothing algorithm



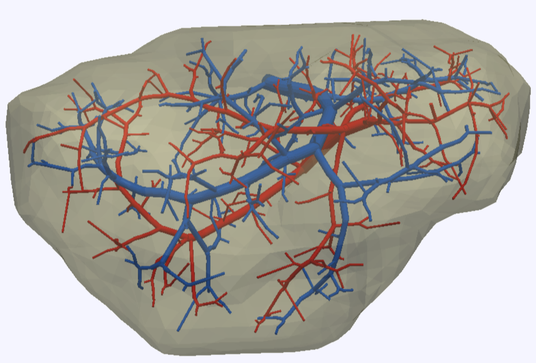
Geometric model of vascular structures

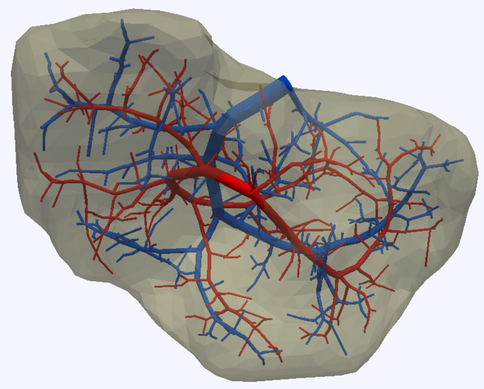
Reconstruction of vascular trees:

- requires perfusion CT examinations - a contrast fluid injected into the blood system
- a voxel-based representation of the detected vascular structures transformed into a graph representation
- a complicated task with uncertain results ⟶ missing parts of the vascular trees generated artificially

Generation of artificial vascular trees:

- constructive optimization method based on minimization of intravascular blood volume and energy lost to friction
- iterative process including smoothing, merging and splitting of the tree

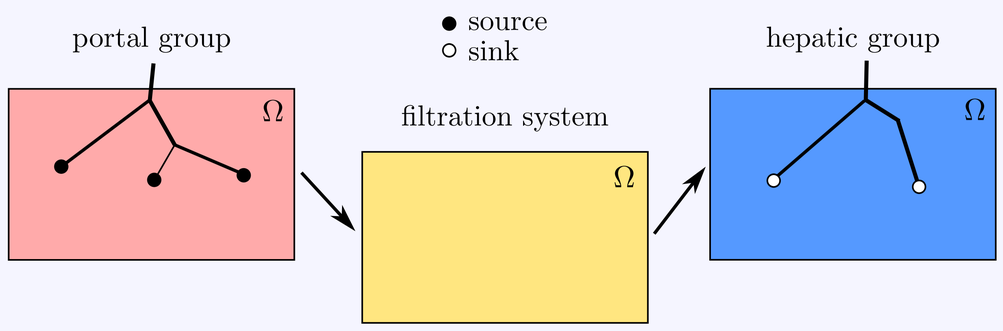




Mathematical model of liver perfusion

Numerical modelling of blood flow through the human liver:

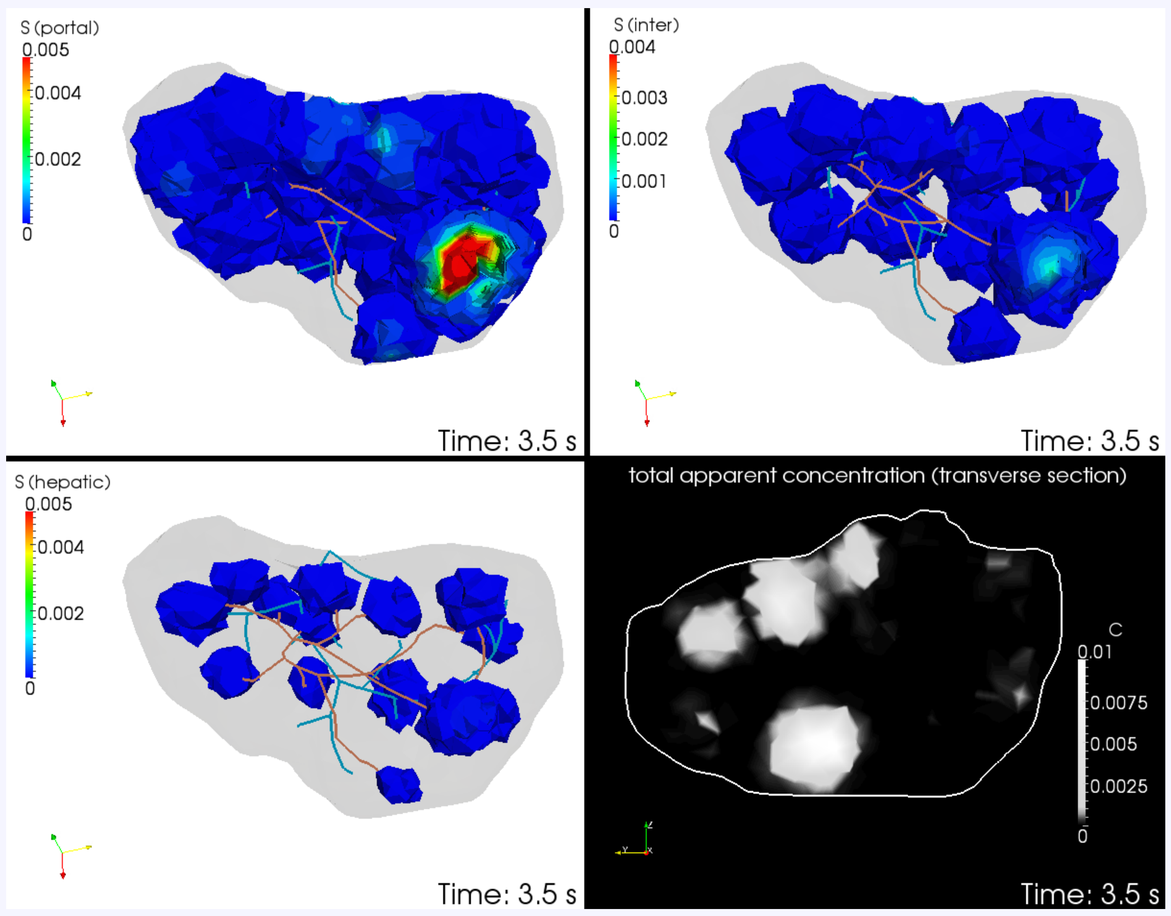
- branching vessels with diameters above 2 mm described by a simple 1D model based on the Bernoulli equation with friction losses ⟶ system of non-linear algebraic equations solved by the Newton method
- blood flow at lower hierarchies modelled as parallel flows in a 3D porous media governed by the Darcy equation extended for multiple compartments
  - compartments - spatially co-existing domains reflecting a certain hierarchy of tissue vascularity, compartments are coupled together and communicate with the 1D flow model through sources and sinks



  - multicompartment Darcy flow model implemented in SfePy (Simple Finite Elements in Python) and solved by the standard finite element method
- modelling of contrast fluid transport through the hepatic tissue
  - simulation of a dynamic perfusion test ⟶ possibility to compare numerical results with real perfusion data
  - numerically solved using an upwind cell-centered finite volume scheme and the two-stage Runge-Kutta method

Numerical results

Saturation in the portal, filtration (inter) and hepatic systems and the corresponding distribution of the total concentration in the transverse section (like in CT scans).



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