ESPRIT/IST 'Concertation' Meeting
"HPC & Simulation and Visualisation Technologies"
October 3rd, 2001, Brussels

Project 10378

SimBio: A generic environment for bio-numerical simulation

G. Lonsdale
C&C Research Laboratories
NEC Europe Ltd.

Overview:

- Introduction to the project & SimBio environment
- Environment components & applications – recent results and developments
- Cooperation with external groups
- Concluding remarks

http://www.simbio.de

Project 10378

IST'99 - Action Line IV.4.1
Project Duration: 36 Months
Commencement date: 1st April, 2000

Expected Impact:

Promotion of HPC & Numerical Simulation within the medical sciences.

Innovation:

Actual scan data from Patients used for modelling, analysis & predictive, physically accurate simulation.

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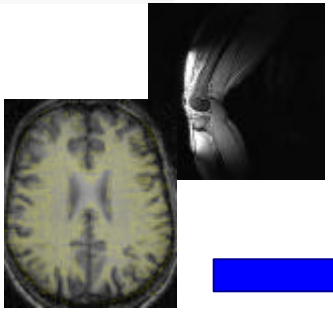
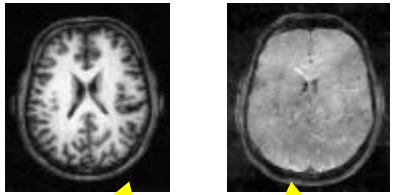
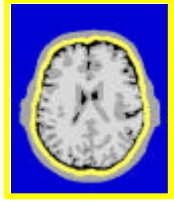
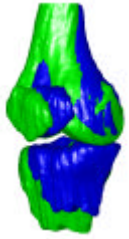
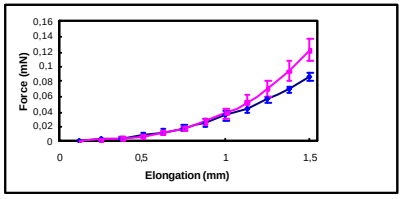
Discrete Representation



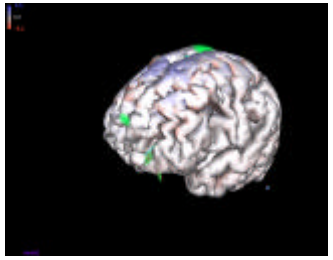


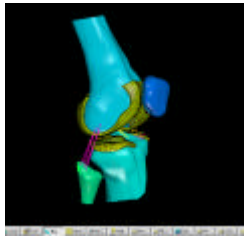


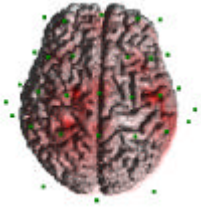


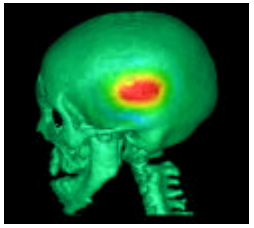


Analysis, Prediction & Design





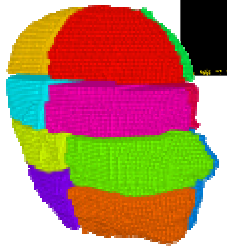


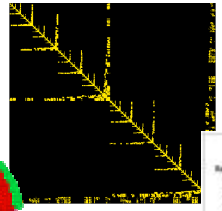


"SimBio-external" Data production

MRI, EEG, MEG,..

Using HPC Computational Technology





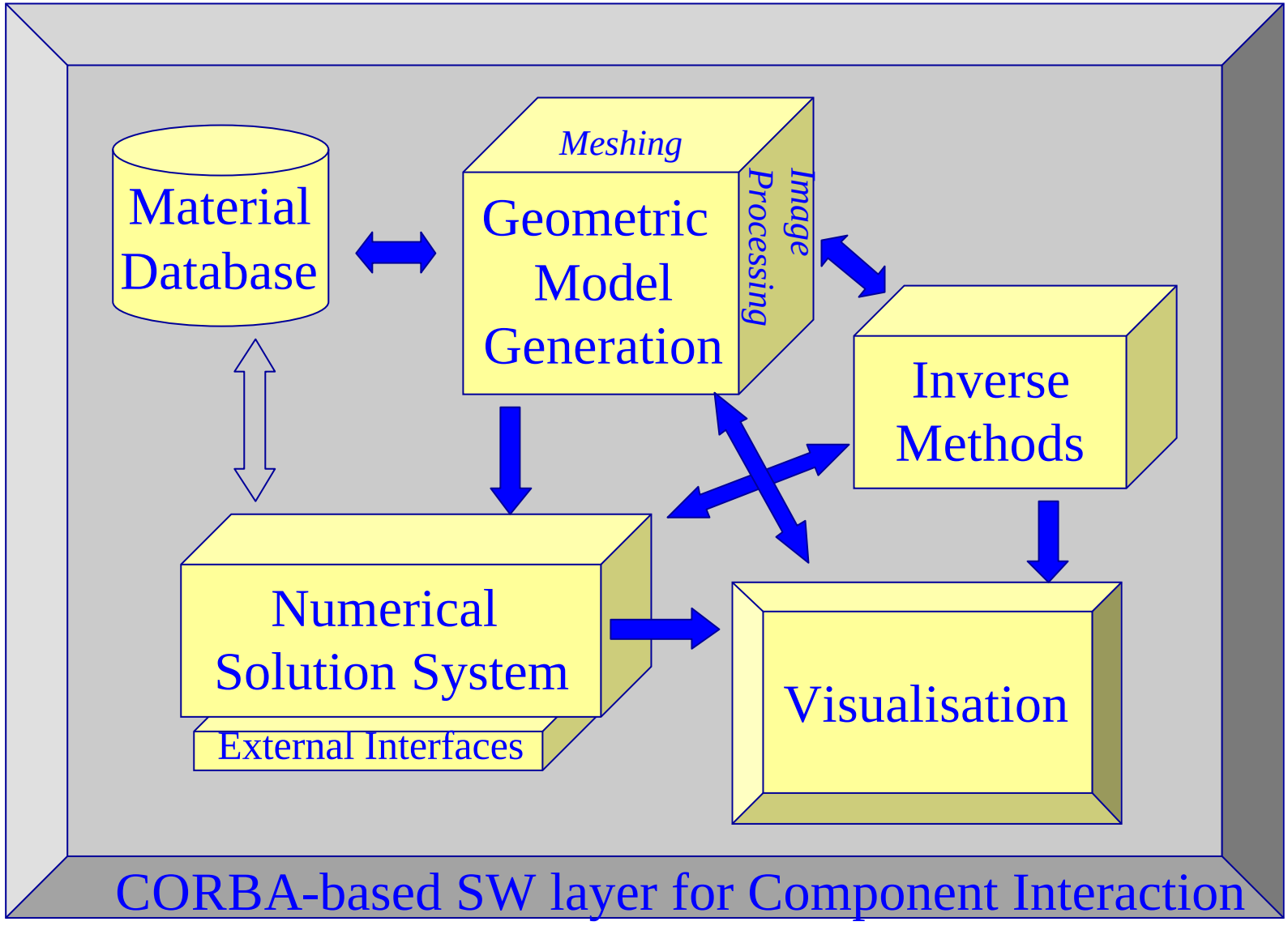
The SimBio Consortium

Participants	Country	Role
NEC Europe Ltd	UK	Co-ordinator
Max-Planck Insitute of Cognitive Neuroscience	D	Principal Contractor
A.N.T. Software B.V.	NL	Assistant Contractor
Biomagnetic Center, F. Schiller University, Jena	D	Assistant Contractor
CNRS - DR18	F	Assistant Contractor
Engineering Systems International S.A.	F	Principal Contractor
The University of Sheffield	UK	Principal Contractor
+ Sheffield Teaching Hospitals NHS Trust		Sub-contractor
Smith & Nephew plc	UK	Assistant Contractor

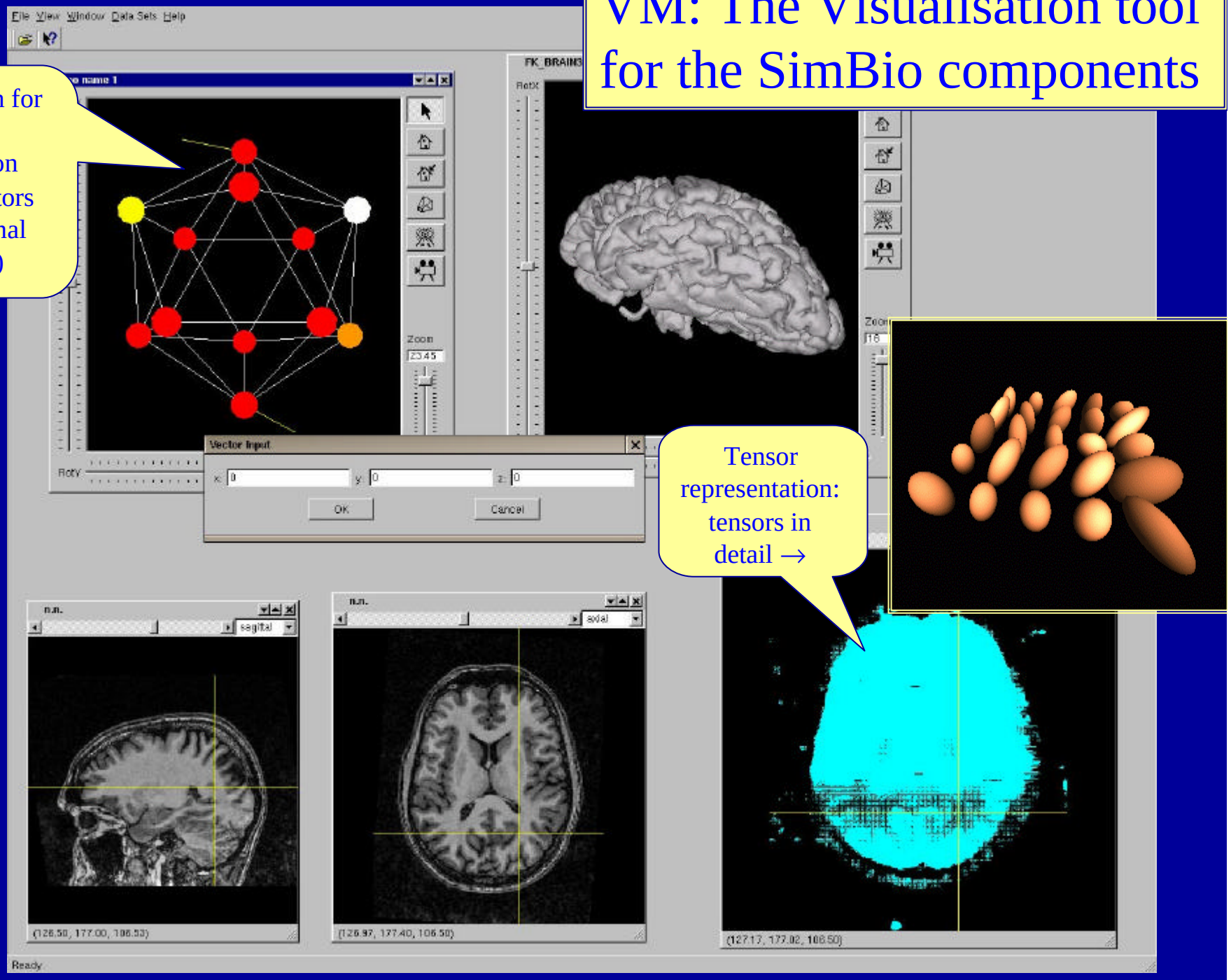
Collaboration Partner

caesar, **Bonn** **D**

SimBio Environment Components



VM: The Visualisation tool for the SimBio components



Interaction for model definition (here vectors for external forces)

Tensor representation: tensors in detail →

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Discrete Representation

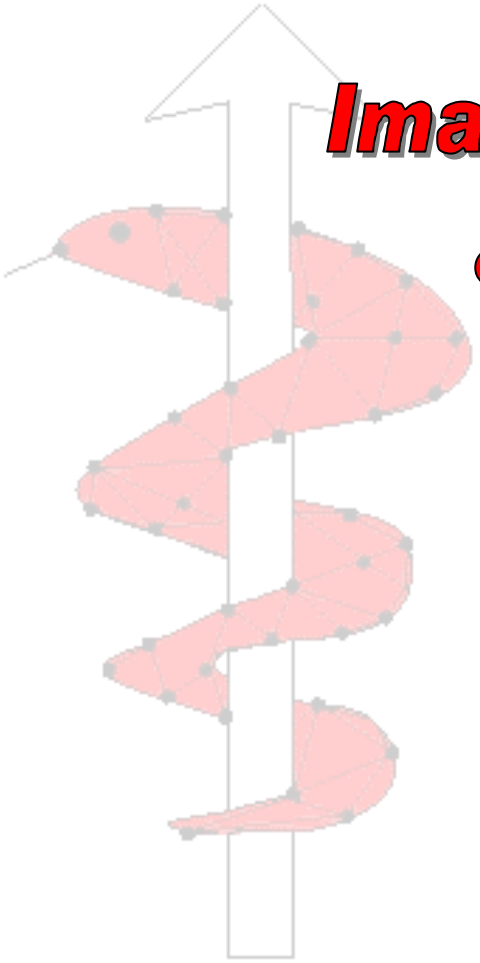

Image Segmentation & registration

Mesh generation

Material Modelling (database)

http://www.simbio.de

2 segmentation approaches followed:

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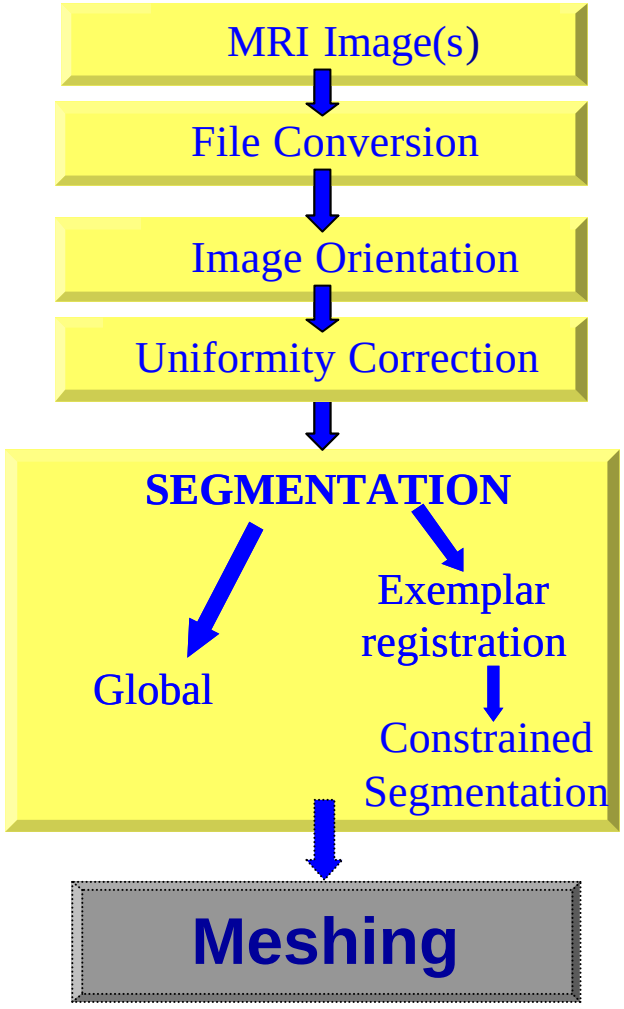

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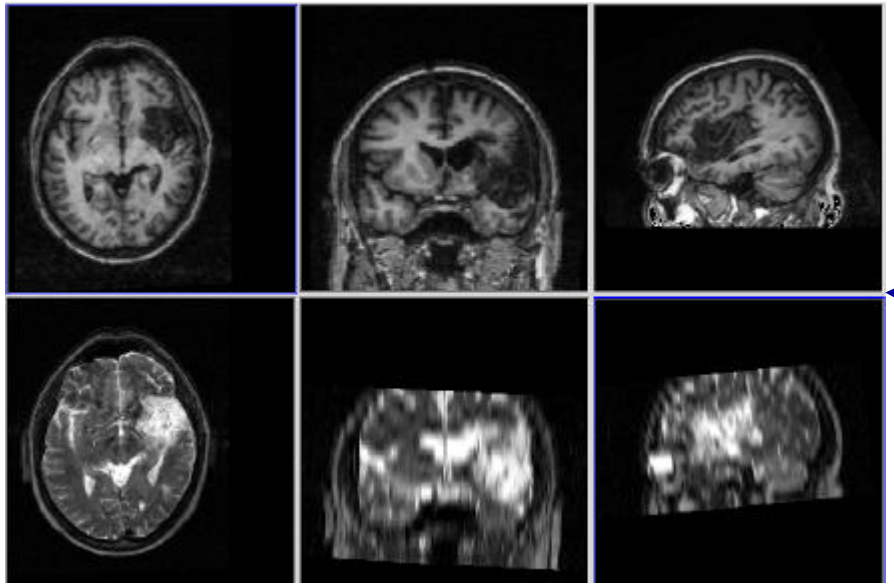
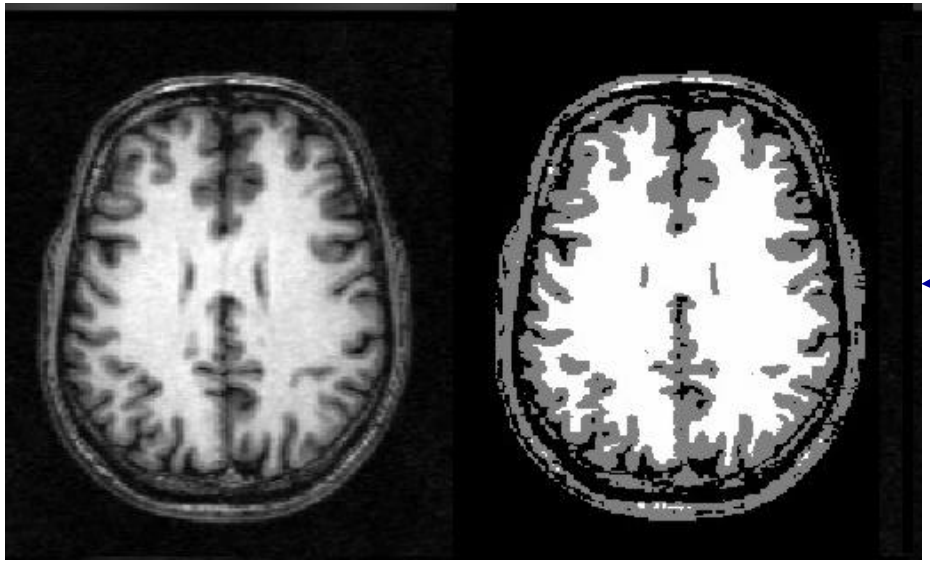
Image processing Toolbox



– Vista file format
  - Implemented for all current and developing tools
  - Dicom to Vista format implemented

– Registration tools
  - Manual image alignment
  - Multi-modality rigid registration
  - *Non-linear registration modules: work in progress*

– Segmentation tools
  - Intensity based segmentation
  - *Model based segmentation: work in progress*



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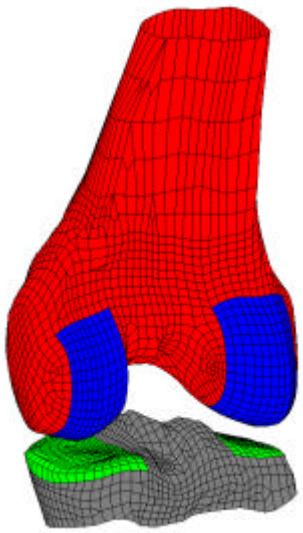
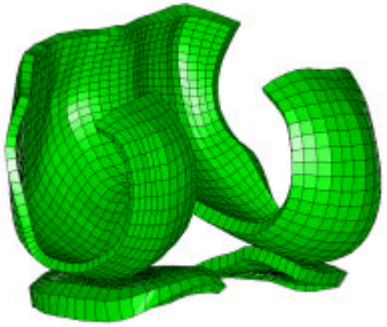
Meshed Segmented Template Approach

- Create detailed meshed, segmented templates of target structures

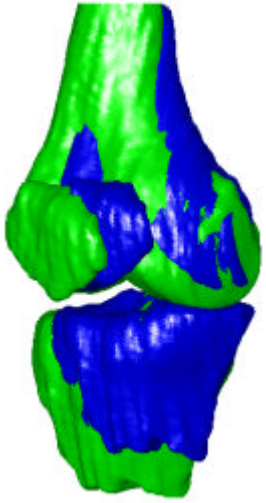


Articular Cartilage



- Produce an <u>image</u> of that template & use that image to register to the patient`s structure (thus, creating segmented, meshed model)

blue: original segmented knee
green: new knee shape after transformation



Material Database

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Main techniques to be exploited within SimBio are:

Magnetic Resonance Strain Imaging

(a combination of magnetic resonance & ultrasound)

Diffusion Tensor Imaging

(a pure magnetic resonance technique)

Literature Values

Example: ongoing work on the determination
of anisotropic mechanical properties of brain white matter

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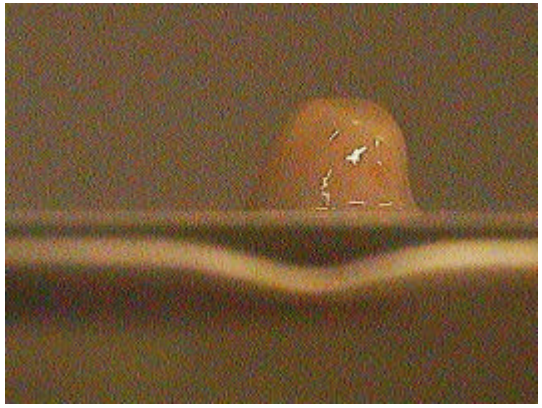
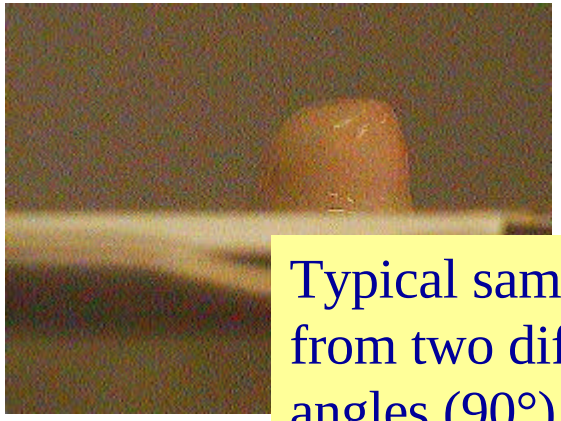
Brain samples

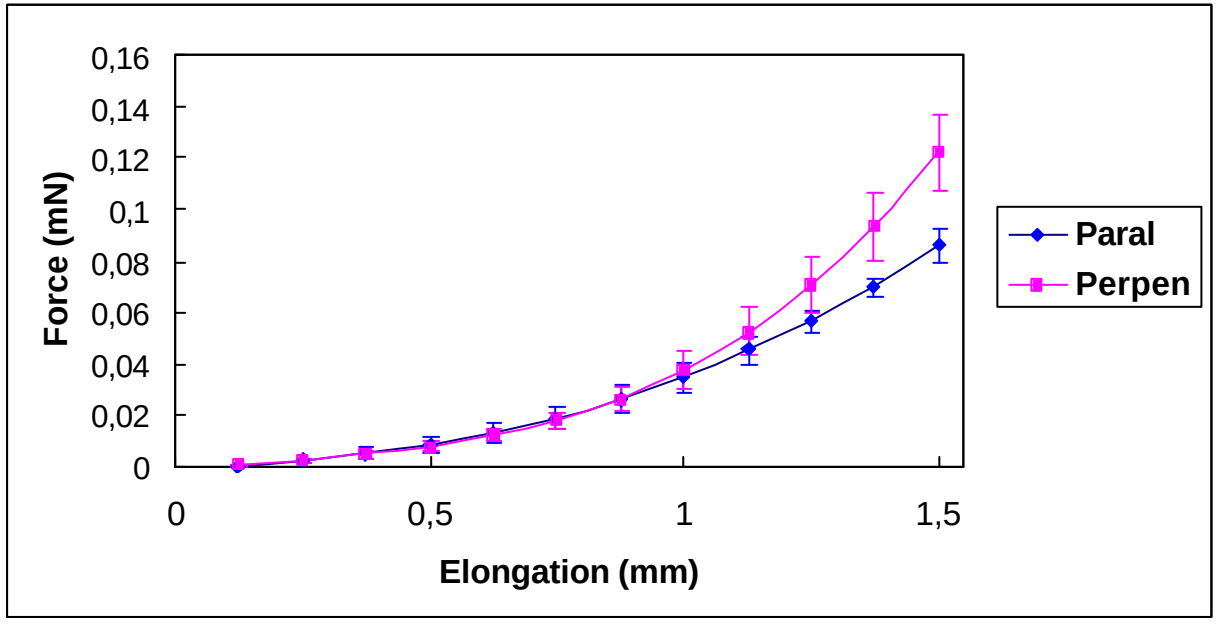
- Cylindrical samples taken from nine pig brains, using a biopsy punch : parallel and perpendicular to fibers





Typical sample shown from two different angles (90°)

Material Properties as input for subsequent modelling



Anisotropy:

- **Small deformation → no anisotropy**
- **Large deformation → pronounced anisotropy**

Numerical Solution System

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Building on Existing Codes/Software:

FE techniques

Linear static, linear dynamic, geometrically nonlinear, nonlinear material models, partitioning techniques

FE techniques

1. HeadFEM,
2. NeuroFEM,
3. PAM-SAFE,
(4. DRAMA Library)

Numerical Solvers

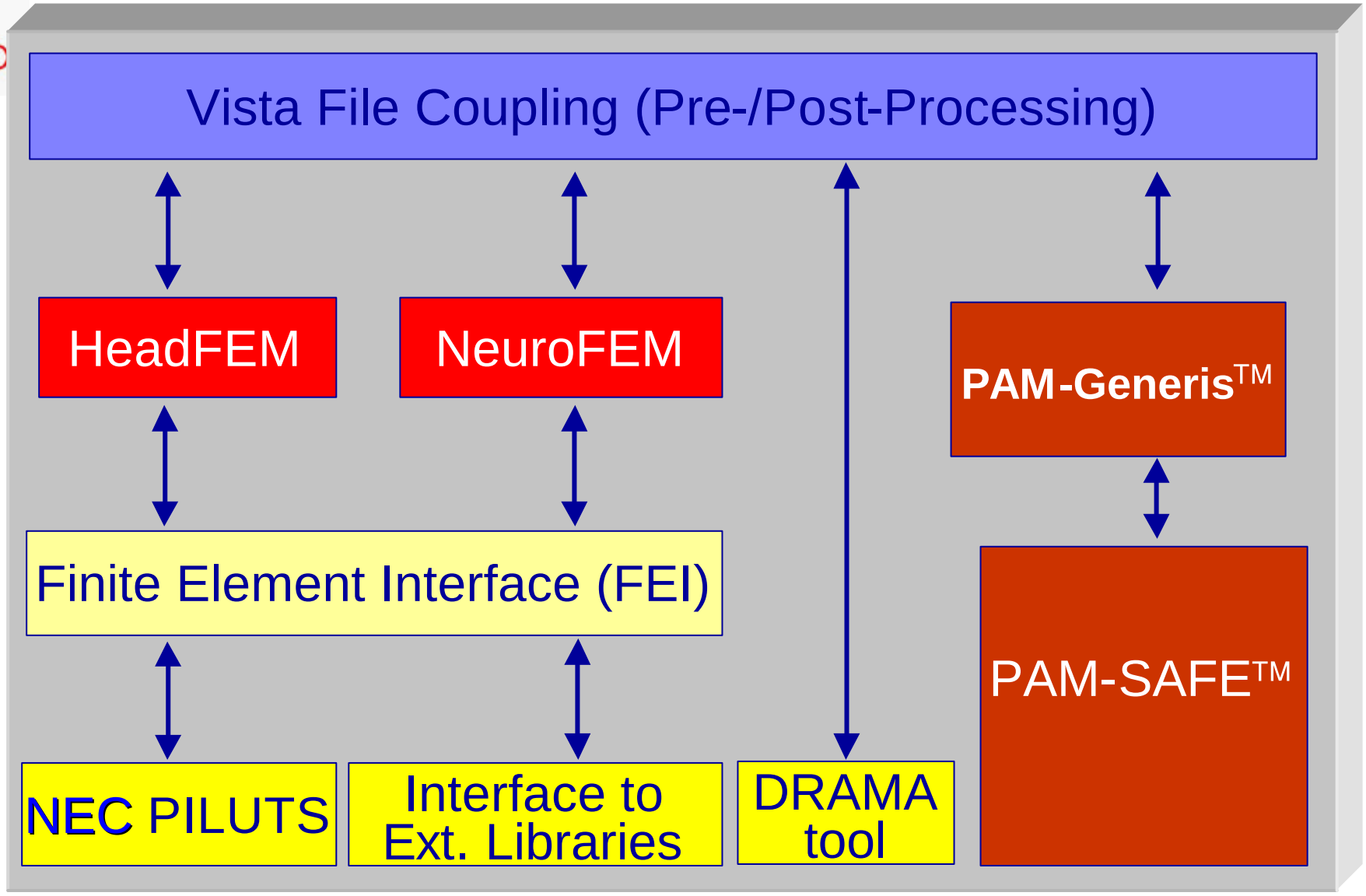
preconditioned Krylov sub-space solvers, multigrid, ...

Numerical Solvers

NEC's parallel MPI-based iterative solvers (PILUTS), FEI-interface, research AMG software from U. Linz, Austria

http://www.simbio.de

Numerical Solution System



Evaluation & Validation Applications & Related Simulation/Analysis Tools

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- Electromagnetic Source Localisation
  - Inverse Problem Toolbox
  - NeuroFEM
- Brain Mechanics Analysis from Time-series data
  - Nonlinear Registration + material modelling
- Head Mechanics for Maxillo-facial surgery
  - HeadFEM
- Knee Analysis & Prosthesis Design
  - PAM-SAFE

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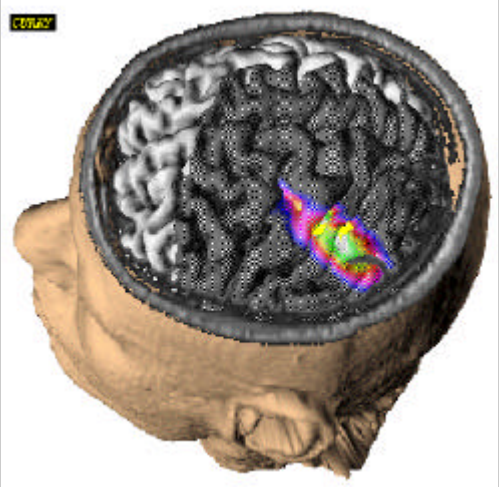
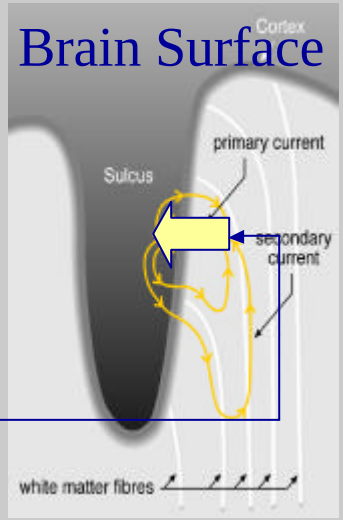
“Reminder”: Electromagnetic Source Localisation



A widespread technique to investigate the functional state of the brain is to record its electromagnetic activity by means of electroencephalography (EEG) and magnetoencephalography (MEG)



dipolar current sources in the brain

<u>Major Goal within SimBio: FE modelling</u>

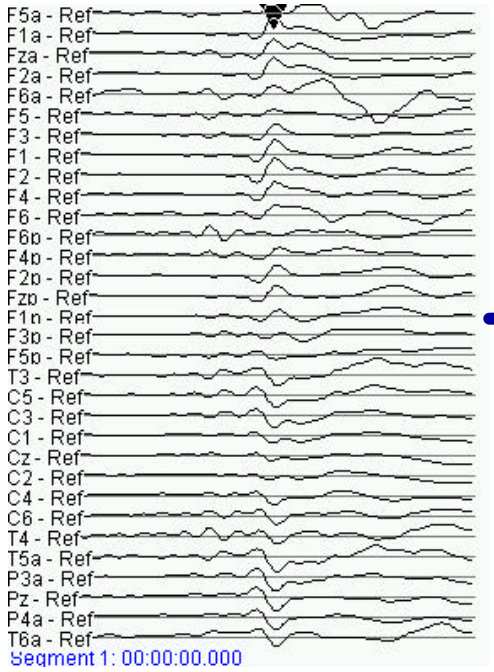
Only the Finite Element Method enables the modelling of internal brain structures and their physical properties, eg anisotropic conductivity!

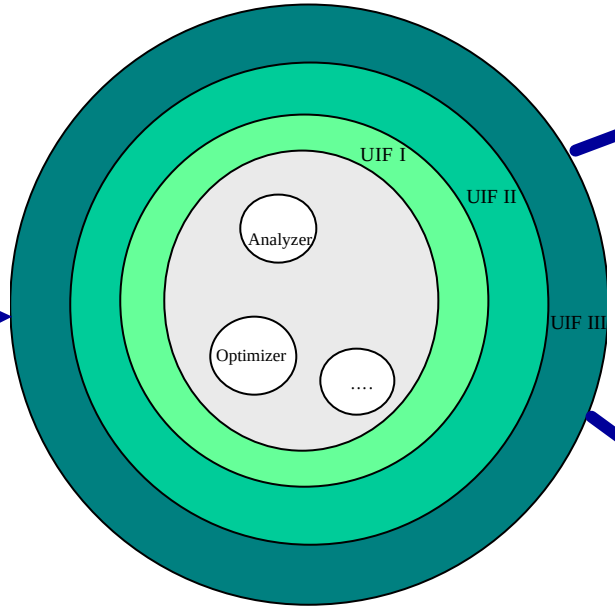
Purpose
- identify brain regions of disfunction (e.g. caused by tumor growth)
- diagnose epilepsy.

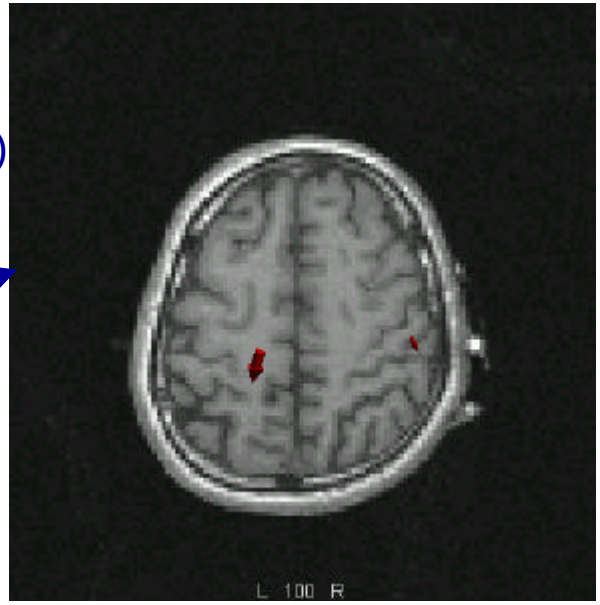
Inverse Problem Toolbox for Source Localisation

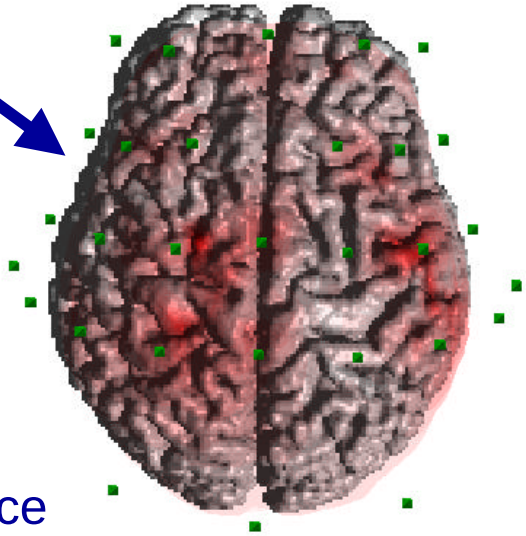
The **Inverse Toolbox** offers:

Novel software architecture for flexible combination of methods
Use of **inhomogeneous and anisotropic head models** (NeuroFEM)









Progress:

1. General structure completed
2. First set of methods implemented
3. Selection of methods and I/O via three-shell user interface
4. Strong coupling to NeuroFEM

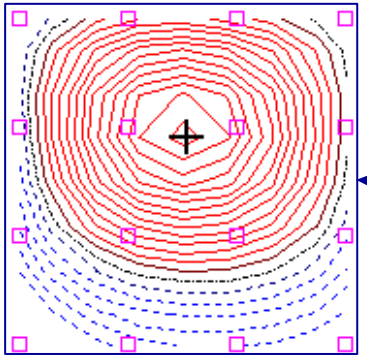
Source Localisation: Experimental Validation

Source localisation carried out using EEG & MEG measurements for 2 known cortical sources

Distance between cortical sources:

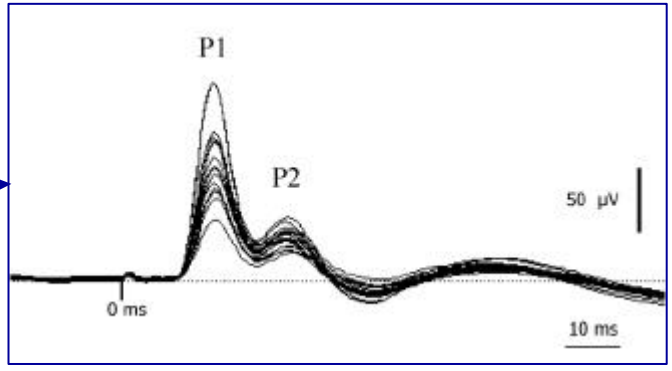
anatomical 2-3 mm

source localisation 2.5 +/- 0.5 mm



Computed Electric Field Source 1, Peak P1

Measured Electrical Signal Source 1, Peaks: P1 & P2



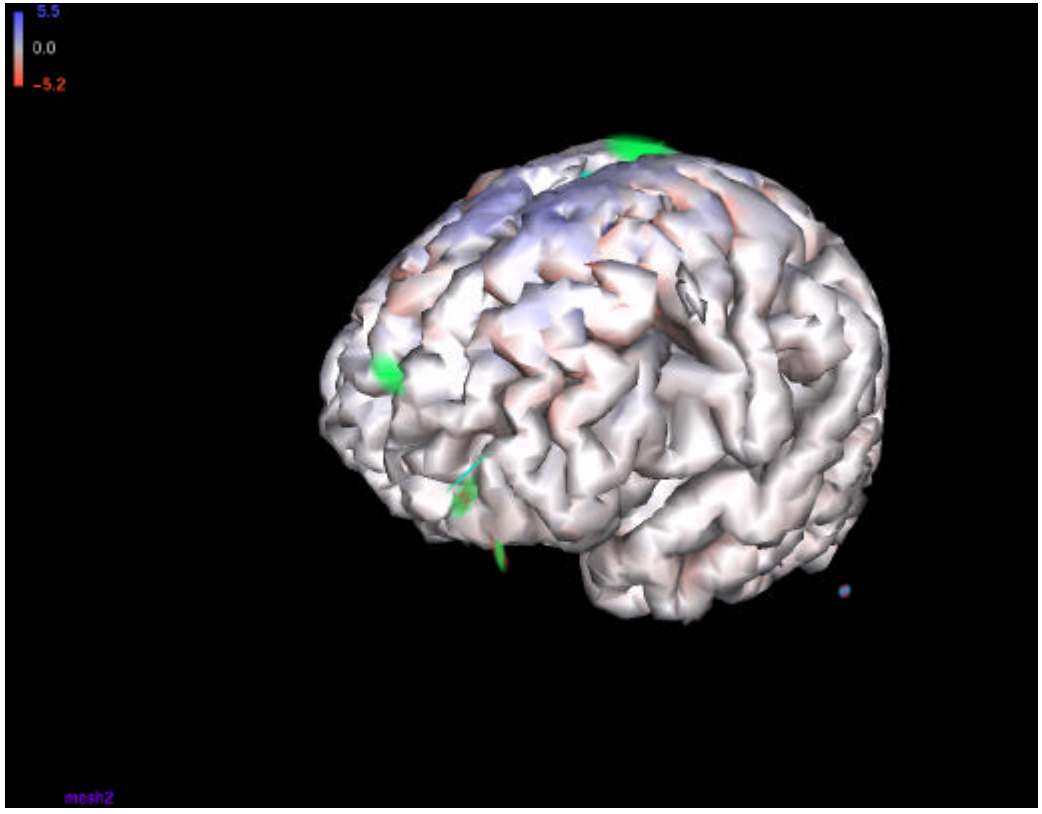
Inverse Biomechanical models:
Brain Mechanics Analysis from Time-series data

Objective: develop inverse methods for the identification of structural changes & underlying bio-mechanical forces

Method: register anatomical time-series data via (non-)linear vector field transformations. Incorporate both realistic material parameters & consistency with behaviour of deformable elastic solids

Results of ongoing study

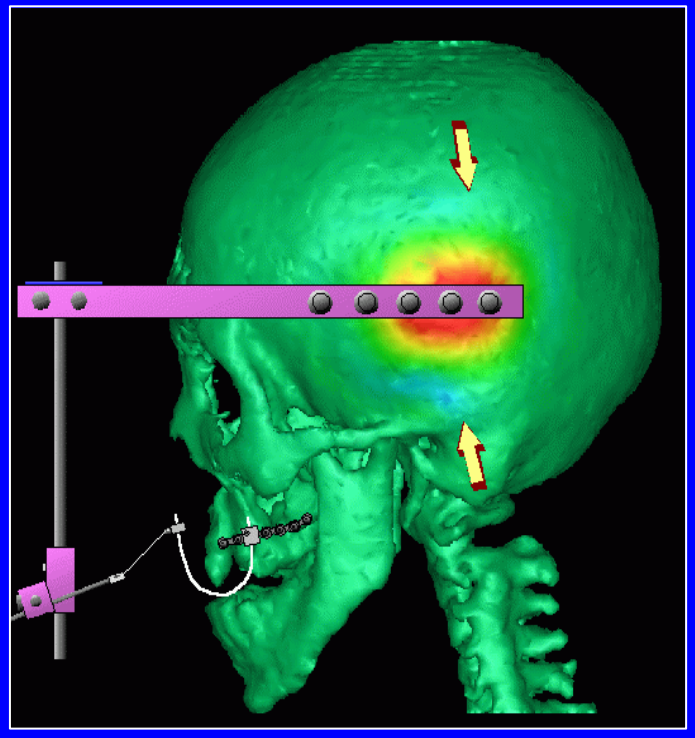
- Car-accident patient
- red & blue colouring indicate inward-outward deformation
- Critical areas highlighted in green: locations which can be related to local brain matter destruction in adjacent areas.



Skull Mechanics Simulation with HeadFEM

Dr. Dr. Hierl
Klinikum Leipzig

Static analysis results in agreement with clinical findings: peripheral outward deformation, inward at screws

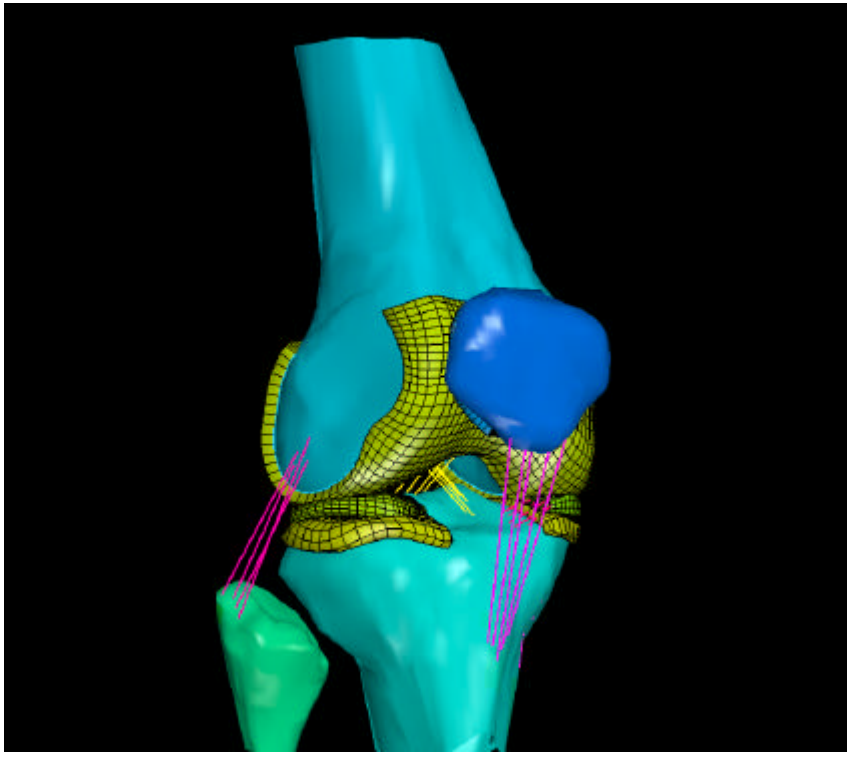


Knee Analysis & Prosthesis Design

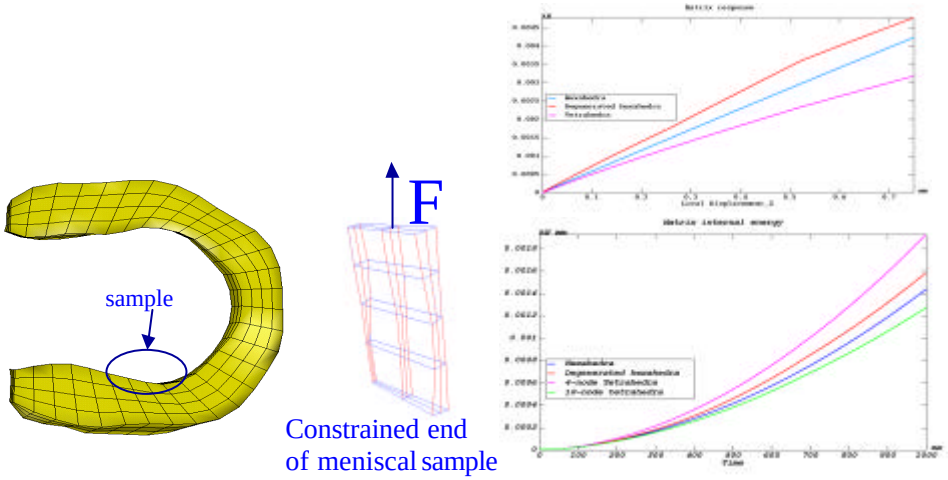
Goal

Validation and evaluation of the SimBio Environment with respect to the knee joint

Latest Full Knee Model:



Study of Finite Element modelling possibilities for the meniscus



Clinical Validation

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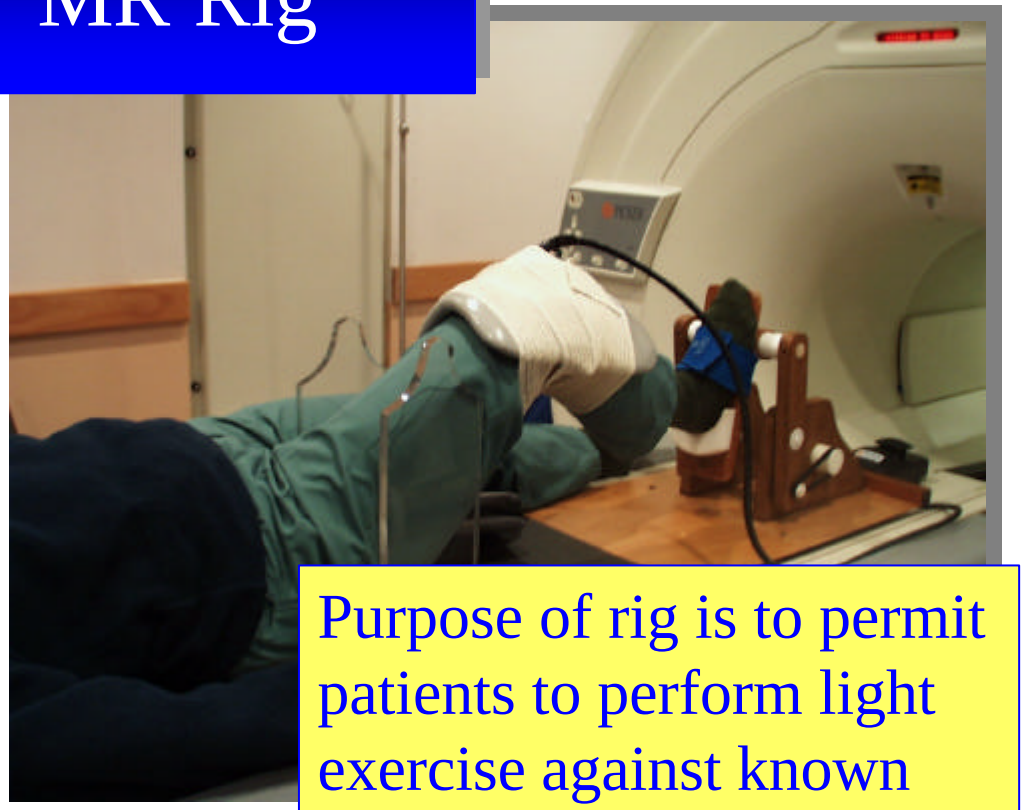
MR Rig



Purpose of rig is to permit patients to perform light exercise against known loads while knee is MR imaged

MR Sequences

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Collaborations with groups external to the SimBio Consortium

http://www.simbio.de

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Collaboration(*) with caesar

- Center of Advanced European Studies and Research, Bonn, Germany

- The caesar research group for Surgical Simulation and Navigation will investigate 3-dimensional visualisation techniques for the SimBio applications.
- Visualisation techniques will use virtual reality environments and tools.
- Collaboration will produce demonstrations of the visualisation possibilities & multi-media or video publicity material.

(*) within the project,
covered by an agreement with NEC

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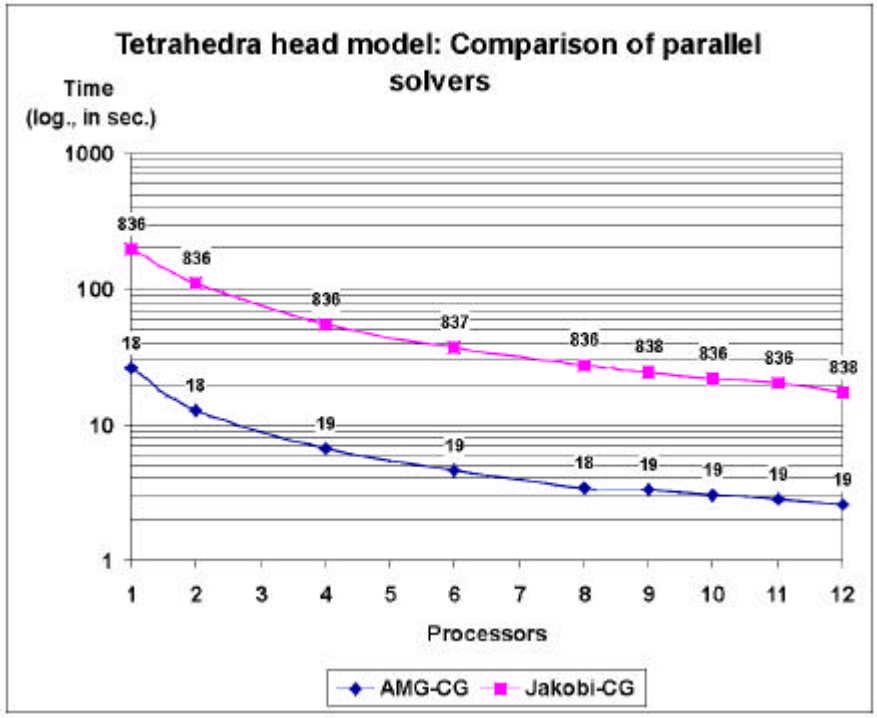
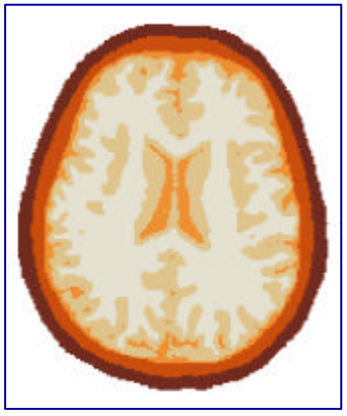
MPI collaboration with U. Linz, Austria

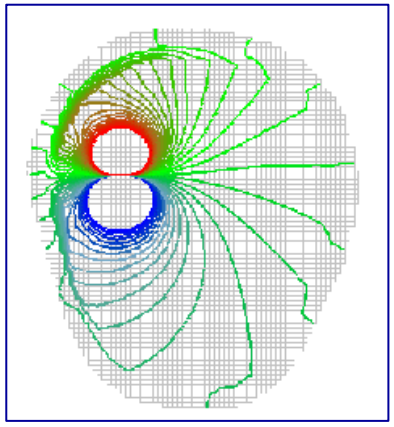
Use of the Parallel Algebraic Multigrid solver parPEBBLES within NeuroFEM

Almost optimal linear speedup.
Solution time of a few seconds!





Segmented scan data slice multimodal MR-imag.



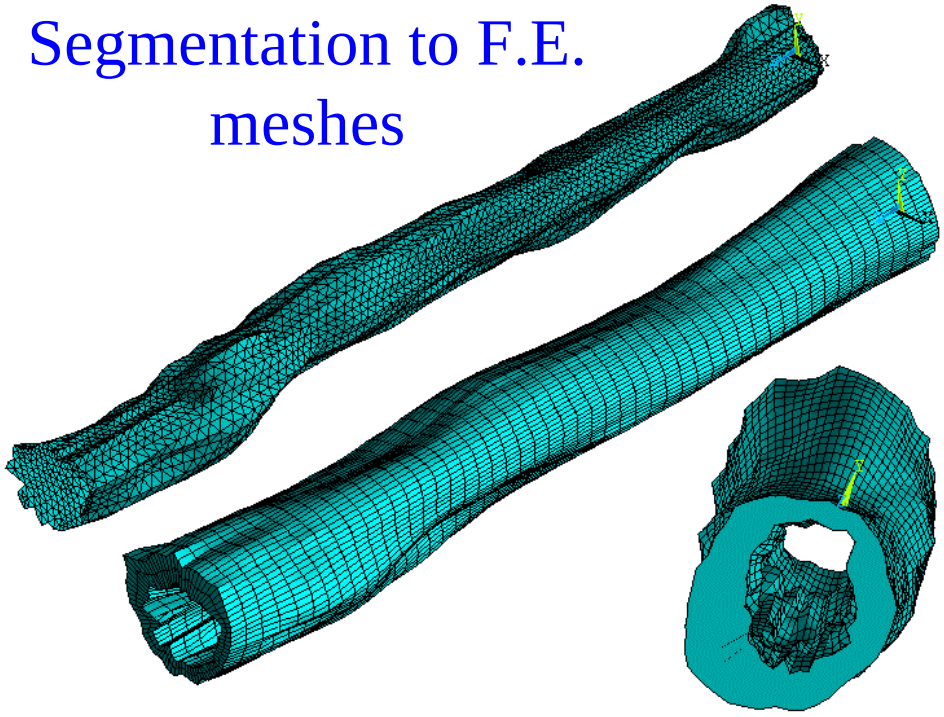
Axial isopotential lines of a NeuroFEM Solution

Use of the SimBio Image Processing Tools within the ESPRIT project BloodSim

Use of SimBio non-linear registration tool to permit a fully-3D approach to coronary vessel segmentation

Post non-linear registration of idealised cylinder

Segmentation to F.E. meshes



Fluid and solid meshes of the reconstructed pre-intervention geometry

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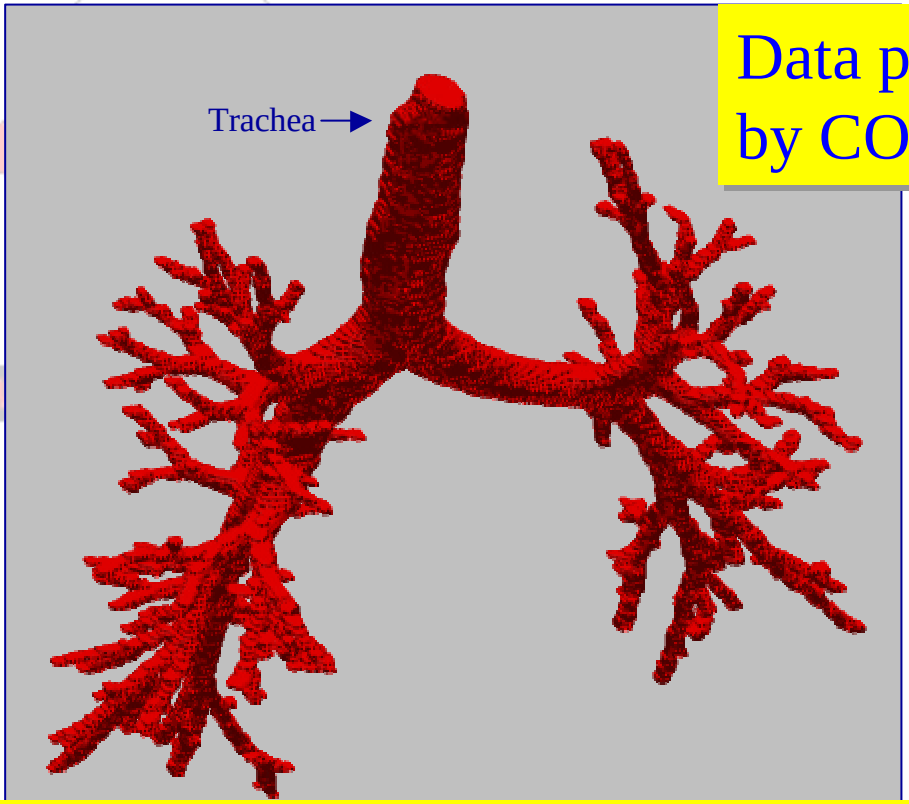
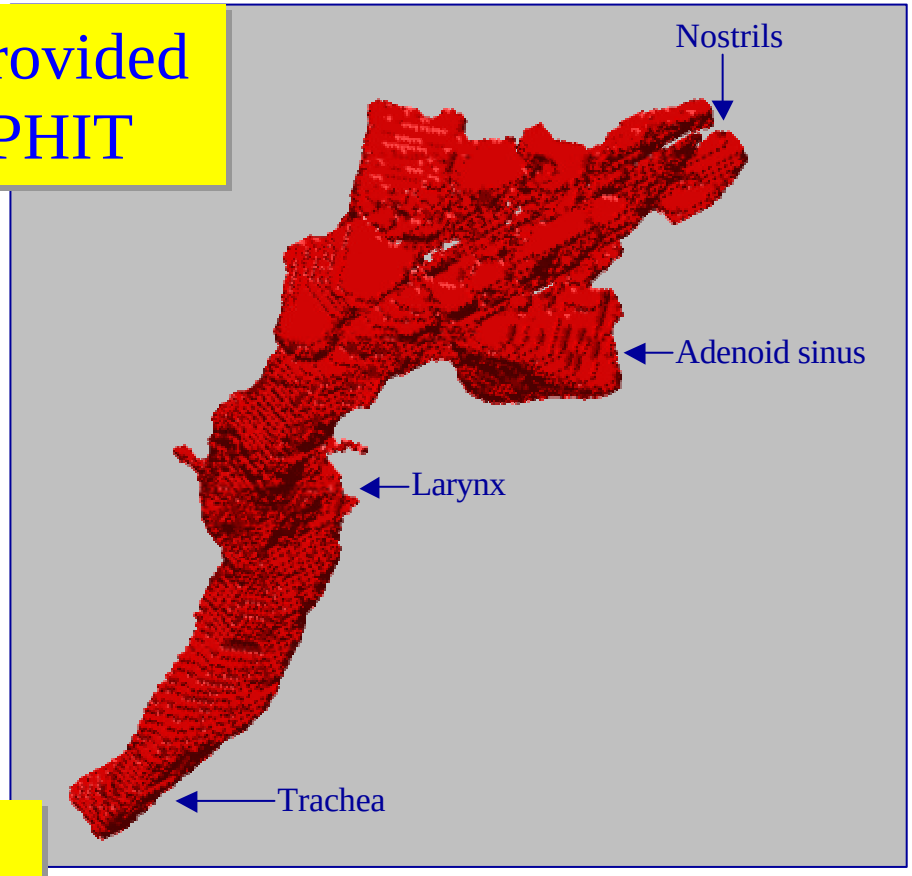
VGrid & other medical data

Lower airways down to 8th generation

Upper airways not including oral cavity

Data provided by COPHIT





1.34 million volume elements (TETs)
Time ~4mins on a single processor Origin 2000 or 800MHz P3 requiring ~1Gb Ram

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Concluding Remarks

- The SimBio environment will combine medical imaging & FEM techniques with up-to-date HPC technology
- The component-based distributed interaction will enable interaction ("networking") of technological expertise (clinical ⇔ engineering ⇔ computing)
- The evaluator applications will improve options in/for:
  - diagnosis and analysis of neurological disorders
  - design of prostheses
  - neurosurgery

For further information → **http://www.simbio.de**