

Model fitting of dynamic data: Implementation of perfusion models for radiotherapy analysis

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Outline

1. On dynamic data modeling and perfusion imaging
 - Dynamic imaging of indicator dilution
 - Demands for a dynamic data modeling tool

2. Infrastructure concepts
 - The fitting routine: optimizer and cost function
 - The model function
 - Parameter maps and modelfit-visualisation

3. Use case: perfusion MRI in glioma patients

4. Summary
 - Advantages of MITK perfusion
 - Outlook

On dynamic data modeling and perfusion imaging

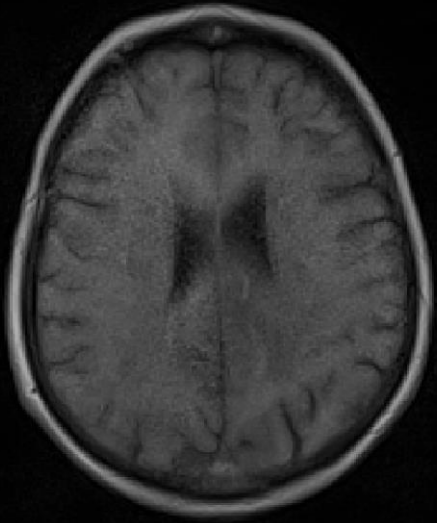
Why we need dynamic data modeling: Dynamic imaging of indicator dilution

- Aim: characterize tissue physiology
- Measure dynamic distribution of an indicator
- Dynamic Contrast Enhanced MRI (DCE MRI)
 - Contrast agent
 - Microcirculation and vascularization
 - Perfusion and permeability
- Dynamic PET
 - Radioactive tracer with metabolite
 - Dynamic tracer uptake → Time-Activity-Curve
 - Metabolic rate and exchange constants

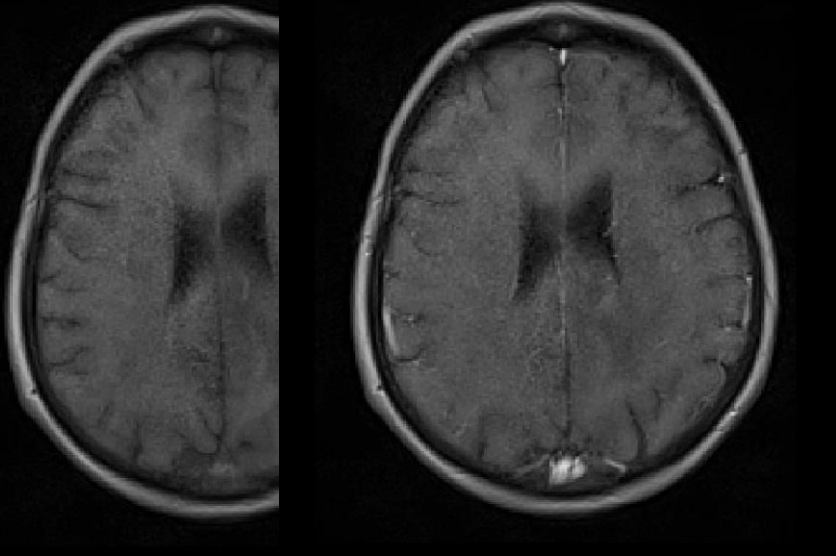
Why we need dynamic data modeling: Dynamic imaging of indicator dilution

- Acquire time series of 3D images over the time course of indicator application
- Analyse time series with indicator dilution theory/pharmacokinetic models
 - Mathematical representation of ongoing physiological process
- Fitting of Signal-Time-Curves (ROI-/pixelbased)

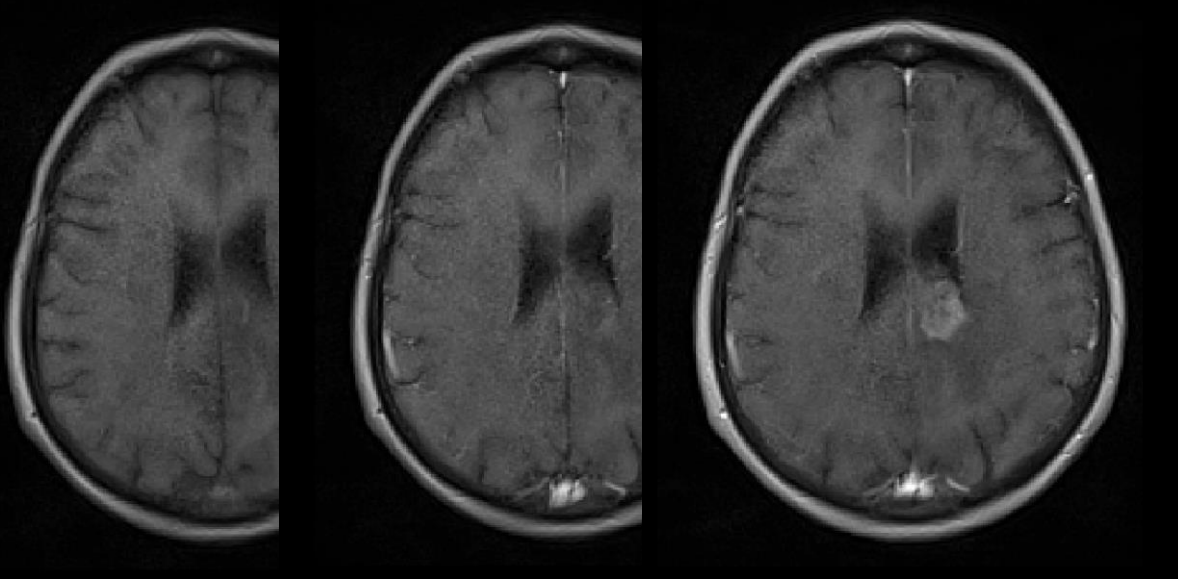
Perfusion MRI (DCE MRI)



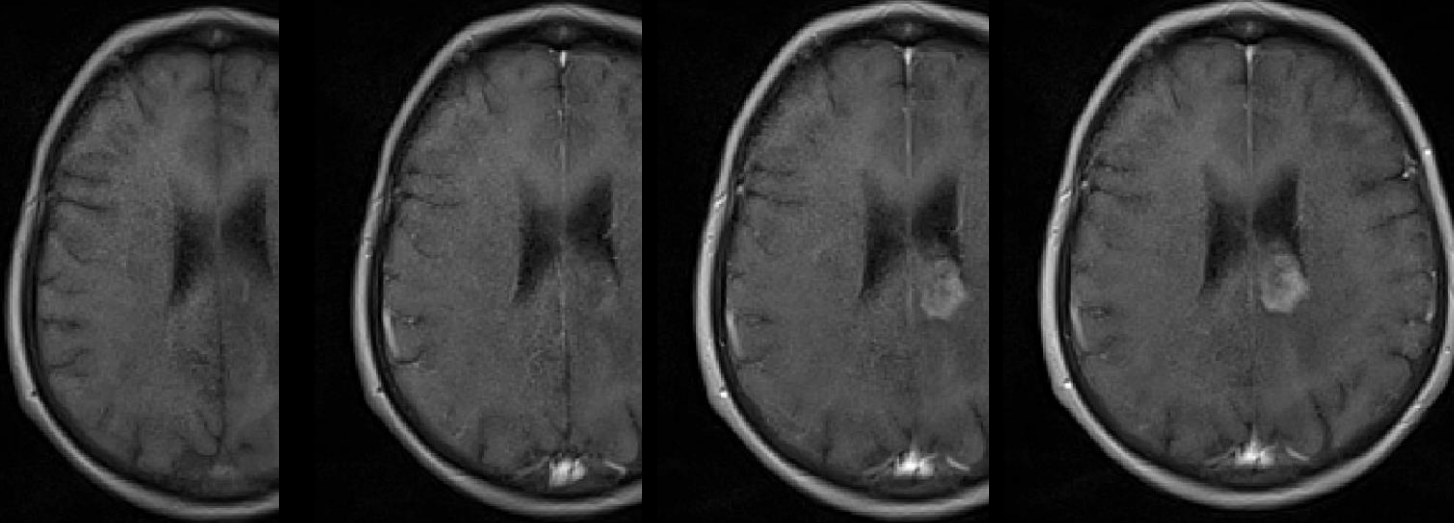
Perfusion MRI (DCE MRI)



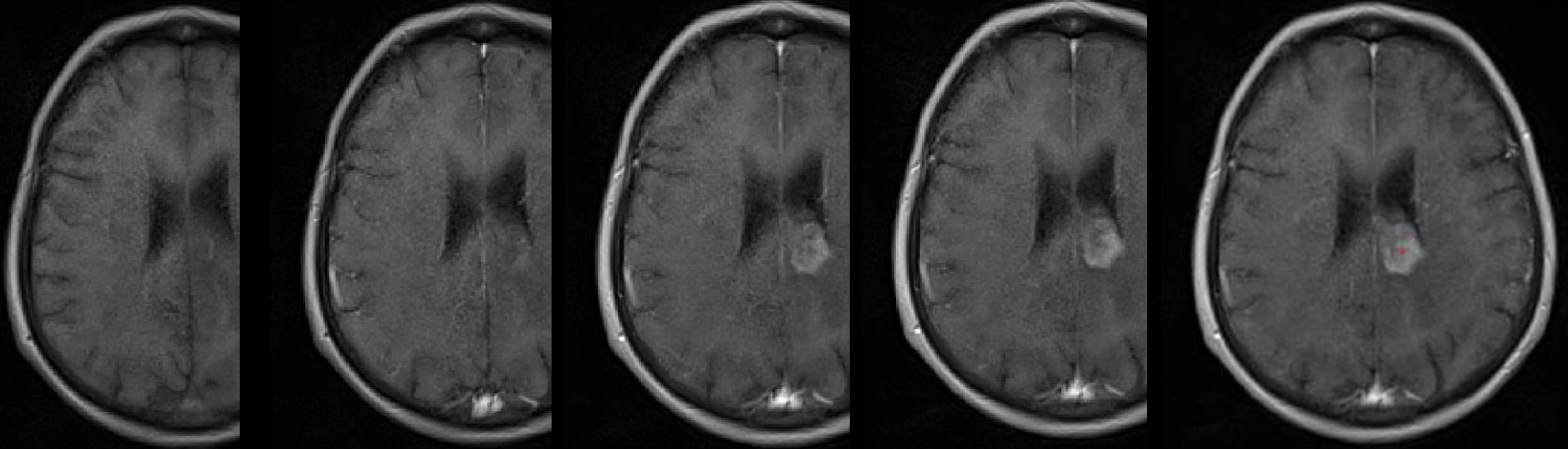
Perfusion MRI (DCE MRI)



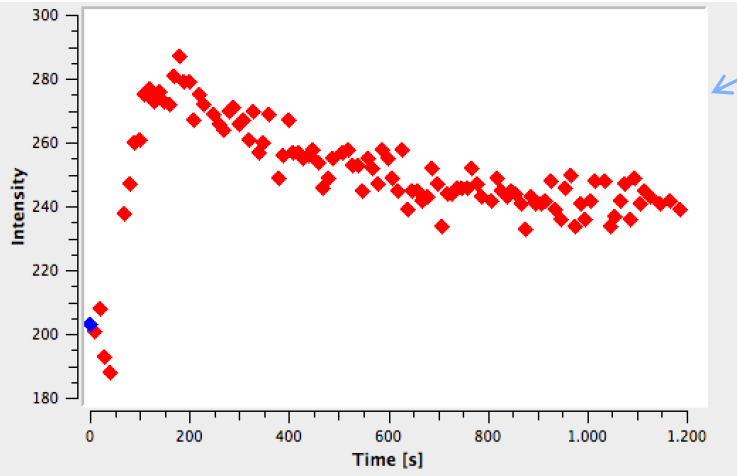
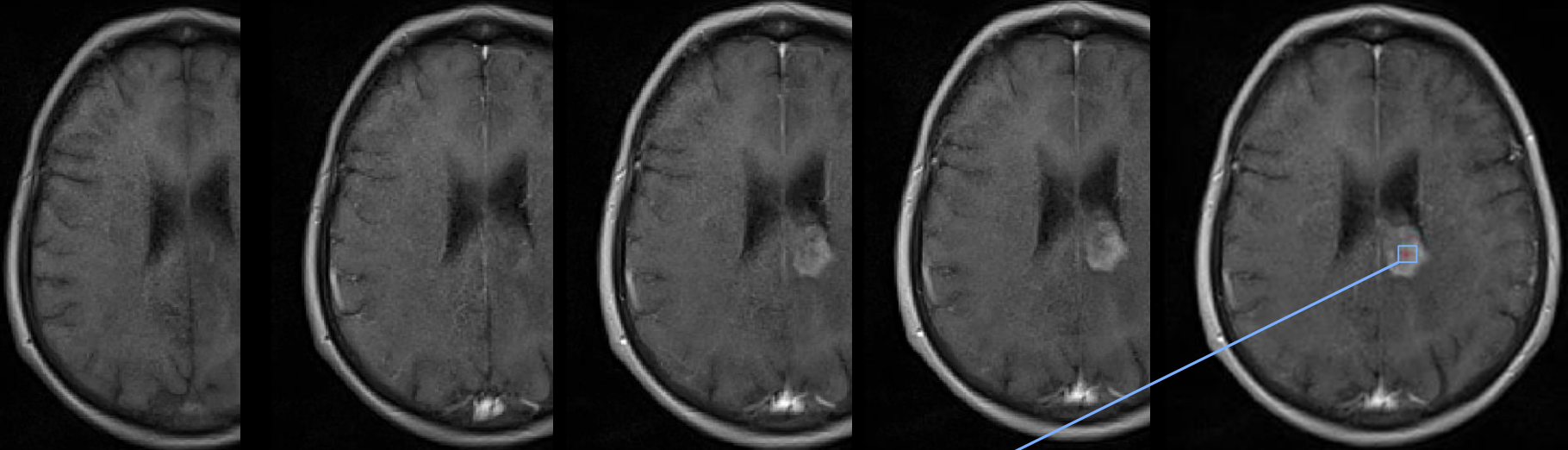
Perfusion MRI (DCE MRI)



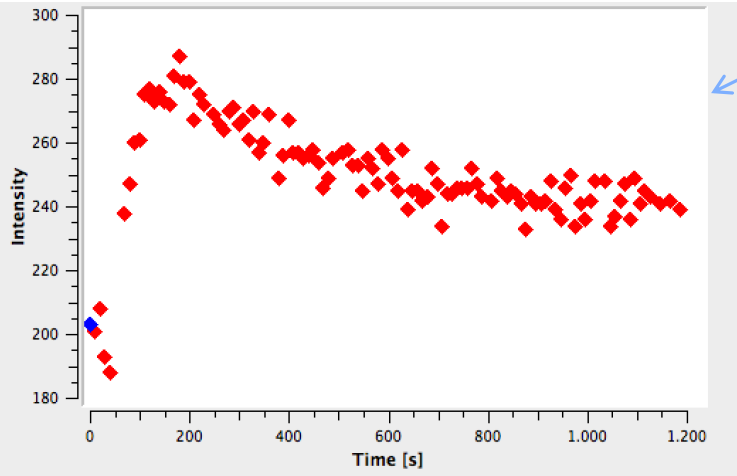
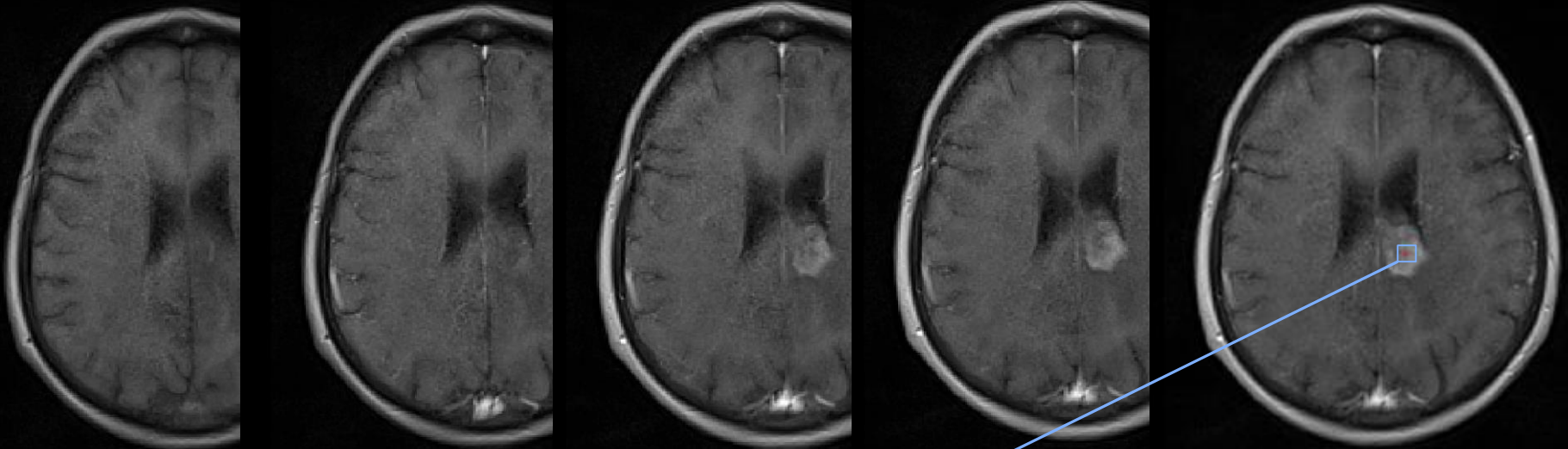
Perfusion MRI (DCE MRI)



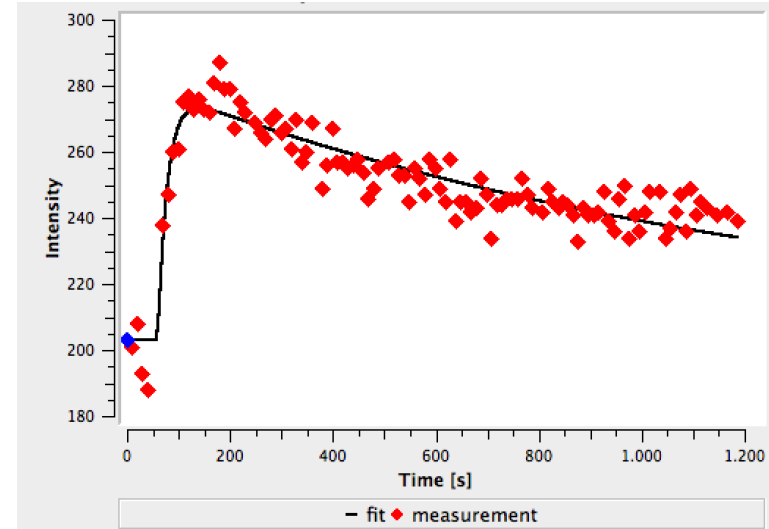
Perfusion MRI (DCE MRI)



Perfusion MRI (DCE MRI)



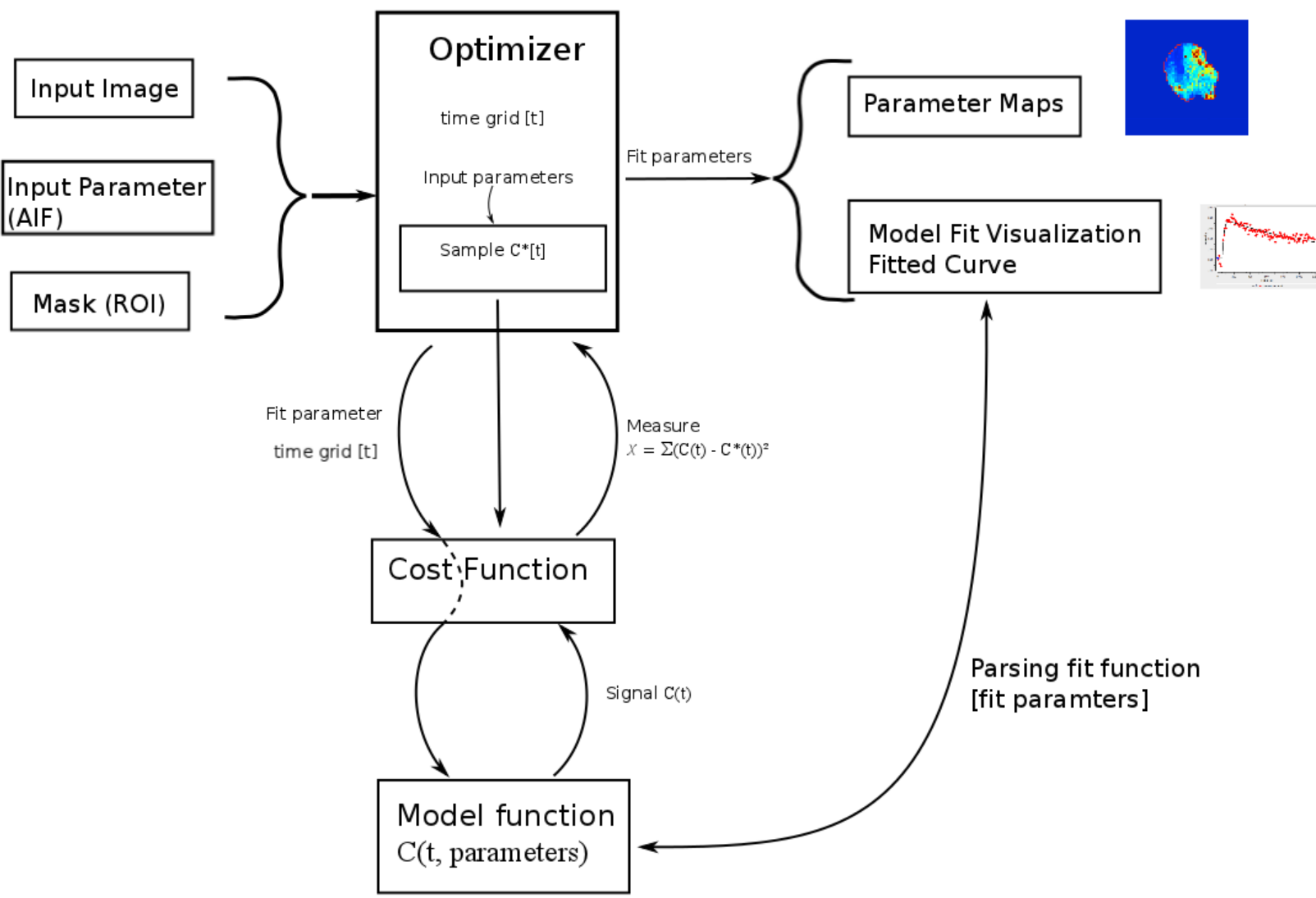
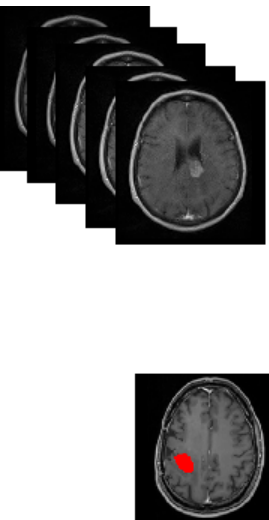
FIT



Task/Demands

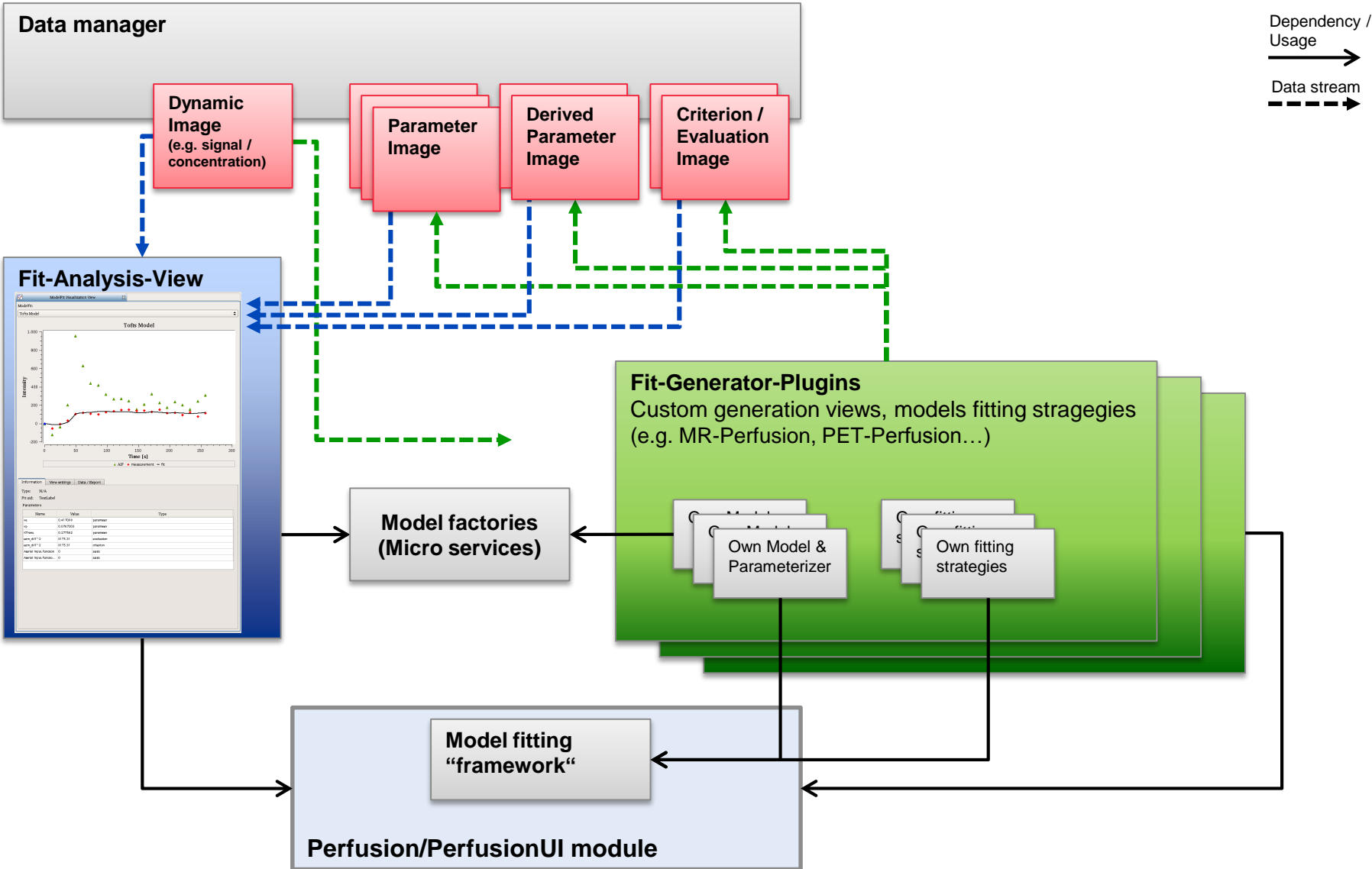
- Load 4D image modality
- ROI definition (segmentation)
- Extract signal-time-curve in every voxel of ROI/
mean signal within ROI
- Model & modality independent fitting routine
 - Optimizer
 - Cost function
 - Display fitting parameters and fit quality
- Modality dependent model specifications
 - Conversion of Signal
 - Model function
 - Parameter constraints depending on model
 - Output parameters (fit parameters, measures, derived parameters, ...)

Fitting routine



Infrastructure concepts

The MITK Perfusion Module: Infrastructure concepts



The fitting routine: optimizer and cost functions

- Fitting routine is decoupled from specific model and input modality
 - High re-usability
- User can choose optimizer with appropriate cost function
- Currently used: itk::LevenbergMarquard with multivalue cost function
- Cost function
 - Compares signal corresponding to current parameters with sample that is to be fitted
 - Own implementations with various „measures“/fit criterions
 - Sum of (squared) differences (χ^2)
 - Squared differences
 - ...

The model function – general

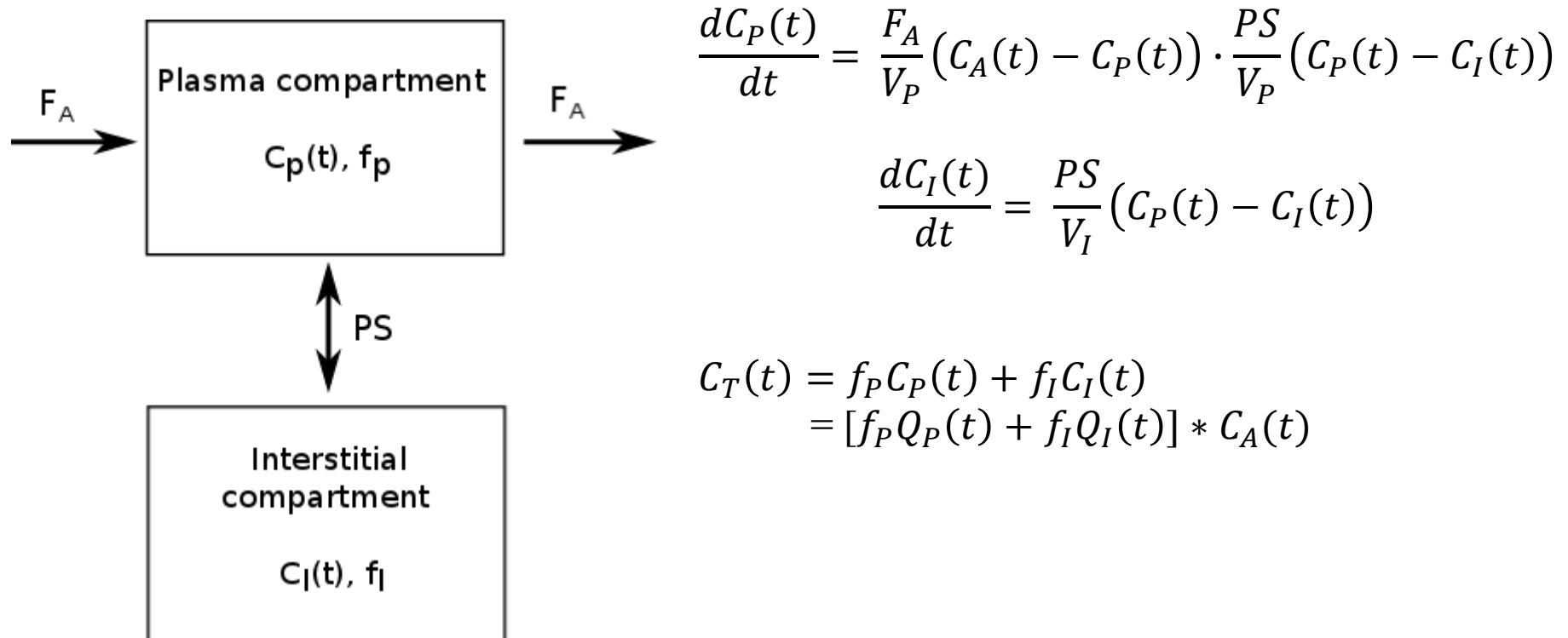
- Modality dependent, specific mathematical model for underlying physiological process
- Function declaration $f(t)$ to describe data curve
 - Conversion of signal
- Is calculated for cost function from current fit parameters and time grid
- Resulting signal curve is needed by cost function to calculate measure

The model function – perfusion

- Function declaration gives concentration-time-curve $C(t)$
- Different types
 - compartment models, deconvolution analysis, semi-quantitative parameters
 - Calculation of $C(t)$ e.g. via convolution, numeric solution of differential equations (ODE), stepwise declaration
- Currently implemented:
 - DCE MRI models: 2 compartment exchange model, extended Tofts, descriptive Brix model
 - PET: 1 and 2 tissue compartment model

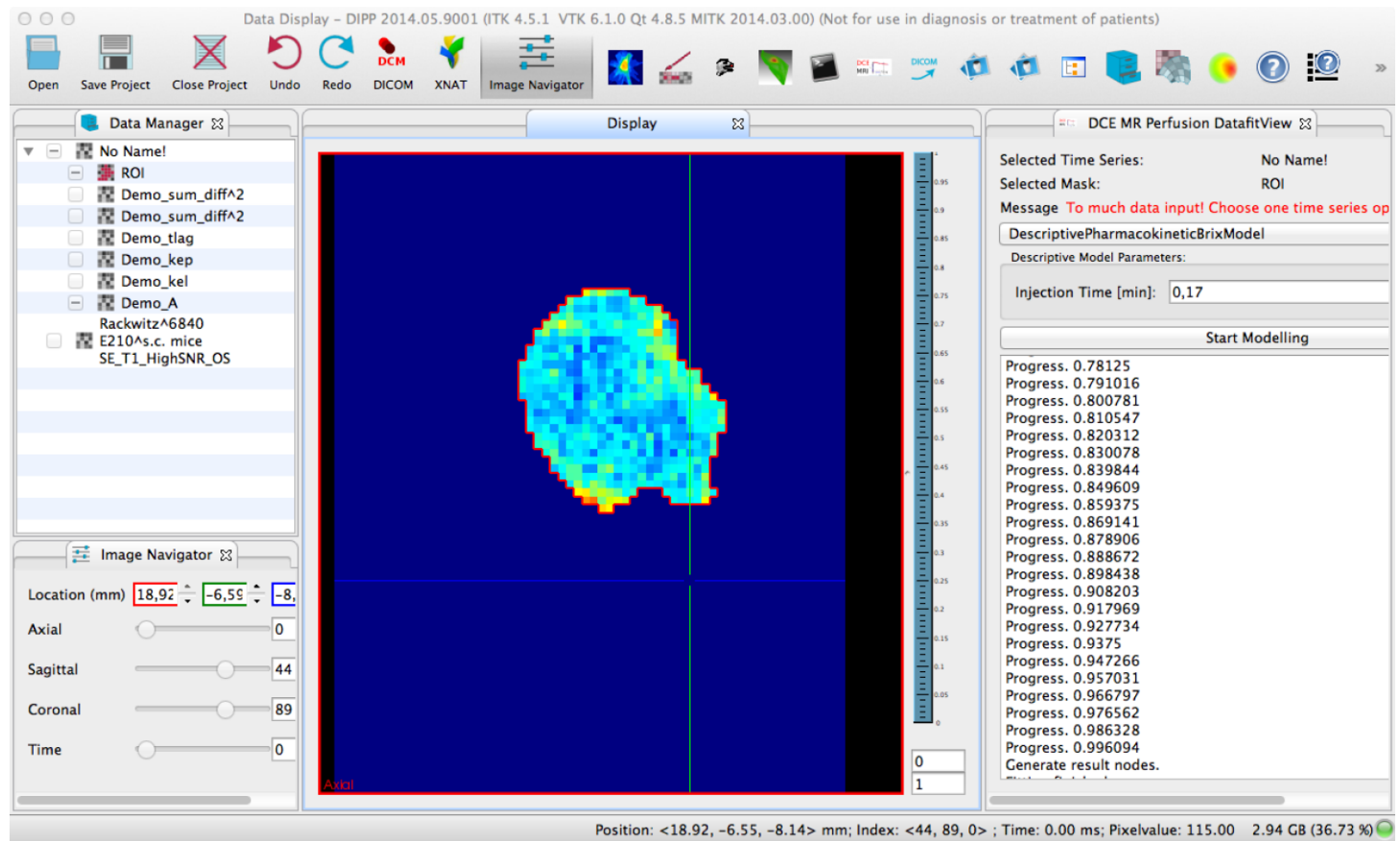
The model function – example

- 2 compartment exchange model



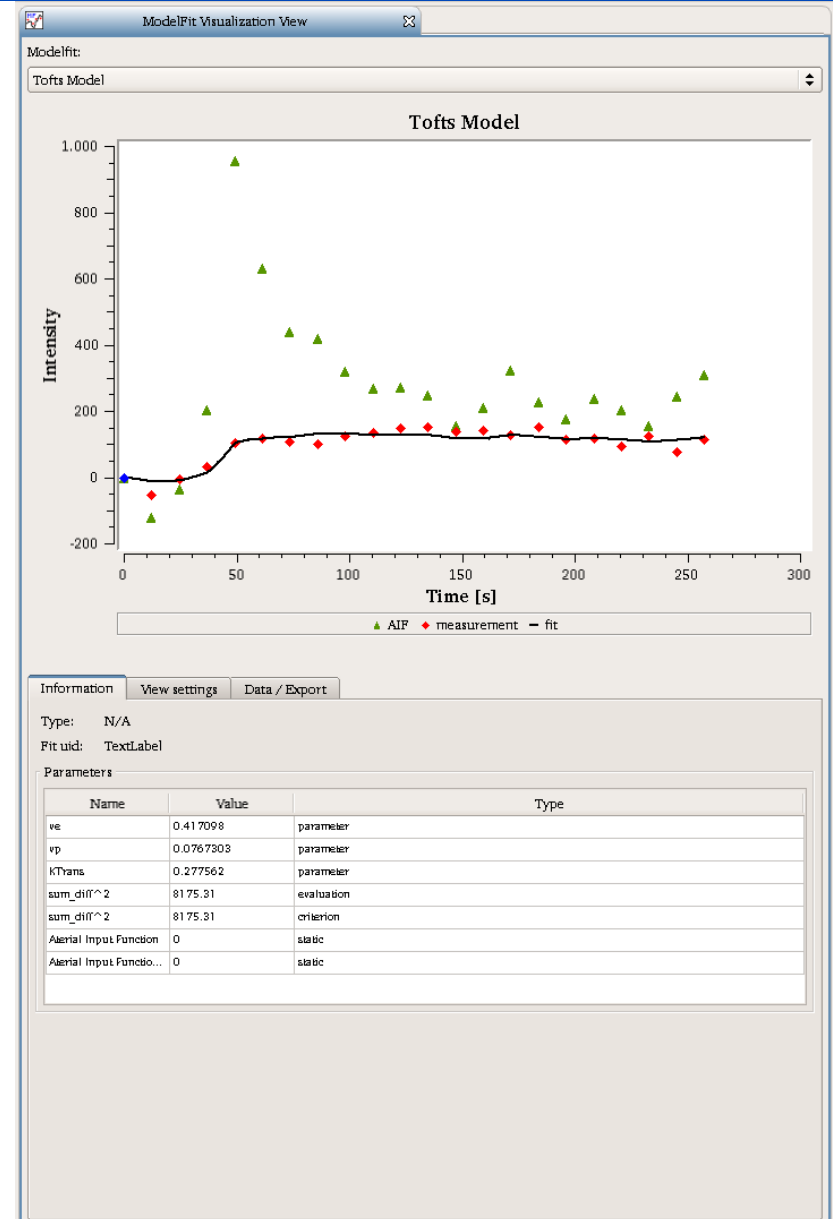
Parameter maps and modelfit visualization

- Result parameters of fitting routine are stored voxelwise as 3D parameter maps/images (one map for each parameter)



Parameter maps and modelfit visualization

- Modelfit-Visualization plug-in using factory structure to display input data points and fit voxelwise



Use Case:

Perfusion MRI in Glioma Patients

Use Case: Perfusion MRI in Glioma Patient

The screenshot displays a medical software interface for MRI analysis. The main window shows an axial MRI scan of a brain with a red contour highlighting a lesion. The interface includes a menu bar (File, Edit, Window, Help), a toolbar with various tools, and a Data Manager panel on the left. The Data Manager panel lists several data series, including AIF_2, ROI_2, Pat_7, MR_Schaeffel_ax KM, and a group named 'No Name!' containing Demo_sum_diff^2, Demo_sum_diff^2, Demo_yp, Demo_ys, Demo_kTrans, and Concentration. The Image Navigator panel at the bottom left shows location coordinates (4,62, 15,88, 42,46) and sliders for Axial (18), Sagittal (96), Coronal (128), and Time (0). The bottom status bar displays the position: <4.62, 15.88, 42.46> mm; Index: <96, 128, 18>; Time: 0.00 ms; Pixelvalue: 0.00e+00 2.99 GB (9.56 %).

Use Case: Perfusion MRI in Glioma Patient

The screenshot shows a medical software interface with the following components:

- Data Manager:** A tree view on the left containing folders and files such as AIF_2, ROI_2, Pat_7, MR_Schaedel, ax KM, No Name!, Demo_sum_diff^2, Demo_sum_diff^2, Demo_yp, Demo_ys, Demo_kTrans, and Concentration.
- Image Navigator:** A control panel at the bottom left with sliders for Location (mm) (4.62, 15.88, 42.46), Axial (18), Sagittal (96), Coronal (128), and Time (0).
- Display:** The main window showing an axial MRI scan of a brain. A red contour is visible in the lower-left quadrant of the brain. A vertical color scale on the right ranges from 0 to 1000. The word "Axial" is written in red at the bottom left of the image.
- Footer:** A status bar at the bottom right displays "Position: <4.62,15.88,42.46> mm; Index: <96,128,18>; Time: 0.00 ms; Pixelvalue: 0.00e+00 2.99 GB (9.56 %)".

Use Case: Perfusion MRI in Glioma Patient

File Edit Window Help

Open Save Project Close Project Undo Redo DICOM Image Navigator

Data Manager

- AIF_2
- ROI_2
- No Name!
- Demo_sum_diff^2
- Demo_sum_diff^2
- Demo_vp
- Demo_ve
- Demo_kTrans
- Concentration

Display

Image Navigator

Location (mm)

Axial

Sagittal

Coronal

Time

DCE MR Perfusion DatafitView ModelFit Visualization View

Modelfit:

Tofts Model

Intensity

Time [s]

▲ AIF ◆ measurement — fit

Information View settings Data / Export

Type: N/A

Fit uid: TextLabel

Parameters

Name	Value	Criterion	Type
sum_diff^2	16131.1	criterion	
sum_diff^2	16131.1	evaluation	
vp	0.119853	parameter	
ve	0.146904	parameter	
kTrans	0.228087	parameter	
Arterial Input Function	0	static	
Arterial Input Funcio...	0	static	

Position: <-26.13, 56.14, 36.58> mm; Index: <62, 173, 18>; Time: 0.00 ms; Pixelvalue: 0.00e+00 3.05 GB (9.73 %)

Summary

Advantages

- Modality independent tool for fitting of 4D data with given model
- Modularity: user can specify different parts according to his needs (cost function and optimizer, model function, output parameters,...)
- User can fit data with own model implementation without concerning himself with the underlying fitting routine
- Ready-to-use analysis software for MRI perfusion data
 - Various model implementations
 - Pixel and ROI-based fitting

Advantages

- Modelfit view for assessment of fit quality
- Countless possibilities due to combination with other MITK tools
 - Registration
 - Segmentation
 - RT Dicom import
 - Statistics
 - Comparison of different modalities and sequences

- Validation of MRI perfusion fitting with simulated and measured data
- Studies on influence of
 - Different optimizers
 - Start parameters for fitting
- Implementation of further models (PET)
- Translation to image analysis other than perfusion
 - E.g. intravoxel incoherent motion (IVIM) models