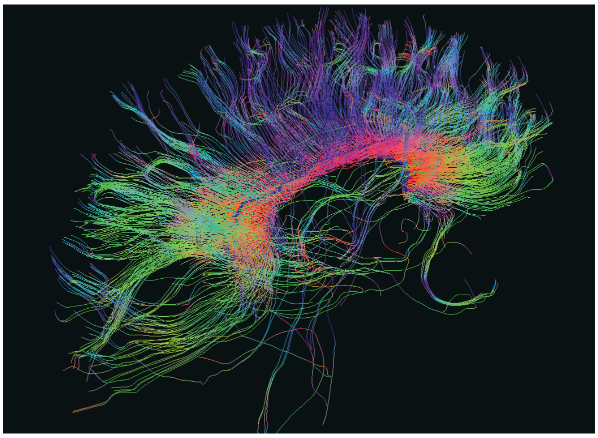
PGEM Geometric Models and Simulation

Fiber Tracking and Visualization

Diffusion weighted imaging (DWI) with MR is a proven tool in brain imaging. The diffusion analysis model in the PXMOD tool processes DWI MR images and calculates diffusion tensors. PGEM implements fiber tracking based on such diffusion tensor information. Various calculation methodologies and boundary conditions are supported, building on the functionality of the proven CAMINO toolkit. The resulting fibers are visualized as 3D structures in PGEM, but they can also be exported for research use in alternative packages.

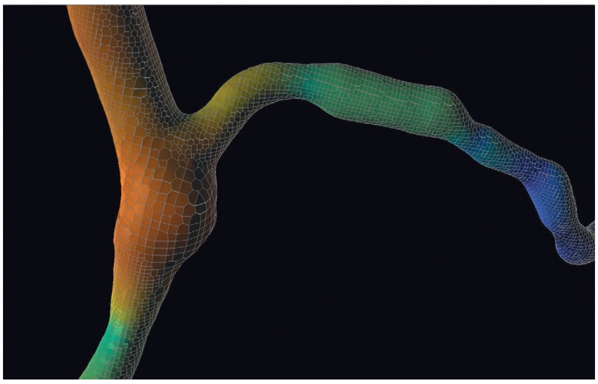
PGEM implements convenient workflows for the analysis and visualization of DWI and 4D flow MR data.



White matter fiber tracks derived from a DWI MR image.

Geometric Model Building

The PGEM tool leverages the power of the PMOD platform for various types of geometric analyses and simulations. A model builder enables the conversion of anatomic structures into three-dimensional geometric models. Such models may become educational tools, the input for external simulators, or they can be used to generate modality-specific phantom images such as a dynamic brain PET with individual kinetics in every brain structure.

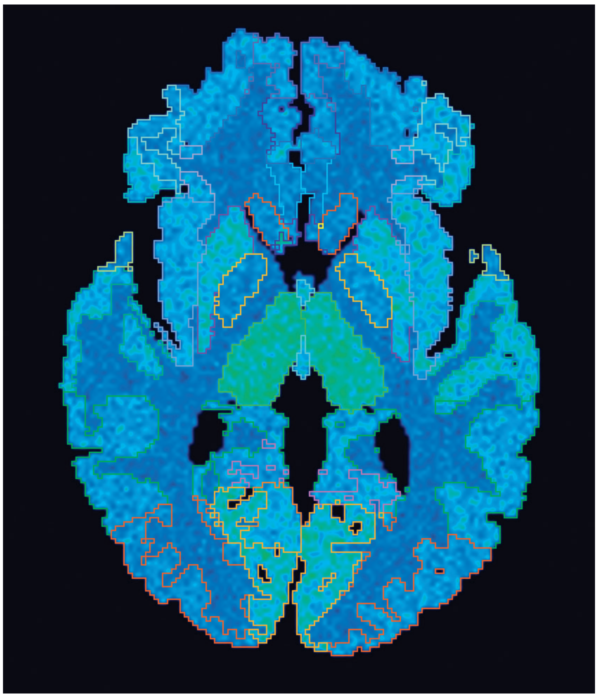


Mesh for CFD calculations in vessel together with the resulting pressure distribution in color.

4D Flow Analysis and Visualization

4D flow MR sequences acquire the velocity vector field of fluids in vessels at multiple times, e.g., across the phases of a heartbeat. PGEM enables connection of the velocity vectors from a given acquisition and visualization as 3D streamlines. When the streamlines are calculated for all acquisitions and animated as a movie, the change of the flow pattern over time becomes apparent.

PGEM supports all CFD preparation steps and offers a convenient interface to OpenFOAM®.



Synthetic PET series with individual, slightly noisy kinetics in functional brain regions.

Computational Fluid Dynamics (CFD)

CFD is a research tool that has been used for analysis of the flow in vessels in a variety of medical conditions. CFD requires a model of the vessel geometry as an input and a computational engine to calculate the flow in the different parts of the lumen, as well as a visualization and assessment system of the results. PGEM supports all required parts for CFD research, delegating the actual flow simulation to the established open source CFD system OpenFOAM®.

Geometric Model Building

Geometric models are built from VOI definitions. The VOIs are converted into surfaces delineating the inner or outer of a structure part. Such parts can be connected to form hierarchical structures, for instance a model of a vessel tree for CFD simulations. By assigning physical properties to the individual parts, anatomical models can be designed which may be utilized for phantom image generation. One application is the synthetic generation of a dynamic PET image series from a brain atlas model, with different kinetics for each brain structure. Another application is the organization of the parts in an atlas-like manner, where high-level structures like organs are successively subdivided into smaller constituents. Each of the elements can be annotated using a range of media for educational purposes. An example model of the coronary arteries is included in the distribution for illustrative purposes.

Fiber Tracking and Visualization

For the analysis of diffusion weighted MR (DWI) images, the gradient configuration during the acquisition needs to be known. PMOD reads this information from the DICOM header, if available. Otherwise, the gradient table can be loaded in 7 different formats, including FSL, Camino, DSI/DTI Studio and Paravision. All tractography calculations are based on the proven CAMINO toolkit code (http://camino.cs.ucl.ac.uk/). Four tracking algorithms are supported (FACT, EULER, RK4, probabilistic PICo), each with a number of parameters to tune the tracking process. VOIs are employed for definition of the seeding region, but also for imposition of restrictions on the resulting fibers, such as passing through or ending in a region.
The resulting fiber tracks are visualized as lines, colored by the direction cosines, by the local fractional anisotropy (FA), or by the seeding VOI color. Each track is an object in a 3D scene and can be manipulated individually. The scene may be enriched by adding FA or Mean Diffusivity (MD) image planes to the tracks. In order to calculate regional statistics from the FA and MD maps, tracks can be converted into VOIs and applied to the images. An alternative to evaluating the tracks in PGEM is export as vtk files. The whole tracking configuration can be saved in a protocol file for later reproduction of analysis.

4D Flow Analysis and Visualization

4D flow analysis requires two data sets, “Magnitude” and “Flow velocity”, which are generated during MR image reconstruction. The magnitude image shows anatomical detail and has arbitrary scaling, whereas the flow velocity data is a 3D field of the flow vector in real-world units. Two formats for the vector field are supported, a format encoding all directions in one file, and a format with separate files per direction. The maximal flow encoding vector of the acquisition needs to be known and manually entered.
Tracking uses the same algorithms as DTI fiber tracking described above, with the flow velocity vector taking the role of the principal tensor eigenvector. The results of the analysis are “streamlines”, comparable to the DTI fiber tracks. Additionally, vorticity and helicity maps are calculated which provide information about further flow properties.
The streamlines are visualized in the same way as fiber tracks, with velocity as a color option instead of FA, and in the 3D scene they can be combined with plane images of the flow magnitude. An additional feature is a summary report that lists the average flow, vorticity and helicity in user-defined regions.

Computational Fluid Dynamics (CFD)

A CFD simulation requires the geometric model of a vessel wall as a starting point. In a first step, the wall surface is converted from VOIs into a mesh representation. If an external STL file is available, the surface mesh can alternatively be loaded. In a next step, the enclosed volume is decomposed into small elements, the cells for the simulation. Parameters for this “volume meshing” process allow trimming of the cell size locally – particularly along the surfaces – in order to minimize the discretization error. The resulting volume mesh may be exported for external use in Fluent® (ANSYS) format. Next, inlet and outlet planes need to be defined, along with initial conditions of pressure and velocity vector. Kinematic pressure can be set as a fixed value that will be maintained throughout the simulation, or by a zero gradient property which will enforce that there is no pressure change at the boundary. Velocity can be configured similarly, with an additional option to keep the surface normal of the flow fixed. Pressure and velocity conditions along the wall surface need to be specified in the same way.
The actual CFD simulation is performed in a client-server setup. All configuration information is compiled into a simulation task, which is sent to a server middleware developed by PMOD for the open source CFD system OpenFOAM® (www.openfoam.org). The server converts the information into an OpenFOAM case and runs the simulation. PGEM can list the status of the running simulation cases, and retrieve the resulting pressure maps and velocity fields of completed cases for analysis and visualization in 3D.