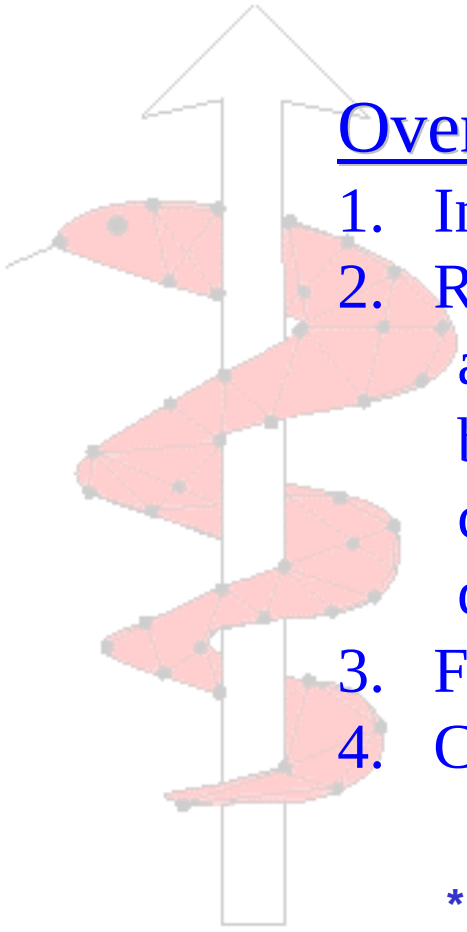
Simulation and Visualisation Technologies
"Concertation" Meeting of IST R&D Projects
13 November 2002, Brussels

Project 10378

SimBio: A generic environment for bio-numerical simulation

*G. Lonsdale**



Overview

1. Introduction to the Project
2. Review of latest developments
   a. SimBio Materials Database
   b. EM Source Localisation
   c. Head Mechanics
   d. Knee Mechanics
3. Future Directions
4. Concluding Remarks

Component developments as applied to / impacting on the SimBio applicaations

* C&C Research Laboratories, NEC Europe Ltd. http://www.ccrl-nece.de

http://www.simbio.de

Empowered by Innovation NEC

SimBio

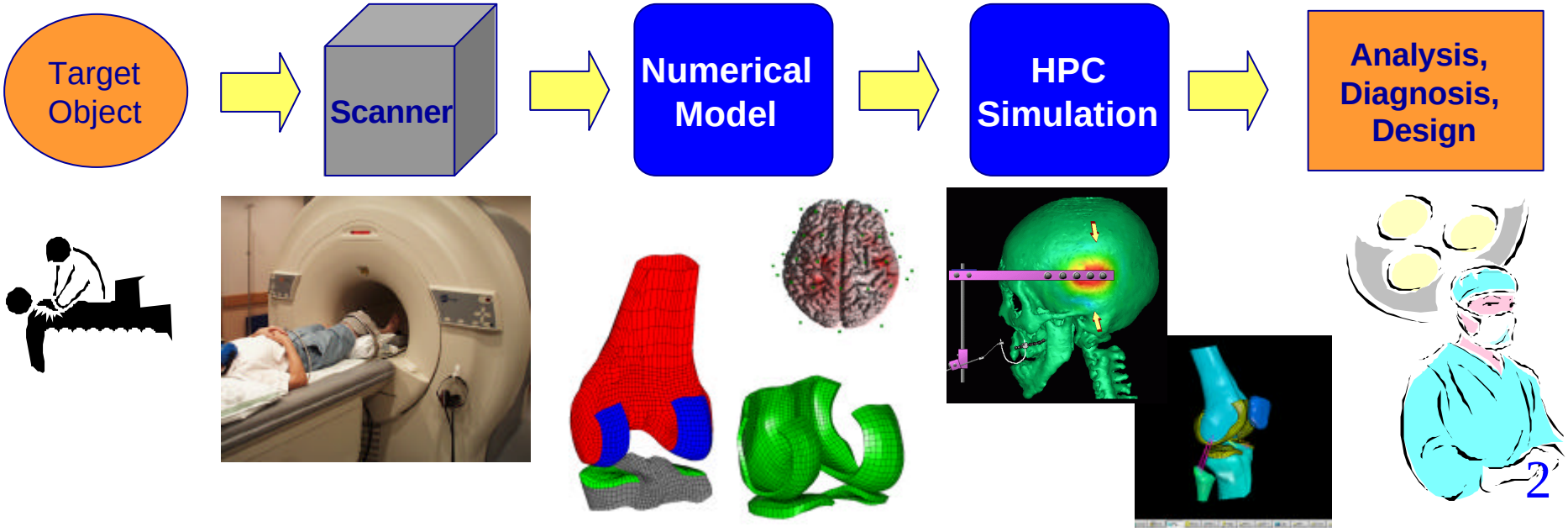
Funded by the European Commission
Duration: 1st April 2000 - 31st March 2003

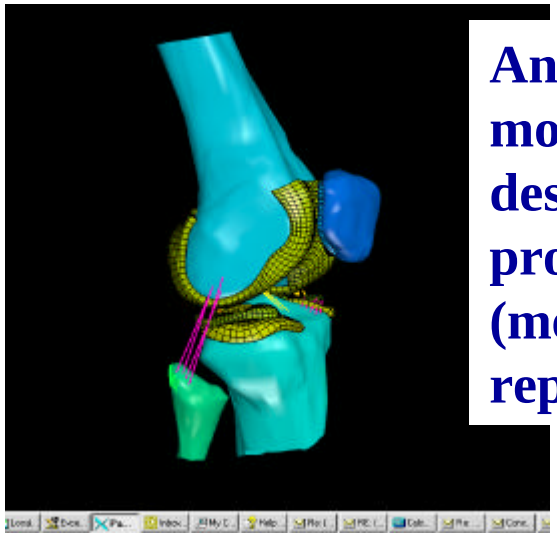
http://www.simbio.de

Extension: 30th June 2003

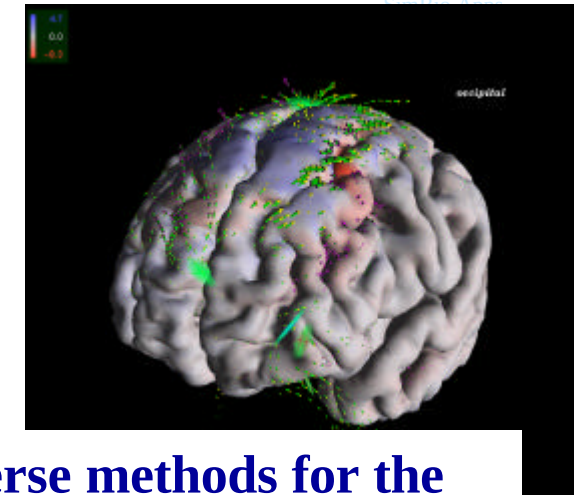
Expected Impact: **Promotion of HPC within the medical sciences.**

Innovation: **Actual scan data from patients used for modelling and simulation.**



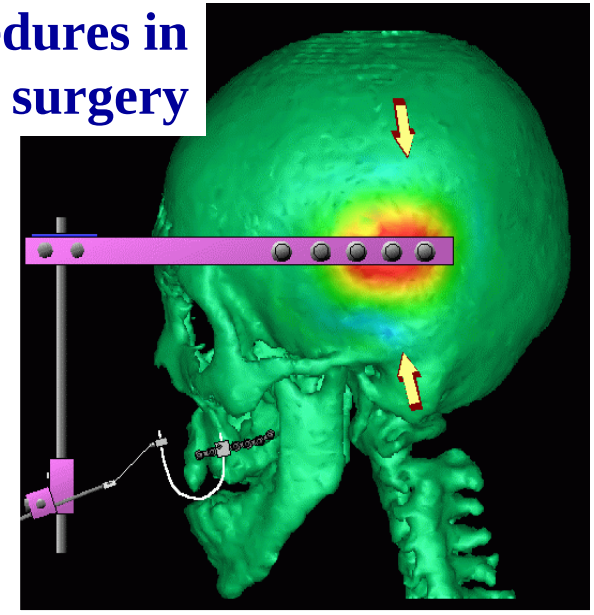


Analysis of knee movement for the design of prostheses (meniscal replacement)

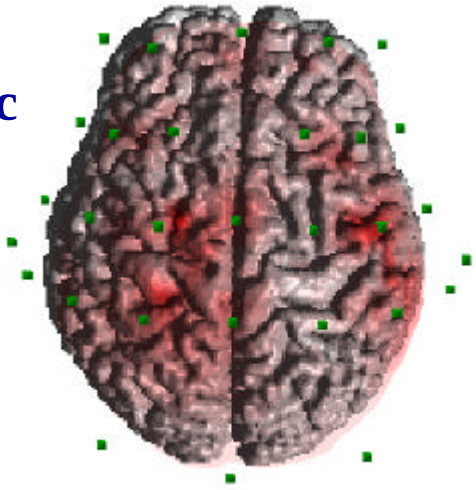


Inverse methods for the identification of structural changes & underlying bio-mechanical forces

Deformation analysis for procedures in facial surgery

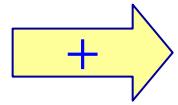


Electromagnetic source localisation for diagnosis of brain diseases



The SimBio Consortium

in Project Year 2



Participants	Country	Role
NEC Europe Ltd	UK	Co-ordinator
Max-Planck-Institute 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**

Proposal - NAS-extension
(Action Line IST-2001-VIII.1.6)

SimBio Contract Amendment No.2 -
Technical Annex Revision of 24.04.02

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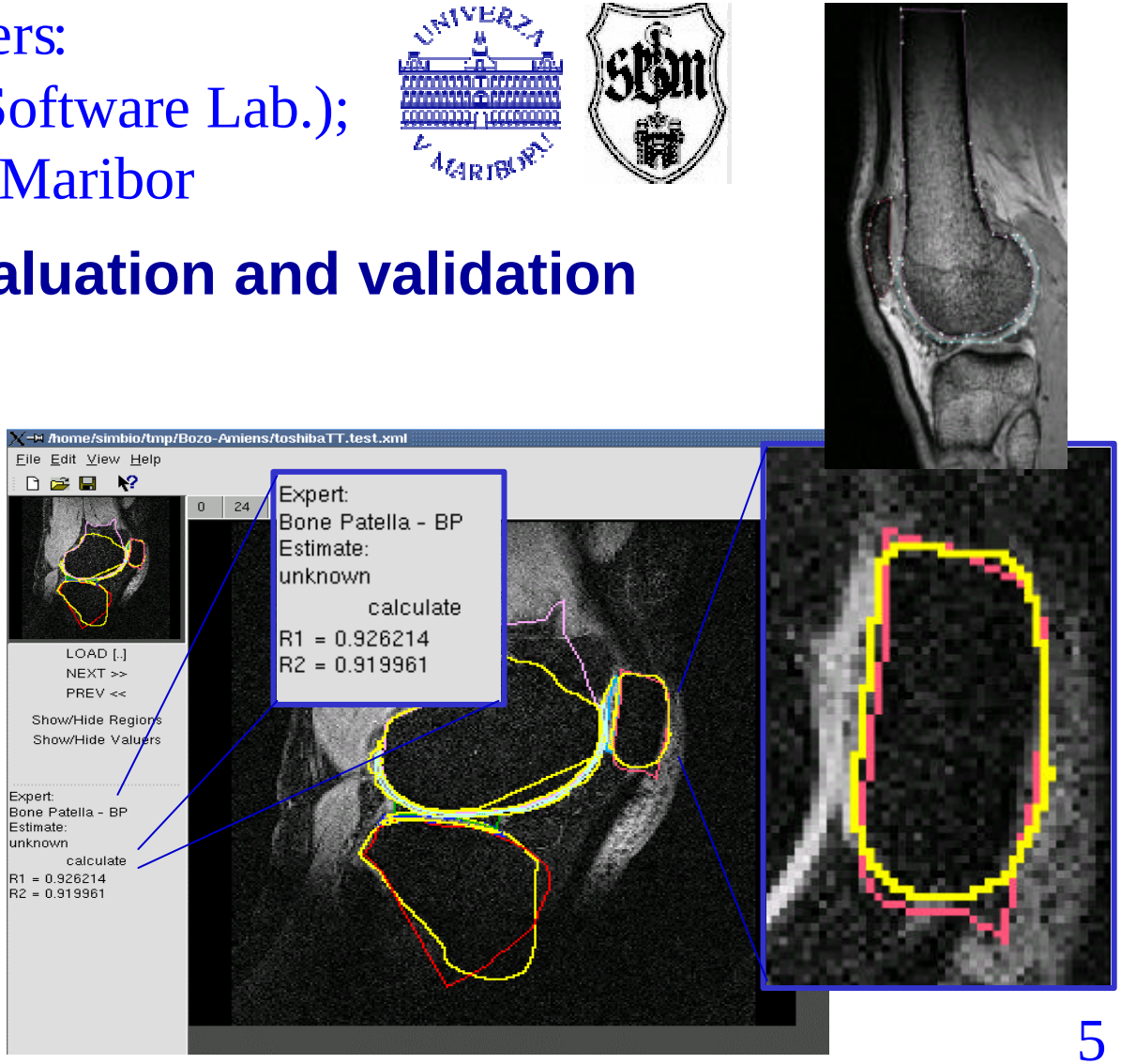
New Slovenian partners:
U. Maribor (System Software Lab.);
Teaching Hospital of Maribor

Site-independent evaluation and validation

Recent/Ongoing work:

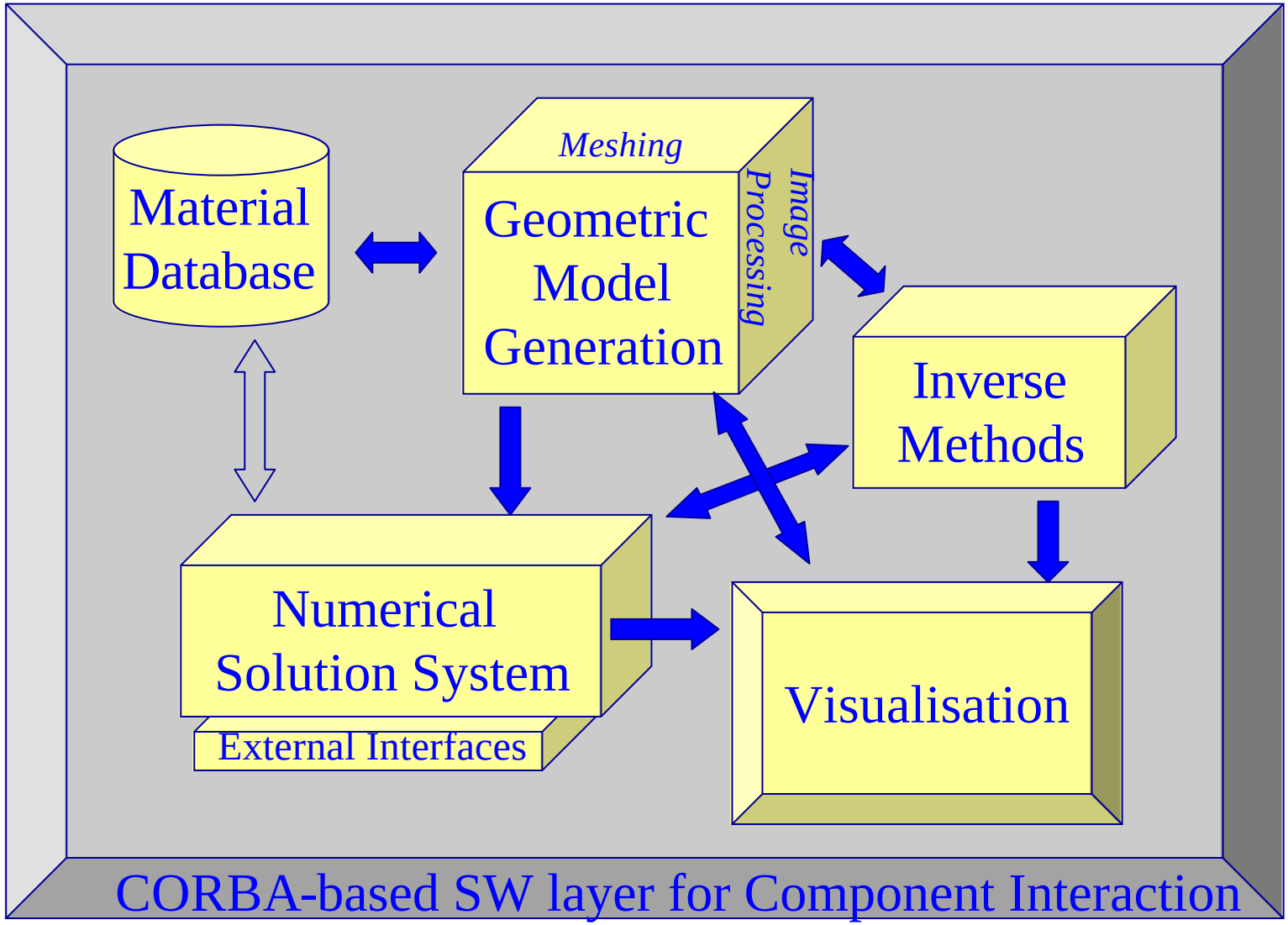
Image Segmentation Tool
- **simplify manual segmentation for evaluation of the SimBio Tools**

Image processing Verification Tool
- **auxiliary tool for analysis of segmentation results**



http://www.simbio.de

SimBio Environment Components



SimBio: Distributed Computing

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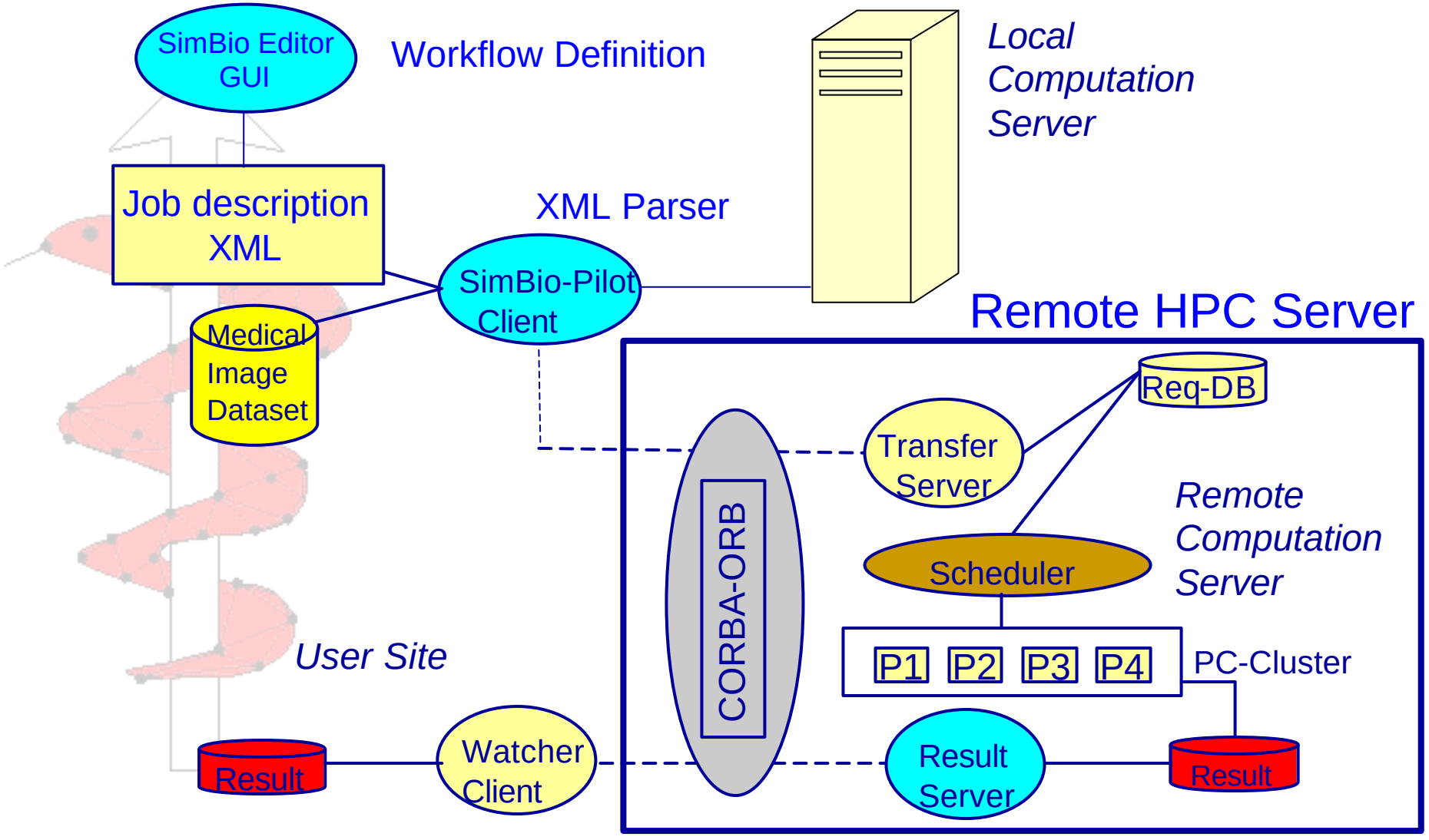

Visualisation

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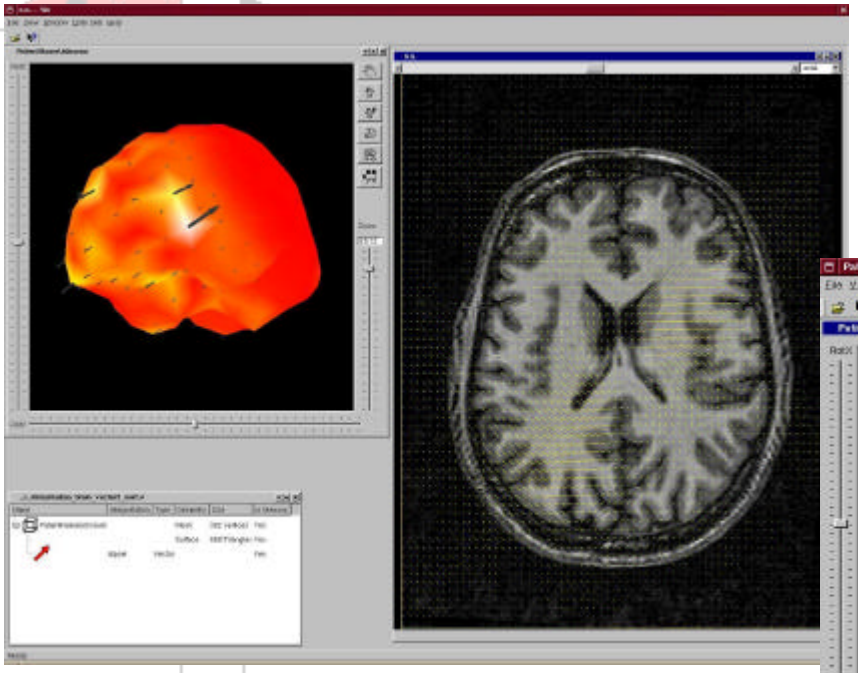
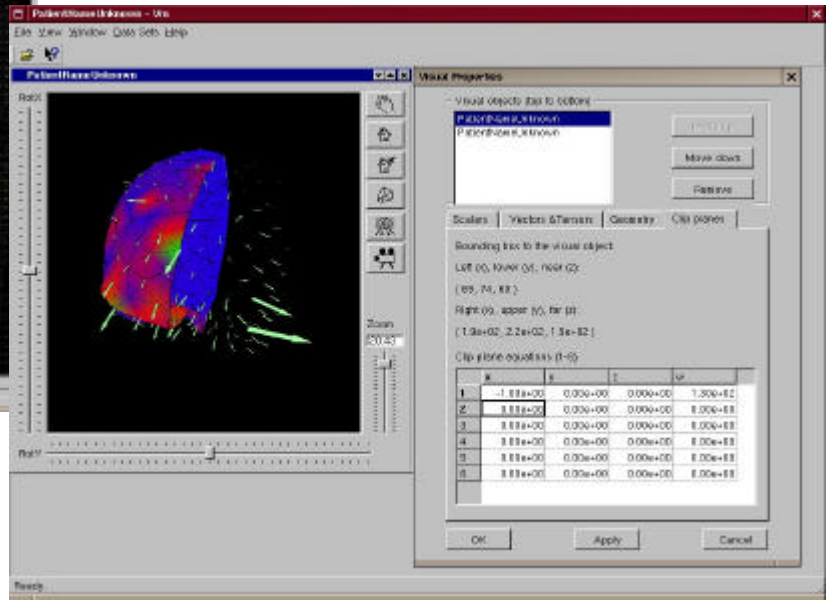
VM Tool
(developed in SimBio Workpackage 5)
- further examples shown later

Collaboration with caesar:
SimBio extensions to the Julius Tool

SimBio relevant Modules

- Vista Import
- Phantom Support
- Flythrough Generator
- Stereo View





http://www.simbio.de

caesar

Flythrough Results

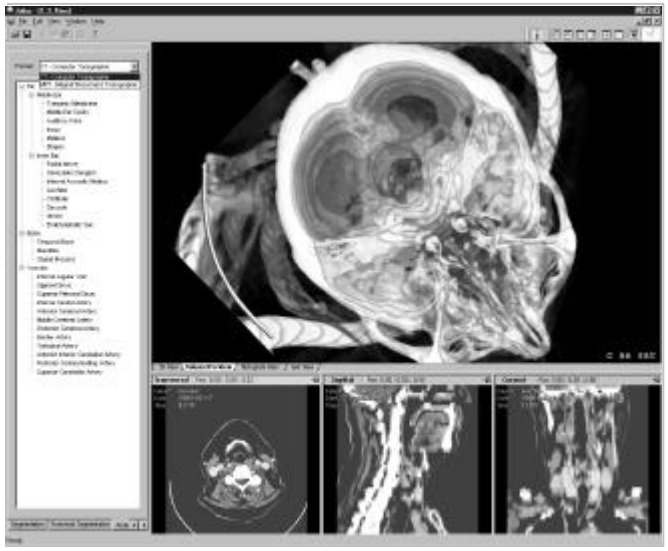
SimBio

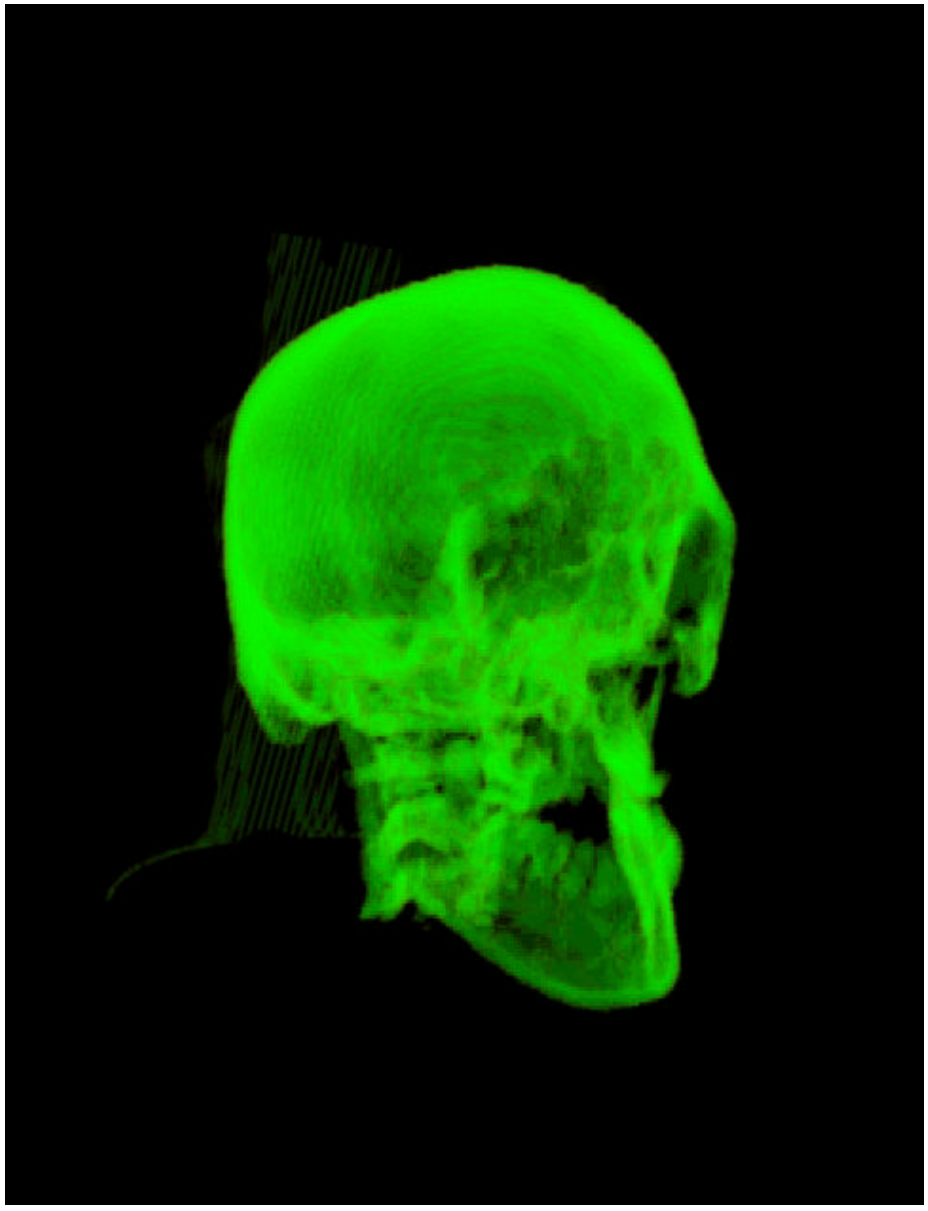
Julius & Julius Light

Available at

www.julius.caesar.de

Versions for Irix, Linux, Windows2000 and WindowsNT





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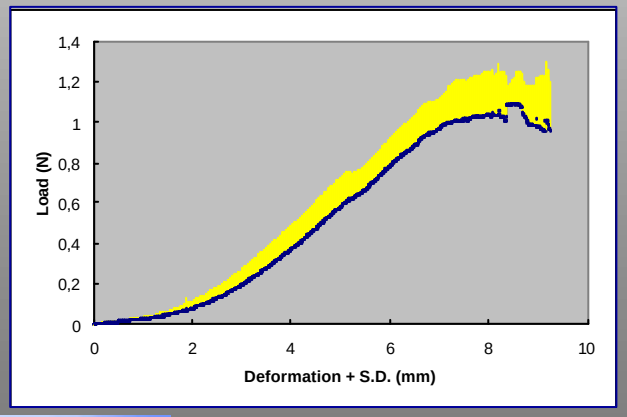
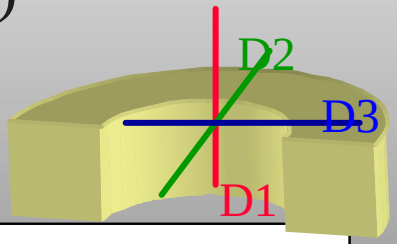
SimBio Materials Database

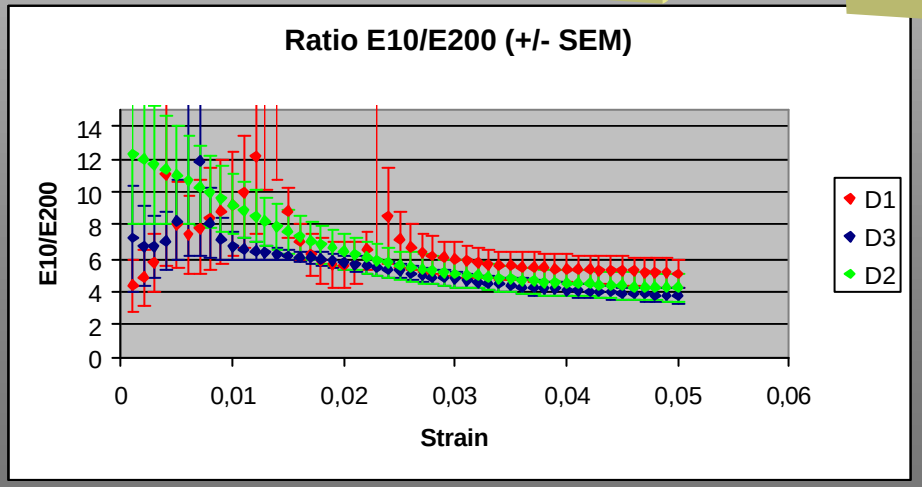
- MS-Access 2000
- SimBio requirements :
  - Classical : single/multiple parameters
  - Curves ←→ raw data
- Source :
  WP2 Experiments + literature (digitized curves)

Brain tissue : *pia mater*



Meniscus : E = f(v)





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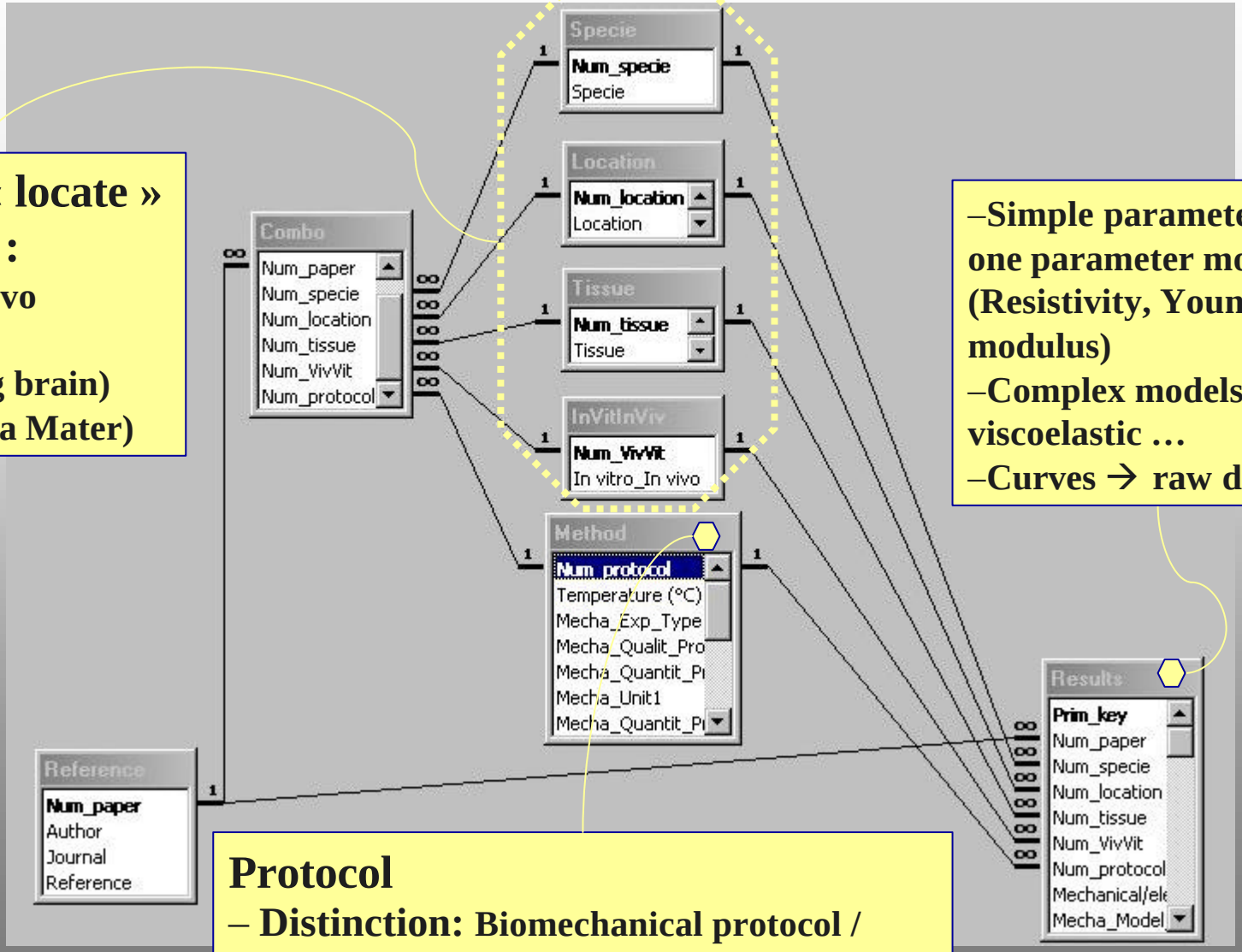
SimBio Materials Database

Tables to « locate » the results :

- **In vitro/in vivo**
- **Species**
- **Location (eg brain)**
- **Tissue (eg Pia Mater)**



–Simple parameters = one parameter model (Resistivity, Young's modulus)
–Complex models : viscoelastic …
–Curves → raw data

Protocol
– Distinction: Biomechanical protocol / Bioelectrical protocol
– Anisotropy : which direction ?
In general related to fibers (collagen, axon …)

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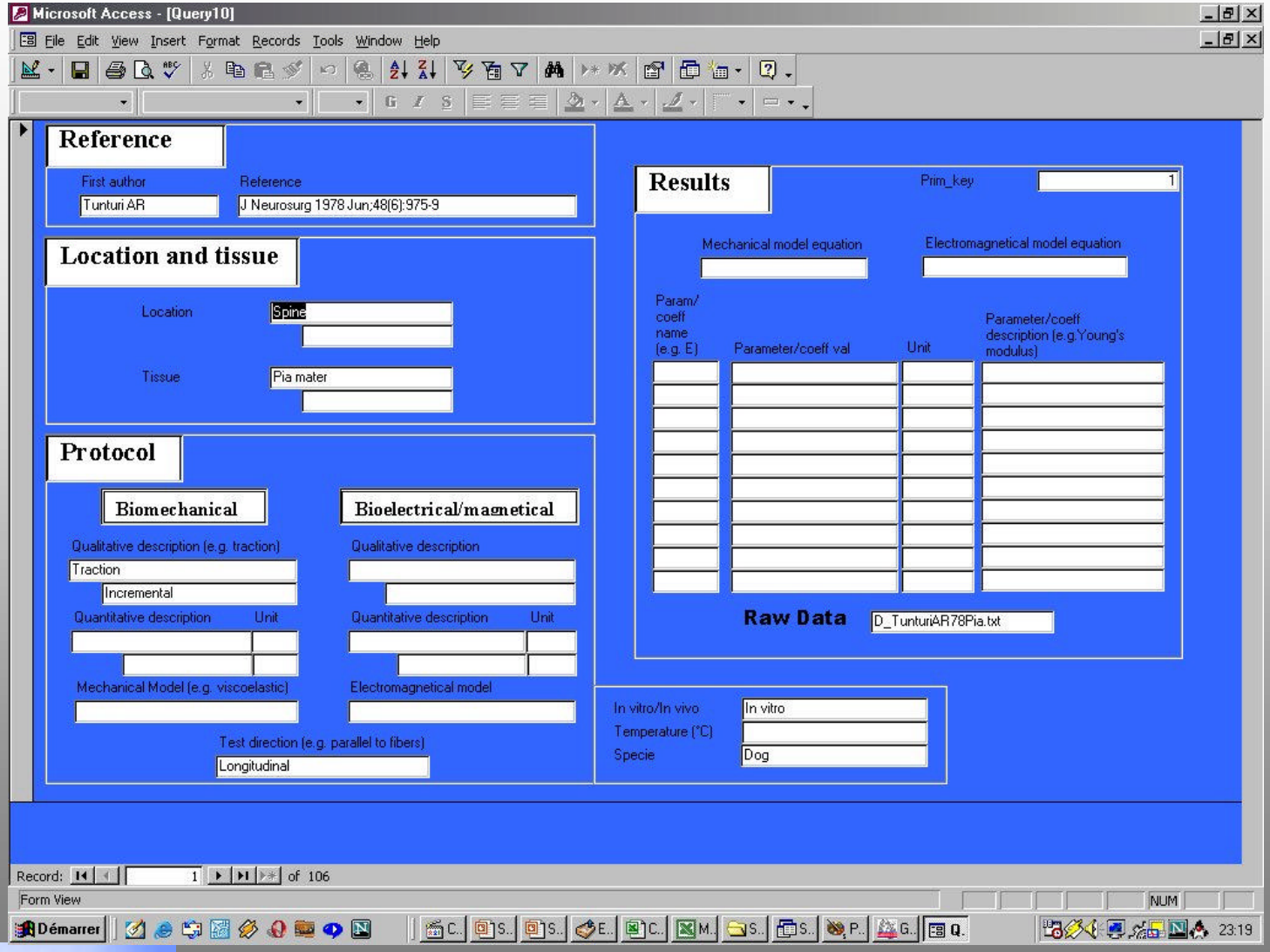
SimBio Materials Database



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.. next steps: internet access

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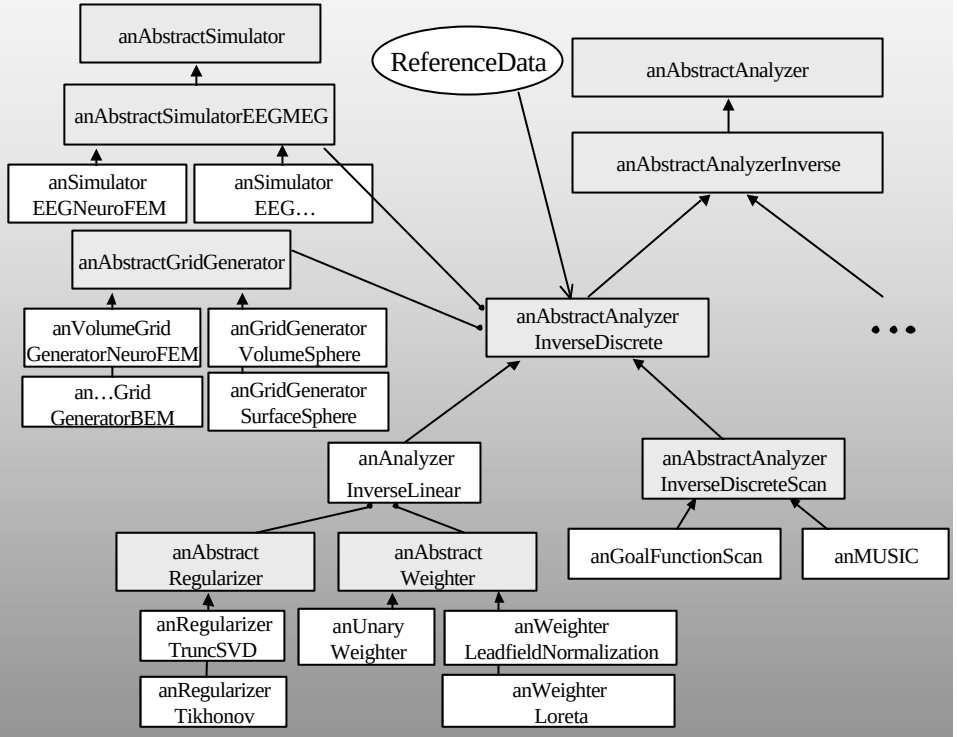
Inverse toolbox

- **Core of the inverse toolbox**

  Concept of abstract class interfaces:

  Flexible, modular, outside algorithm are easy to adapt



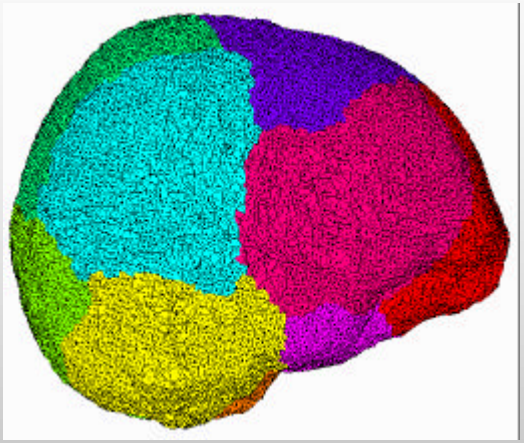
- **Sensitivity analysis software framework**

  Concept of abstract class interfaces:

  Flexible selection of simulators, inverse procedures,…:

  Systematic investigation of the sensitivity of inverse results towards forward model errors

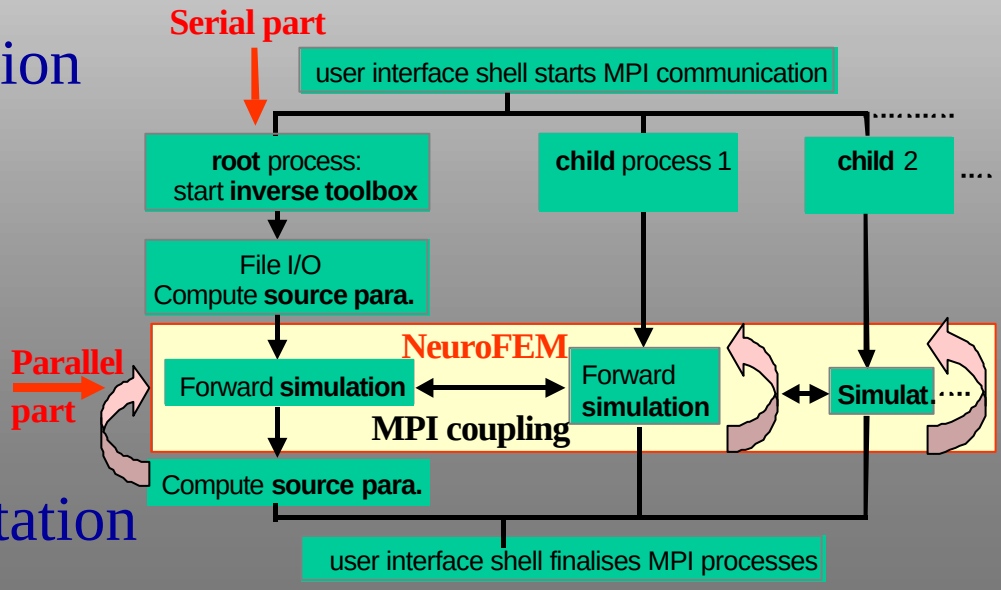
Coupling of inverse toolbox to NeuroFEM



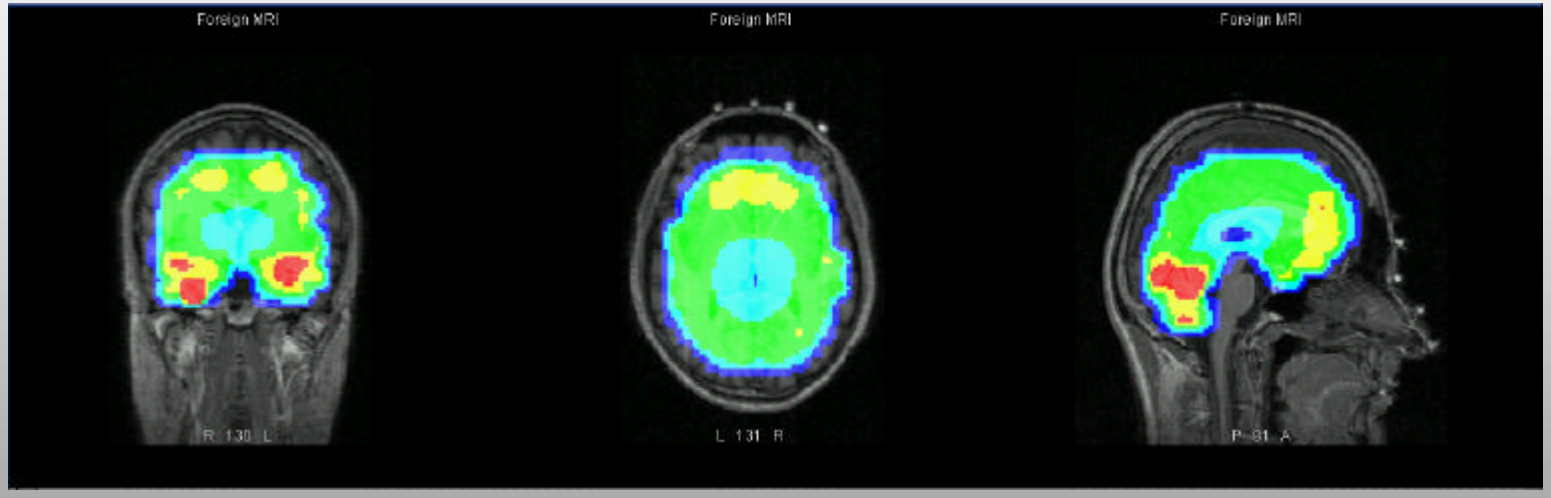
- **Serial and parallel NeuroFEM:**
  - •parallel PILUTS solver
  - •parallel AMG solver (Pebbles)

- **Loose (File) coupling:**
  Pre computed forward solution (leadfield matrix)

- **Close coupling:**
  Serial inverse toolbox can iteratively call parallel forward or leadfield computation



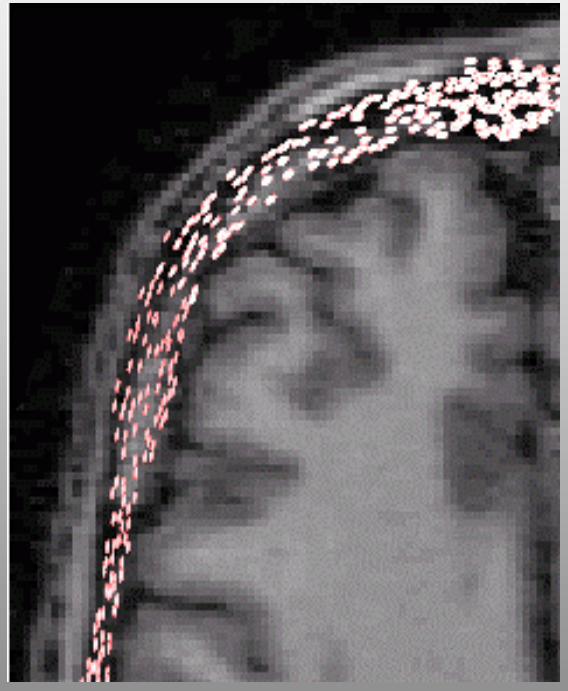
Sensitivity Analysis (BIOMAG 2002, Jena)

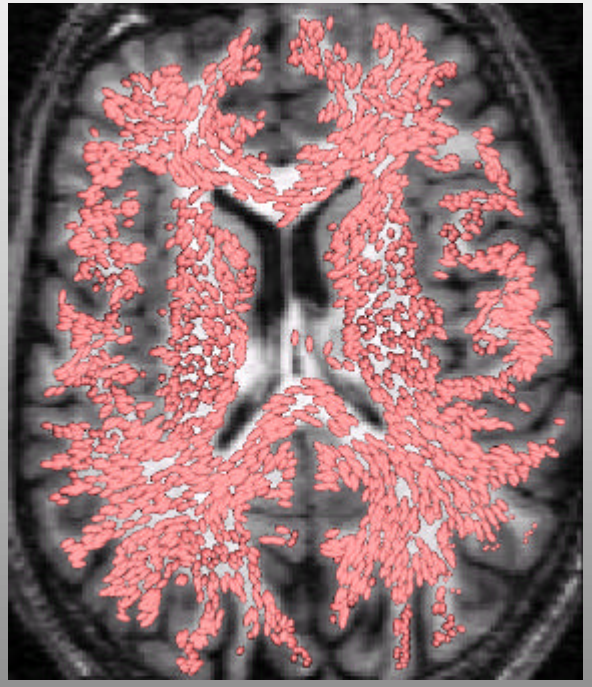


Dipole localization displacement: < 5mm < 10 mm < 15 mm < 20 mm > 20 mm

Sensitivity of inverse source reconstruction results towards forward model inaccuracies: Application of a universal sensitivity analysis software framework on different tissue conductivity ratios. Dümpelmann M., Knösche T.R., Anwander A., Wolters C.

Sensitivity Analysis (BIOMAG 2002, Jena)



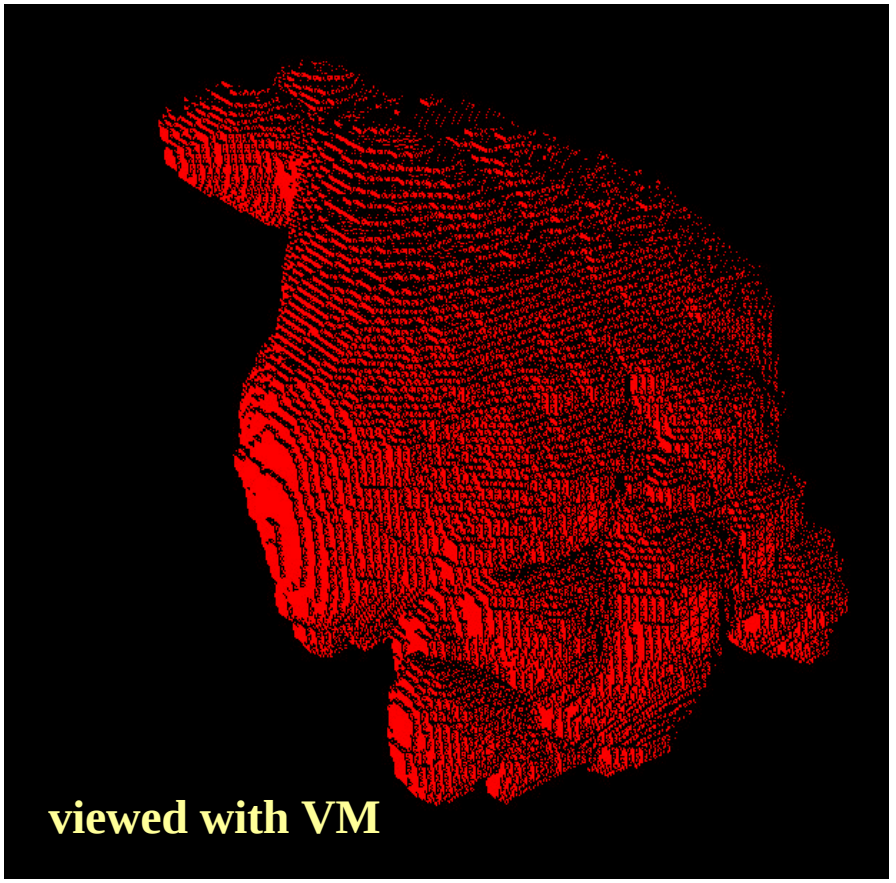


Young investigators award:

Influence of realistic skull and white matter anisotropy on the inverse problem in EEG/MEG-source localization. Anwander A., Wolters C., Dümpelmann M., Knösche T.R. .

Grid generation (FEM)

- grid generation with Vgrid -cortex only
- 172 812 vertices
- 746 060 tetrahedra



Diffusion Tensor Scan

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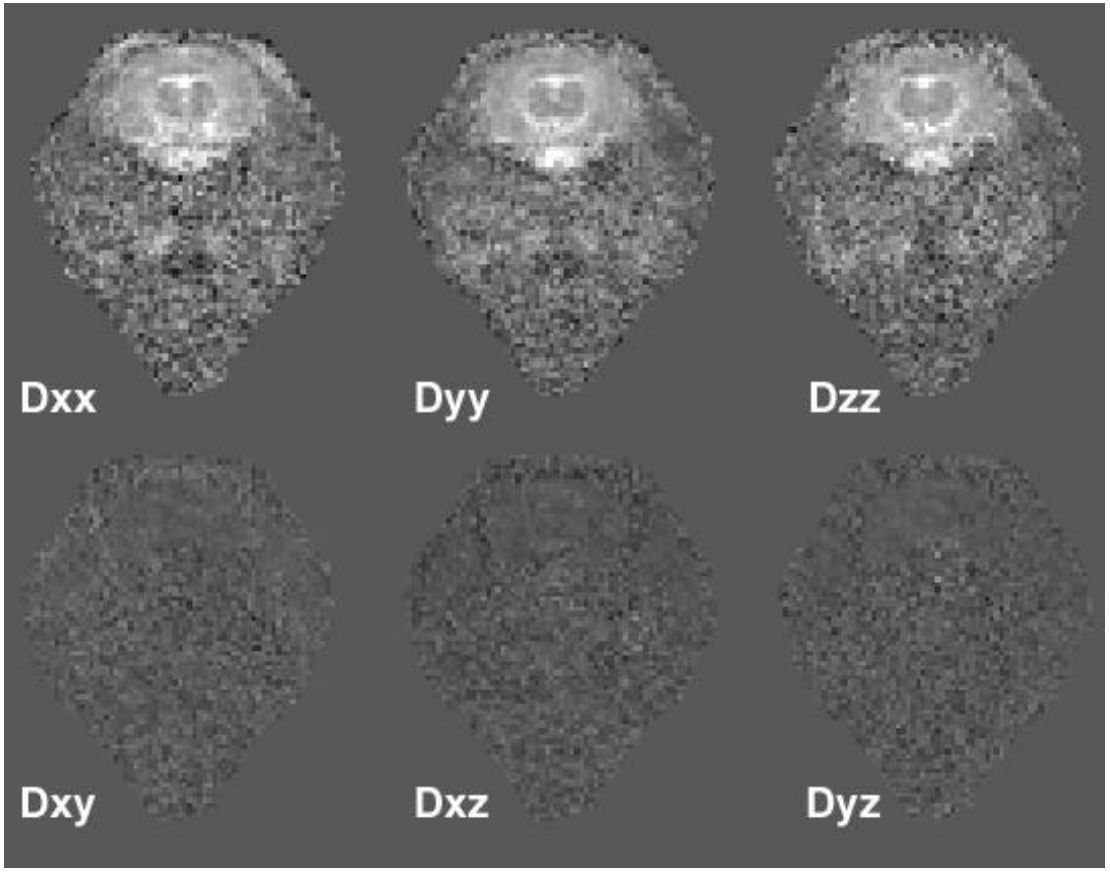
- first DTI scans of rabbit head/brain performed (in-vivo)
- improve accuracy by taking into account imaging gradients
- use of an optimal DTI-acquisition scheme (icosahedron)
- using anisotropy information in FEM model



Biomagnetisches Zentrum Jena

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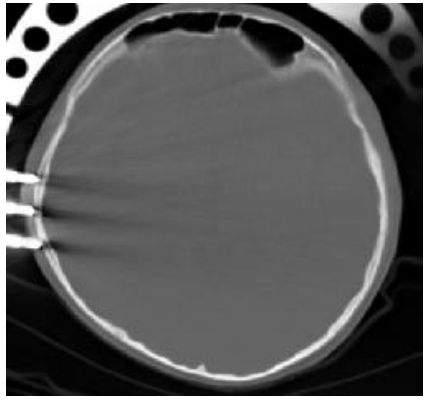
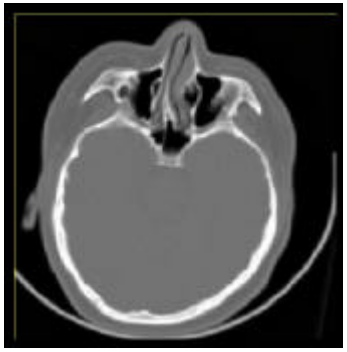
Maxillo-facial surgery

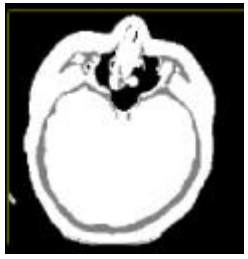


Pre- and post surgery

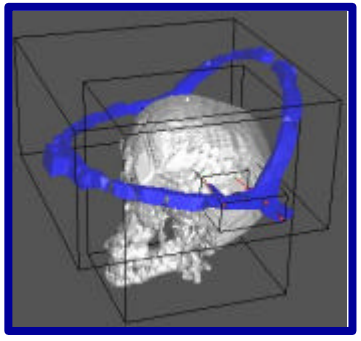
Courtesy Dr. Dr. Th. Hierl, Clinic for Facial Surgery, University Clinic Leipzig.

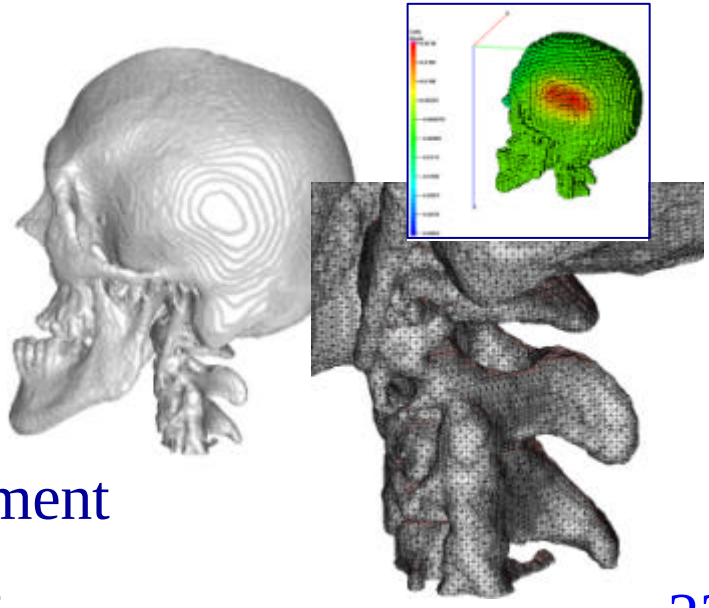


CT image(s)



Identification of sub-structures





Finite Element Modelling

VGrid

Results - Improved Surface Smoothing

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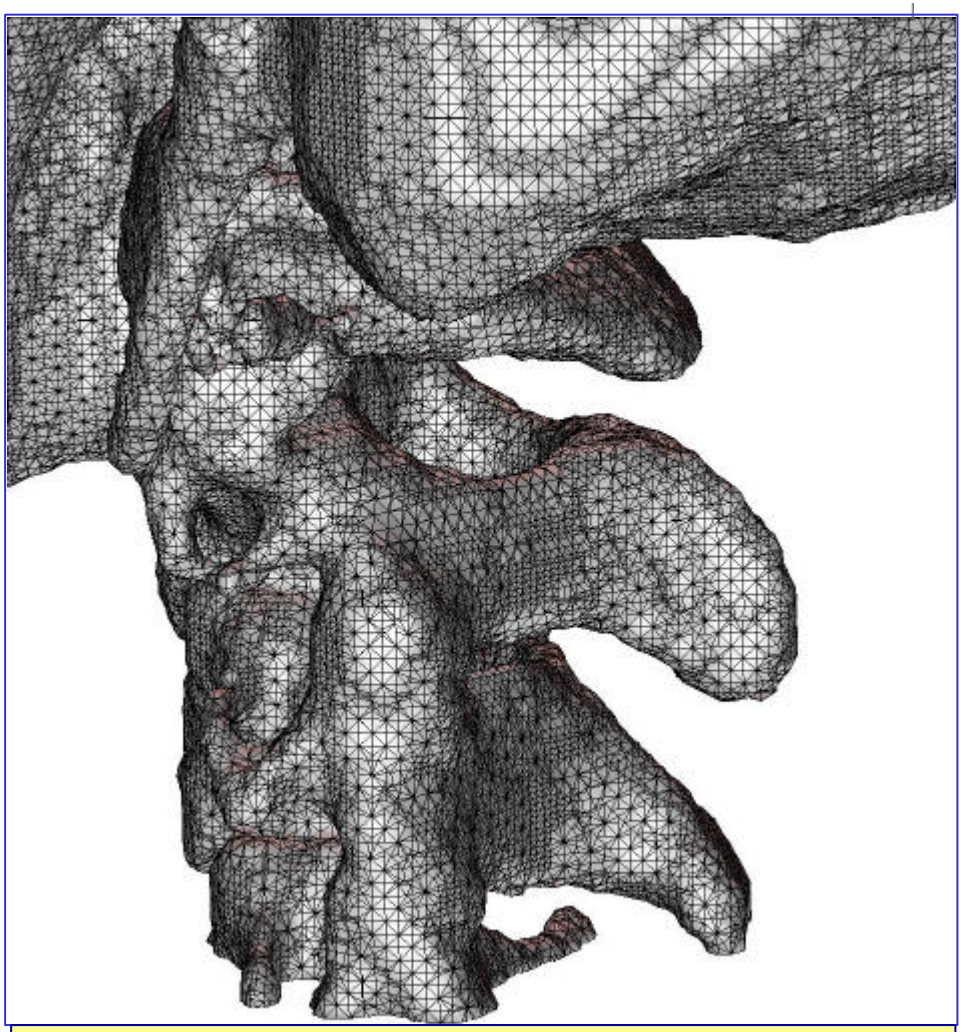
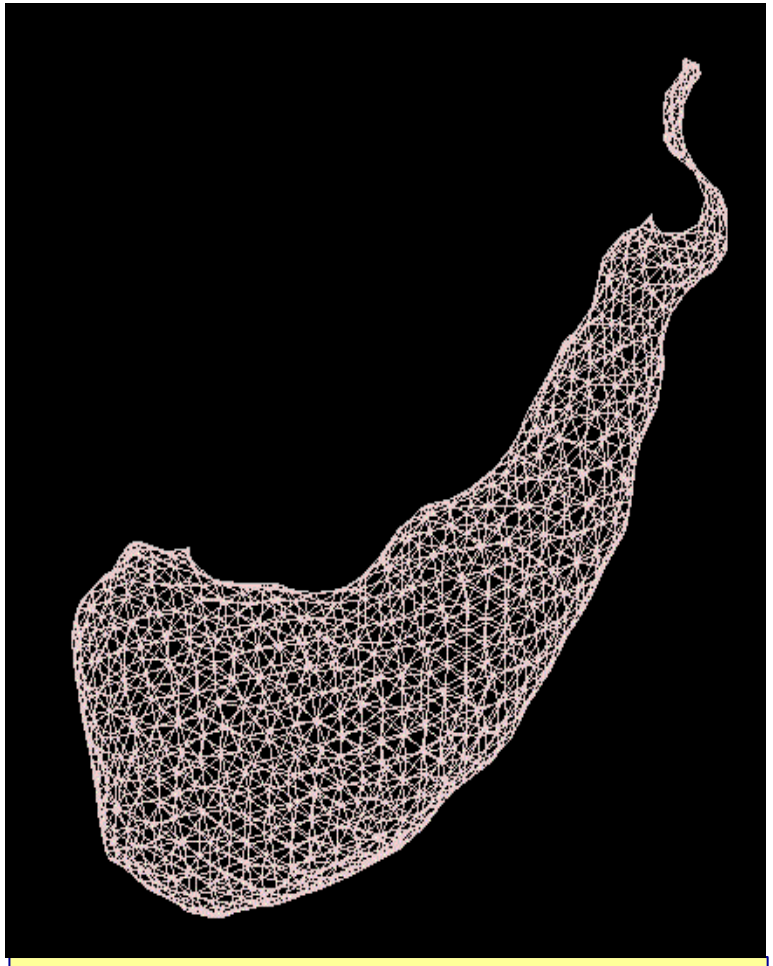


Tetrahedral Skull Mesh



Neuroanatomical Structure (Surface Mesh)

Semi-Automatic setting of boundary conditions

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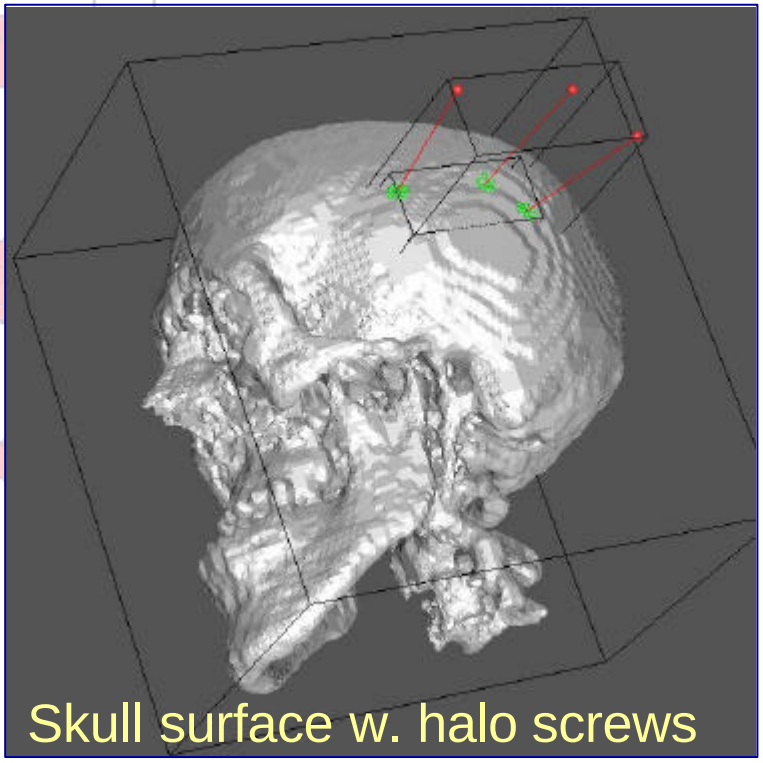
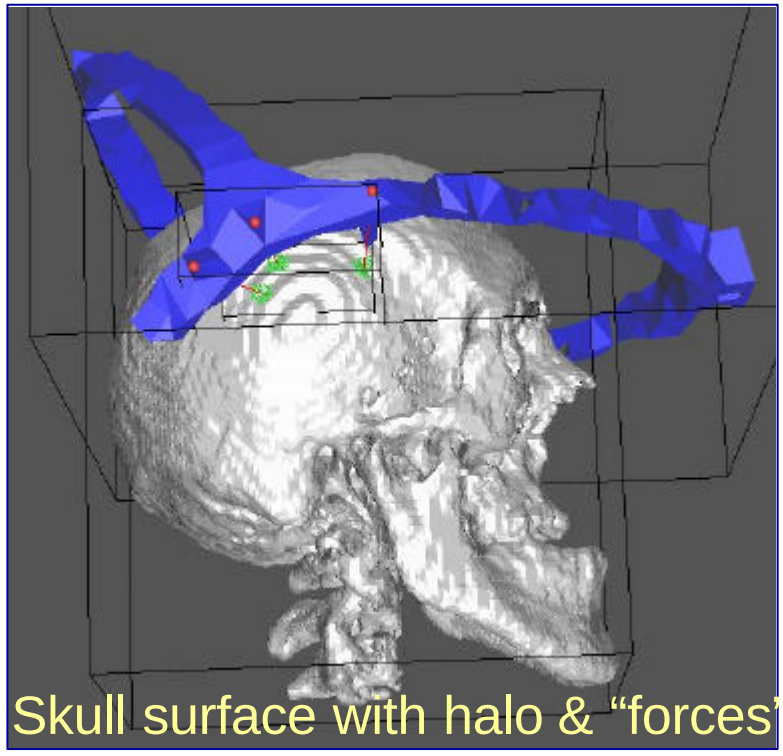
1) **Filtering: connected mesh components.**
2) **Halo Positioning.**
3) **Apply Forces.**
4) **Apply Boundary Conditions.**



Skull surface w. halo screws



Skull surface with halo & “forces”

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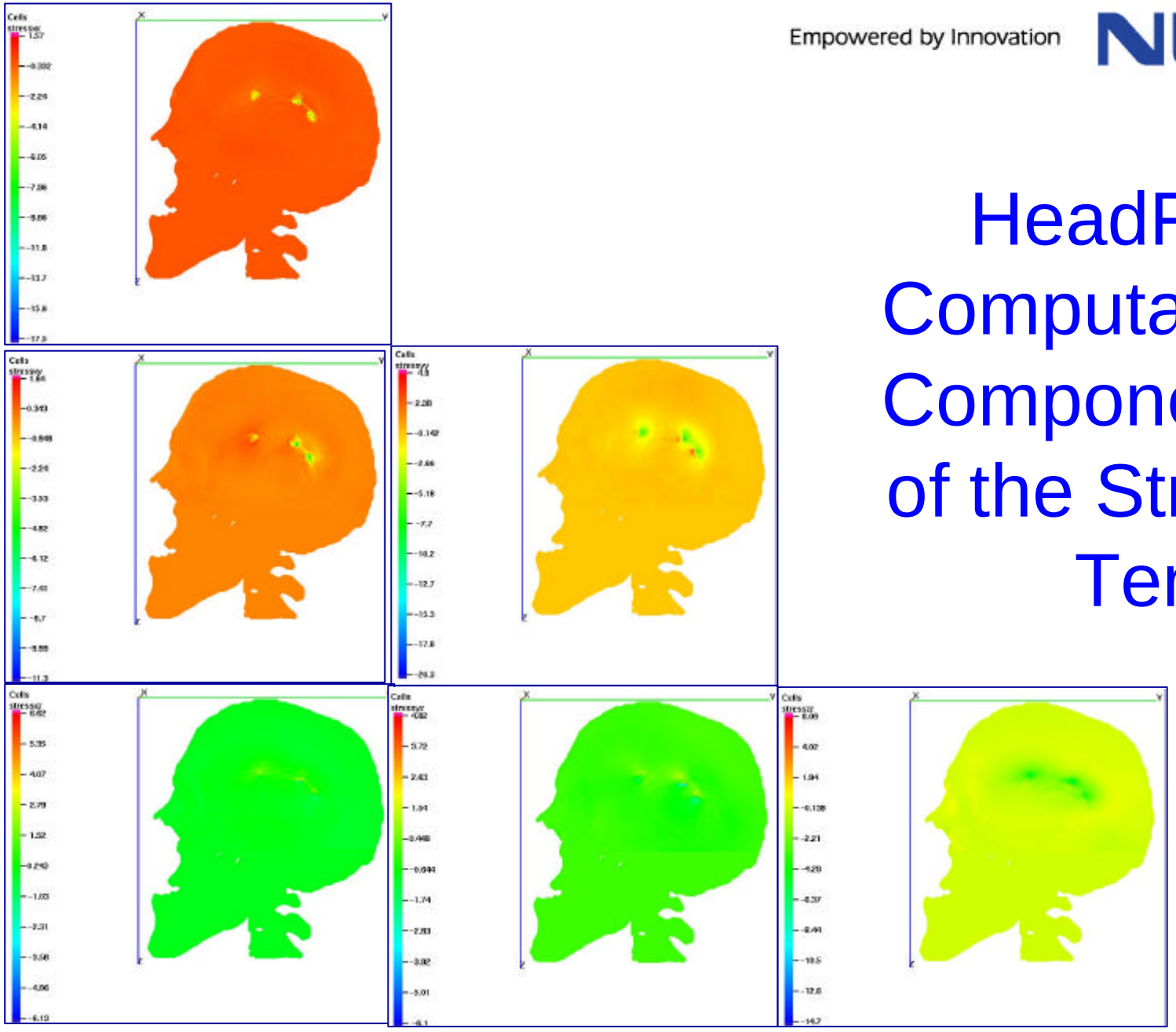
HeadFEM Computation. Components of the Stress Tensor:



Inverse Biomechanical Models

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- **Objective**:
  develop methods to invert for structural changes within subsequent medical scan data
- **Approach**:
  apply bio-mechanical modelling (registration with suitable constraints) by incorporating realistic material parameters

Toolbox contains

- *consistent, linear-elastic image registration*, vlet3d
- *fluid dynamic image registration*, vfluid3d
- post-processing of vector fields
  - vector field application, vassignshift3d
  - vector field analysation, vcpdetect
- pre-processing for visualisation
  - overlay vector fields on meshes, vmaddvf

Inverse Modelling: Focal Brain Lesions

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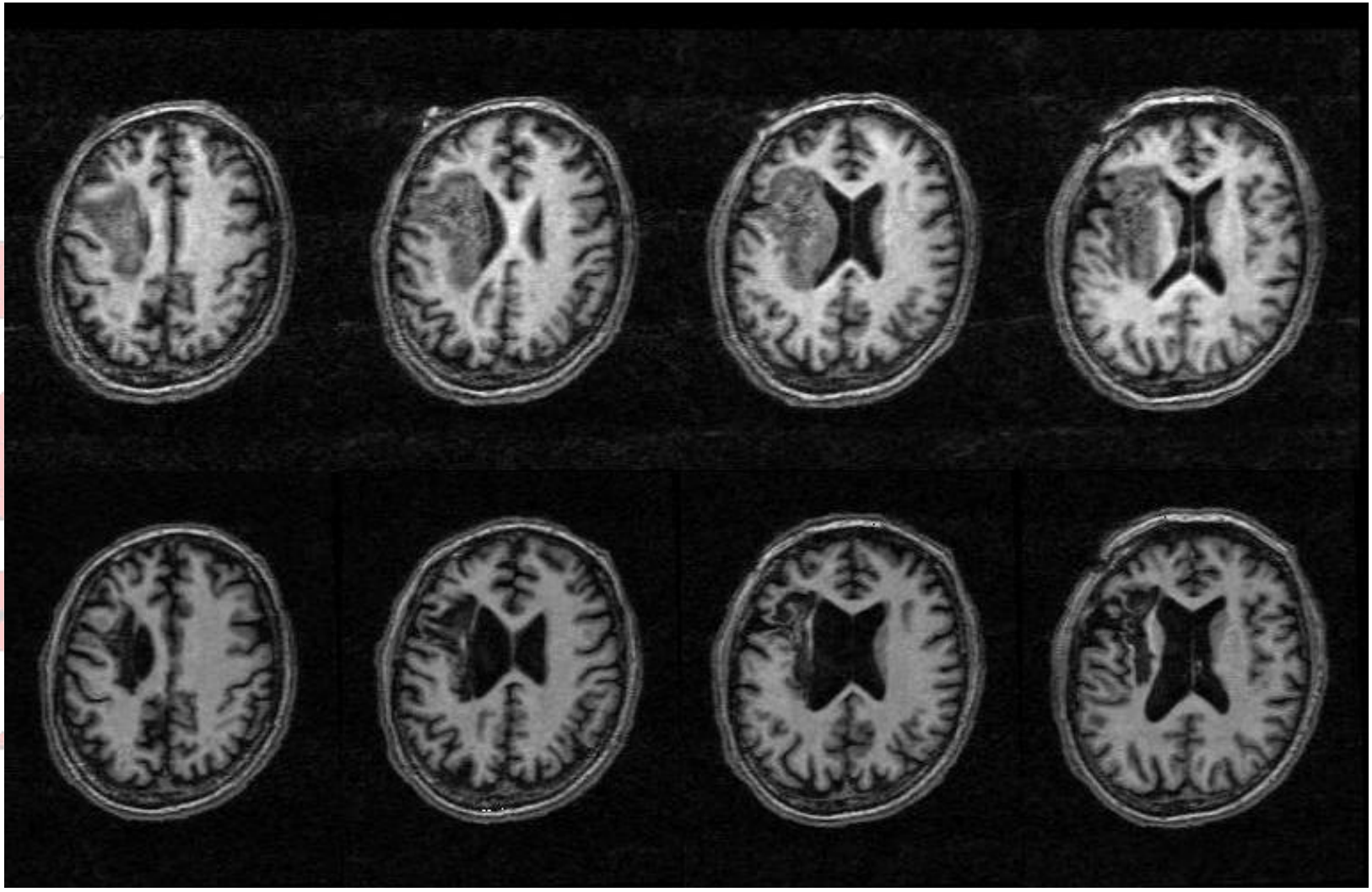

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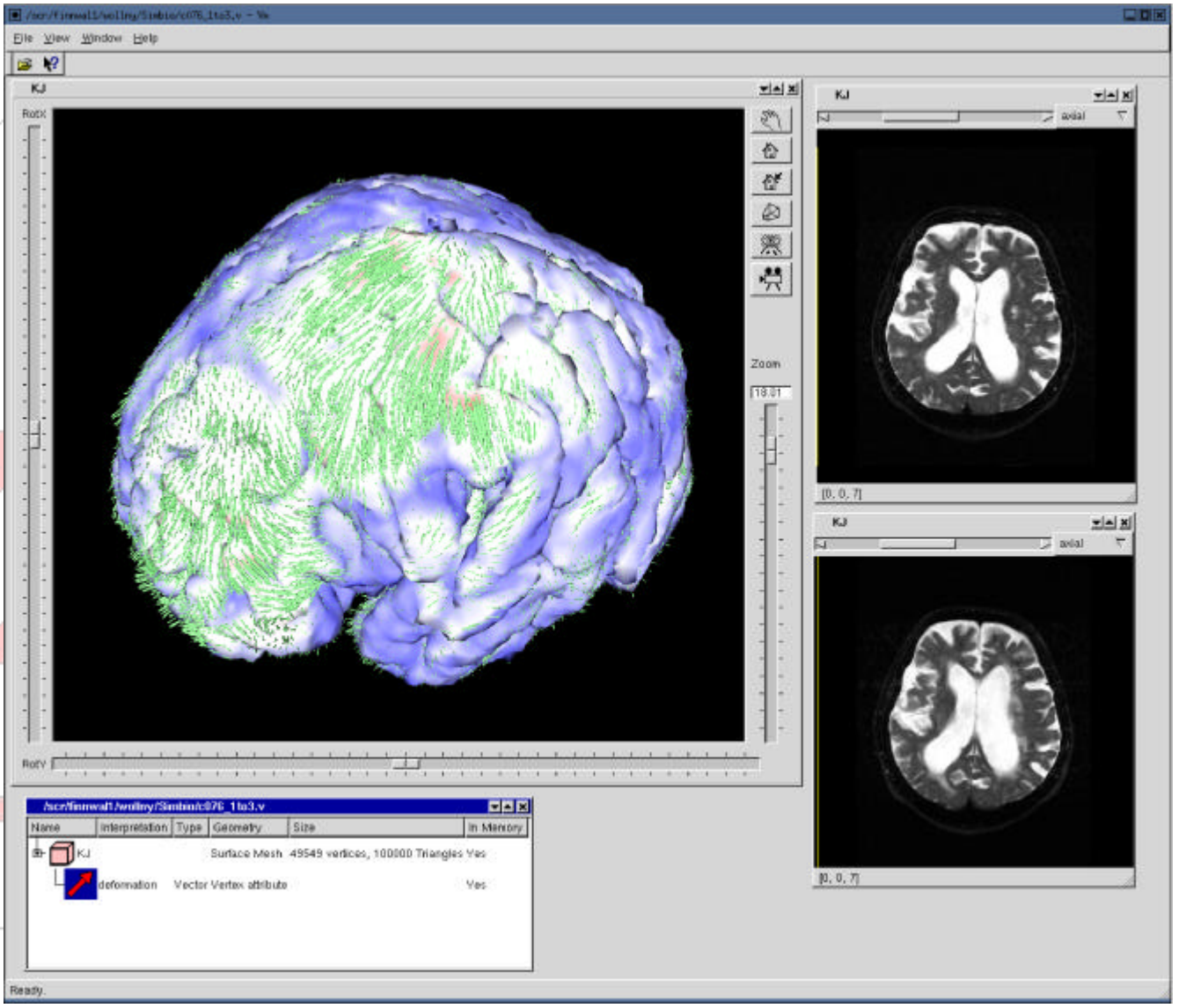

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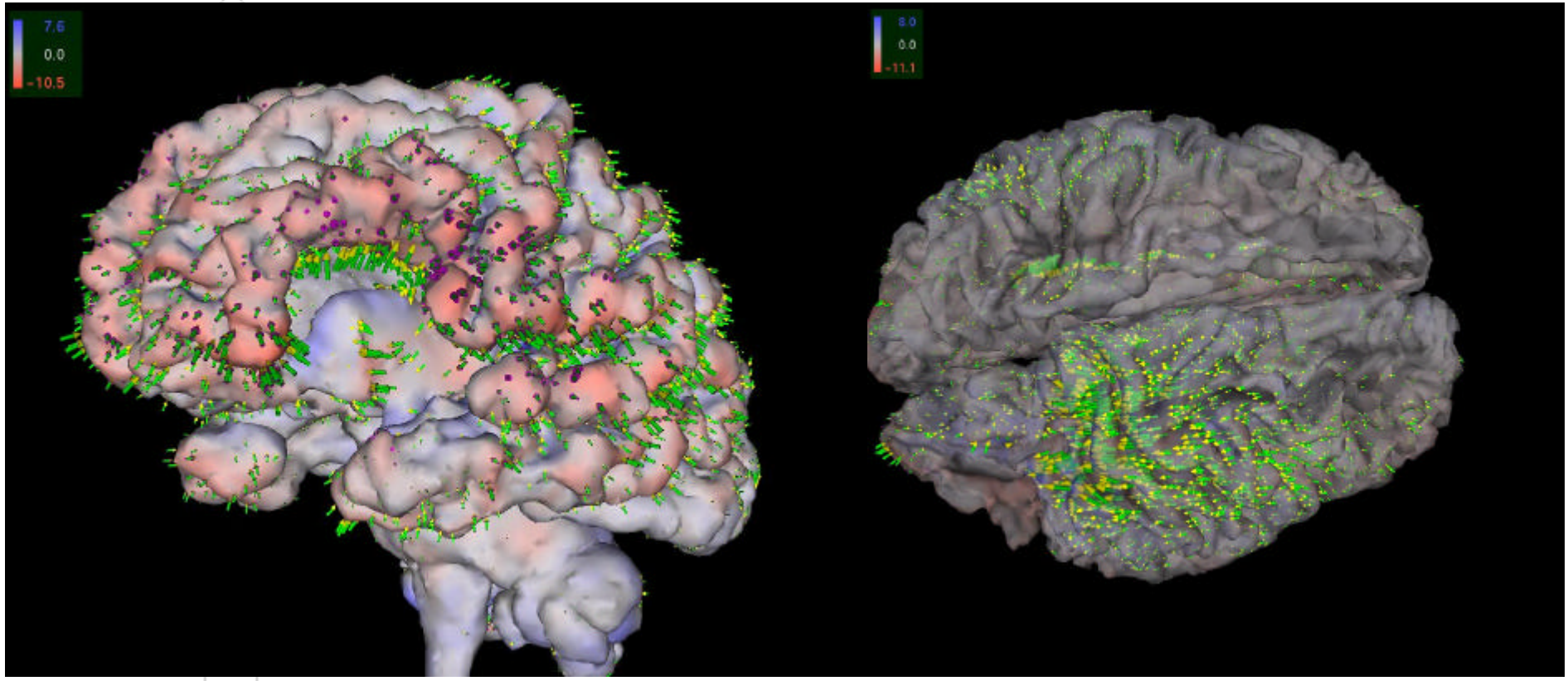
Structural Reorganisation after Brain Damage



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Segmentation

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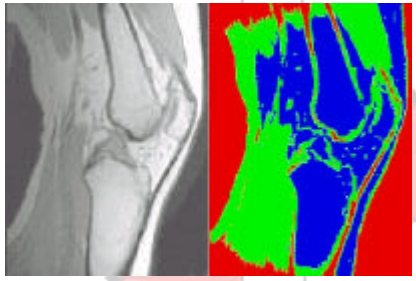
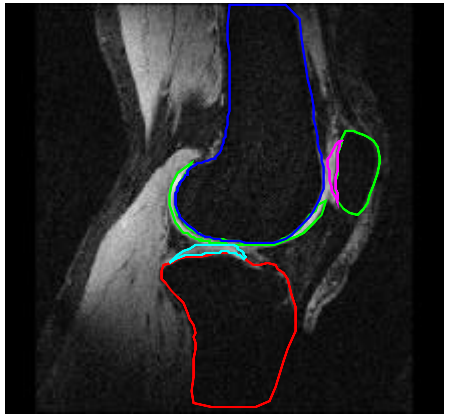
- Why segmentation by low level processing?
  - Flexible, fast computation
  - Works well for brain
  - No ‘guaranteed’ solution. Solution by experiment.
  - Not obviously suitable for knee



- Why segmentation by registration?
  - Generic:- a clear methodology
  - Mapping of predefined meshes
  - Requires preparation of a reference image and reference segments and meshes
  - Slower than low-level methods.



Non-linear registration - Using a Sum-of-squares Quality Measure

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- **Explicitly differentiable Quality measure**
- **Fast computations**
- **Sensitive to intensity mismatches between target and template**

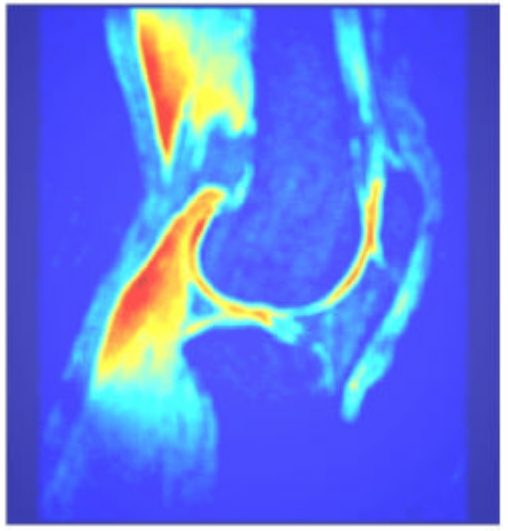
However: A class of images for which the sum-of-squares quality measure is appropriate are binary images

- **All** images are binary images if an extra dimension is added

Treat 3D intensity images as 4D binary images

– **Small increase in computational overheads**

– **Large increase in robustness compared to treating the images as intensity images**



Example: Non-linear registration

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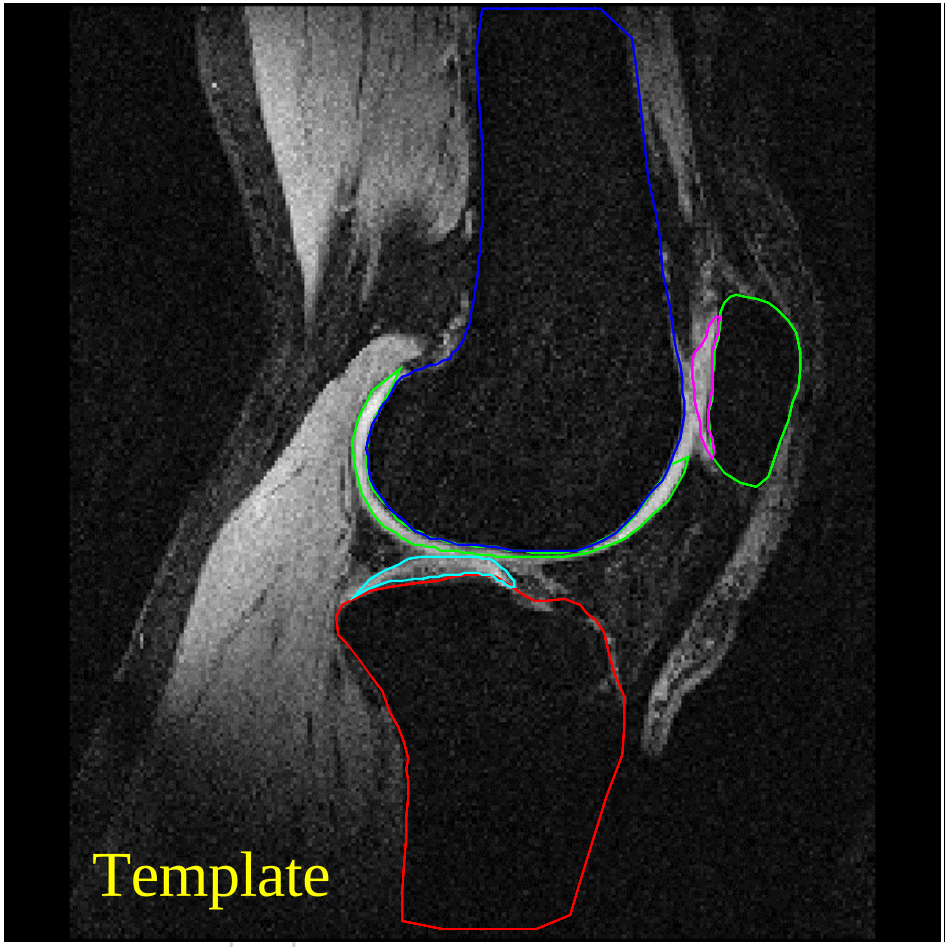

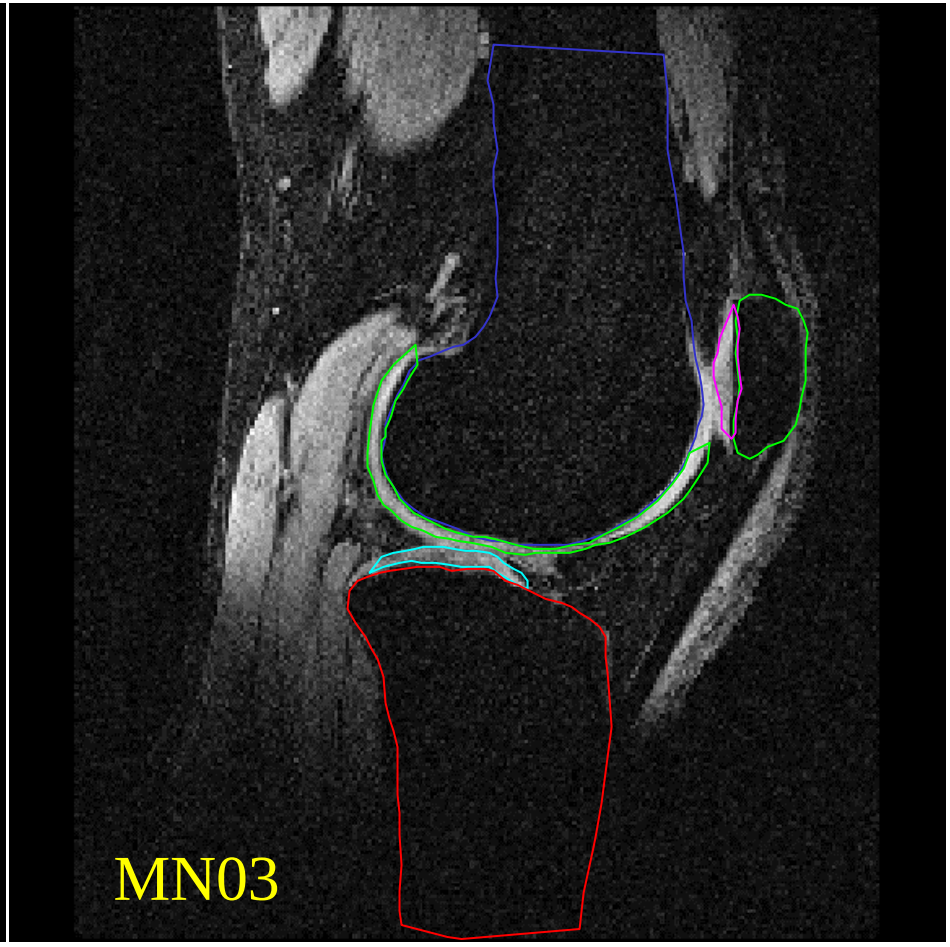

Mesh Generation

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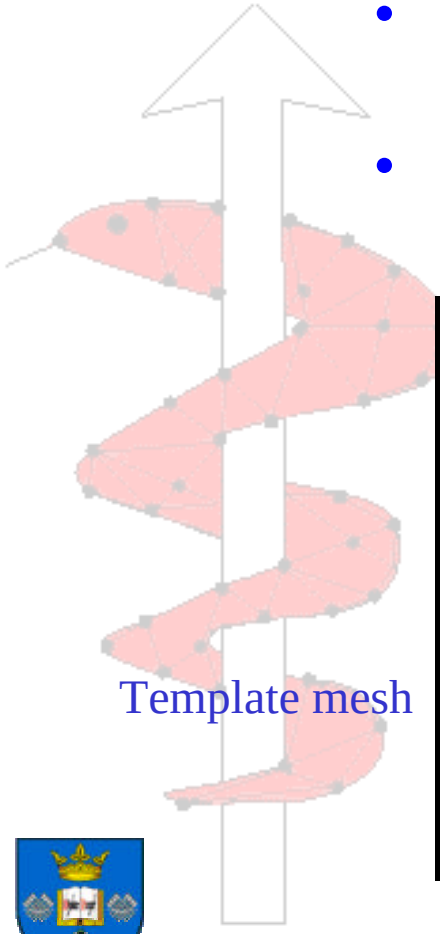
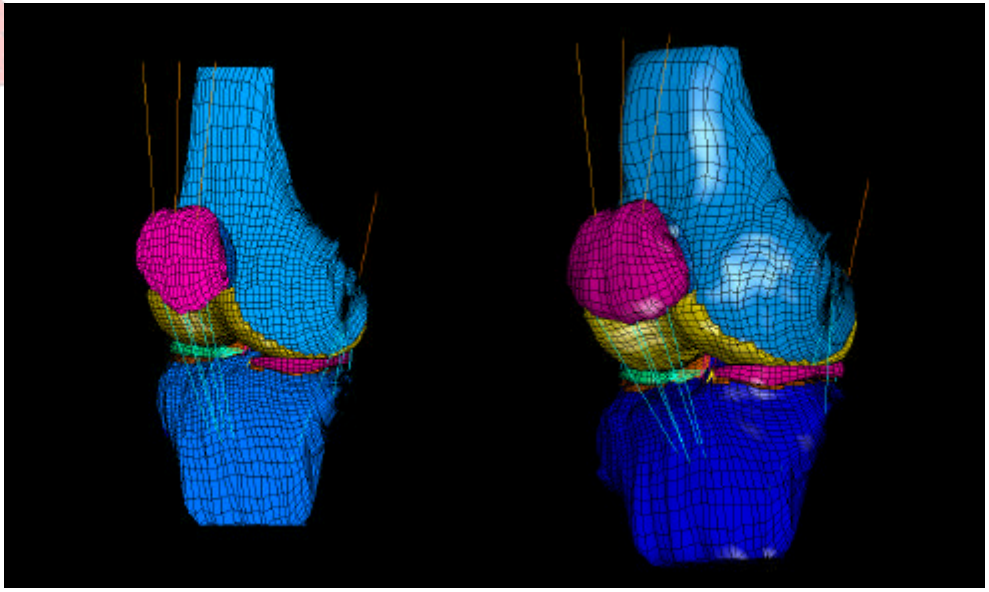
- Image mapping can be applied to FE mesh
  - Using *vtranspose* algorithm
- Permits FE template mesh to be morphed
  - To produce patient-specific vista mesh



Template mesh



Transformed mesh:
Patient MN03

Kinematic Modelling

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The objects of interest are segmented from dynamic scans

Kinematic Modelling

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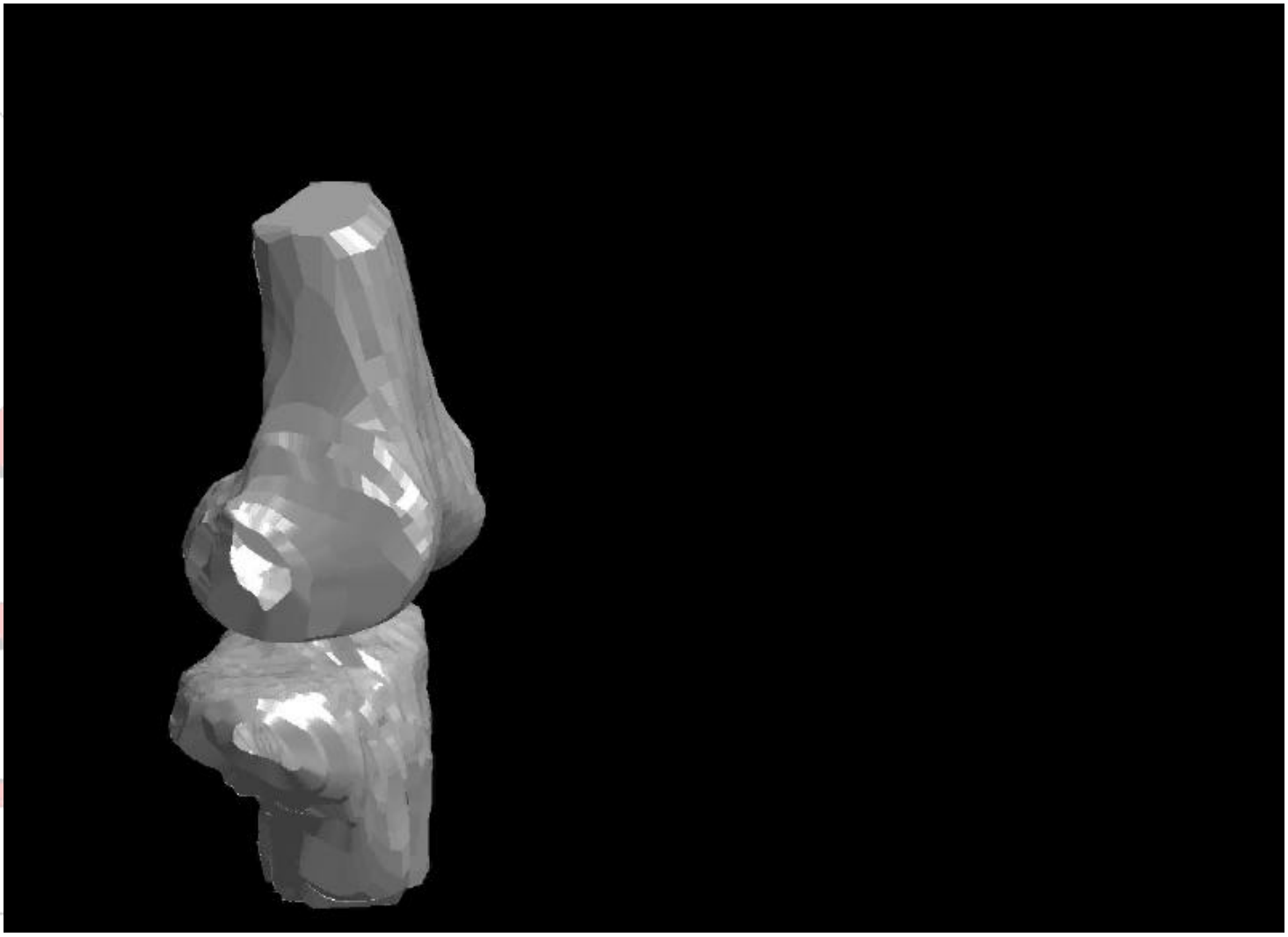

Simulations

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Lateral view of lower limb system flexing in rig


Oct26rig.qt

Superior view of cartilages flexing in rig


simbioknee_rig_no_men_oct26cart.qt

Posterior view of bones flexing in rig


simbioknee_rig_no_men_oct26p.qt

– **3D model of lower limb / foot plate system**

– **PAM-SAFE™ - run on SGI Origin 2000 (4 250 Mhz R10K processors, 2560 Mb)**
  - CPU time 20.5 hours using 3 processors
  - 2092 solid elements, 17,324 shell & 46 bar/beam elements

– **PAM-GENERIS ™ with SimBio extensions for data preparation (interfaces for Vista)**

http://www.simbio.de

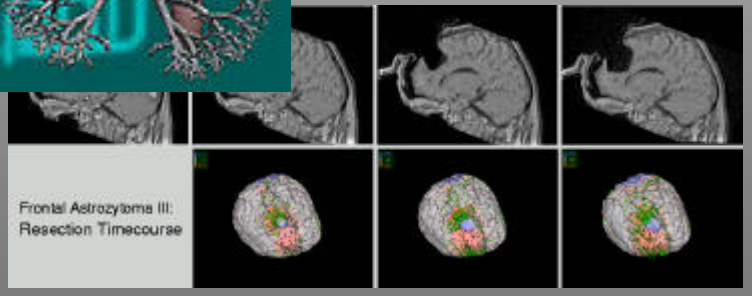
Overview

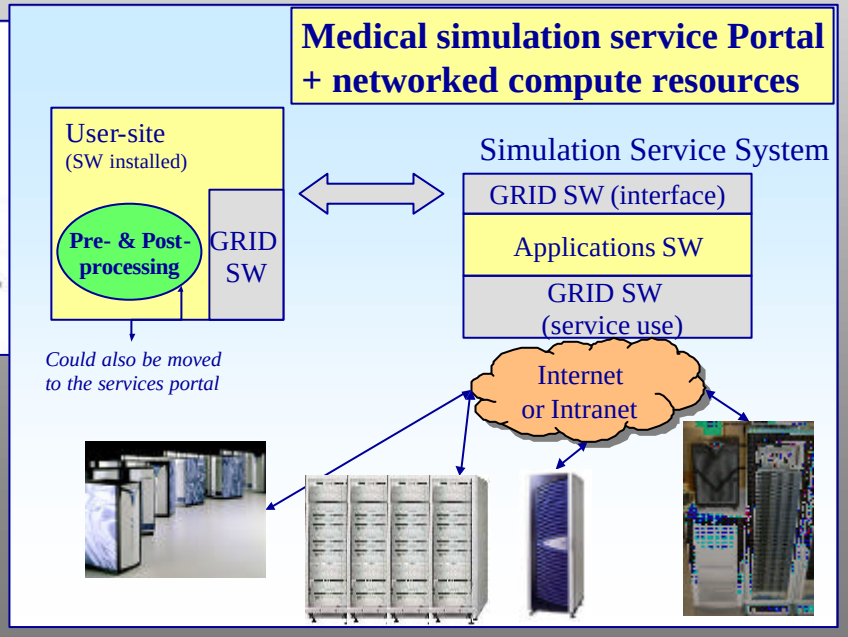
1. Introduction to the Project
2. Review of latest developments
   a. SimBio Materials Database
   b. EM Source Localisation
   c. Head Mechanics
   d. Knee Mechanics
3. **Future Directions**
4. Concluding Remarks

GEMSS: GRID-enabled Medical Simulation Services

Project Duration: 30 months, Commencement: 1.9.2002

Grid Software /solutions	Simulation /Imaging Software	Bio-numeric modelling	Medical Expertise	Legal Aspects





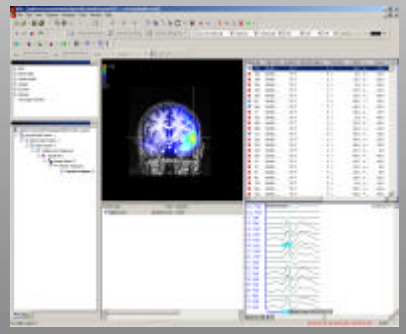
- **Future co-operation Related to Source localisation**

  HTSC (Homme, Technologie et Systèmes Complexes):

  Une nouvelle approche de localisation de sources en EEG chez l'enfant.

  Objective: Adaptation of inverse methods to the needs of small children

  Partners: CHU Amiens, UTC Compiègne, MPI-MIS Leipzig, A.N.T., …



Radiotherapy planning & Dose Minimisation

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STHT has a new combined low resolution CT & functional image scanner (‘hawkeye’) without the need for registration.

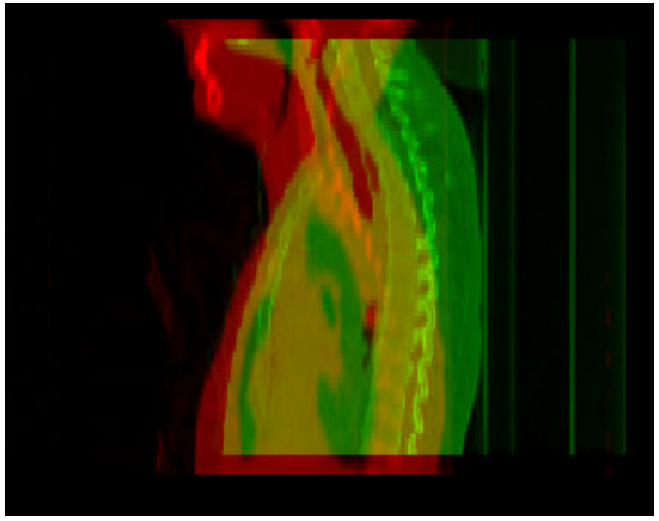
The new SimBio nonlinear registration techniques will allow this to be registered to the radiotherapy planning high resolution scan.

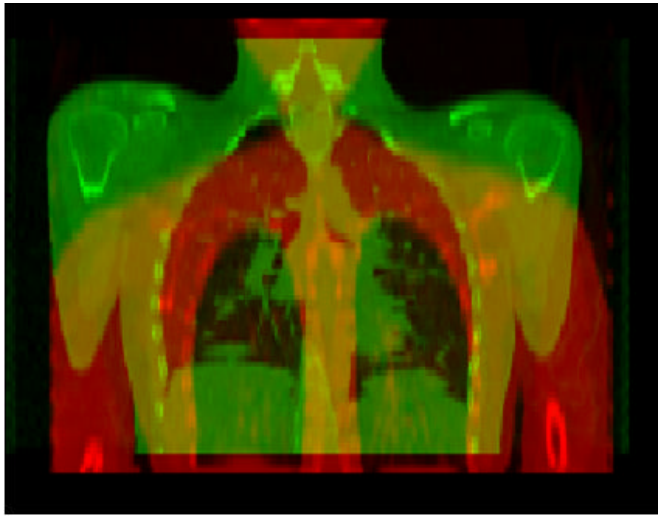
The combination of these steps allows a much more accurate localisation of the tumour - allowing a reduced and more effective radiation dose.

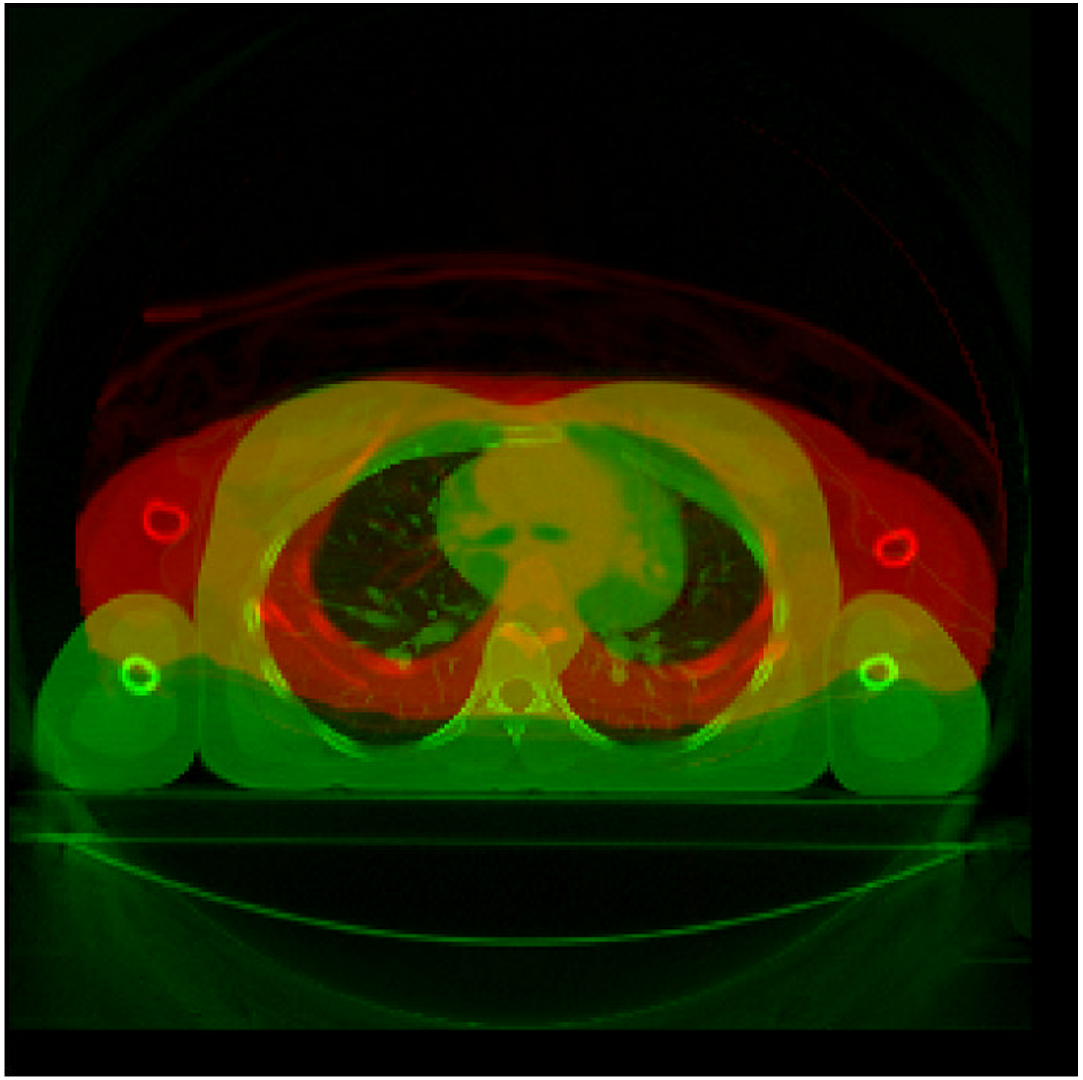
Treatment planning:

Radiotherapy
Hawkeye

Unregistered data set



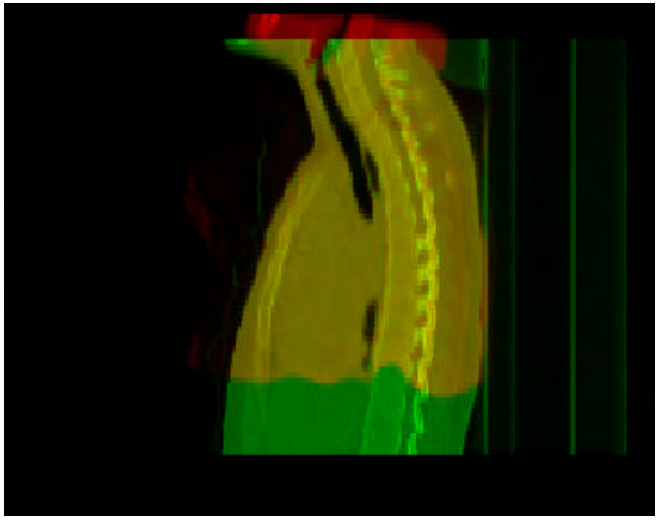


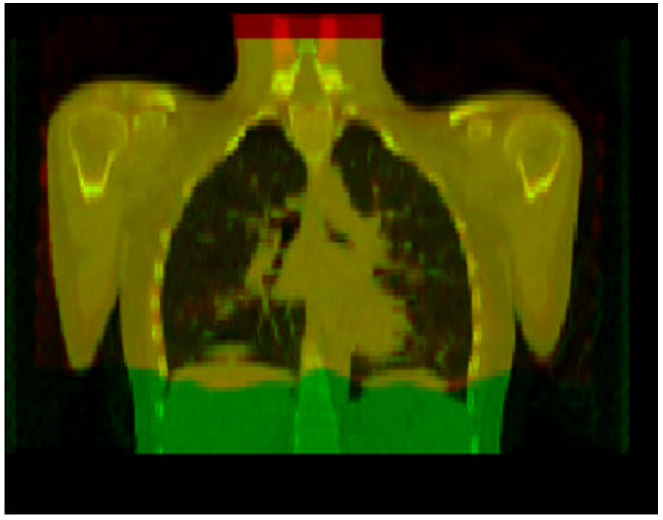


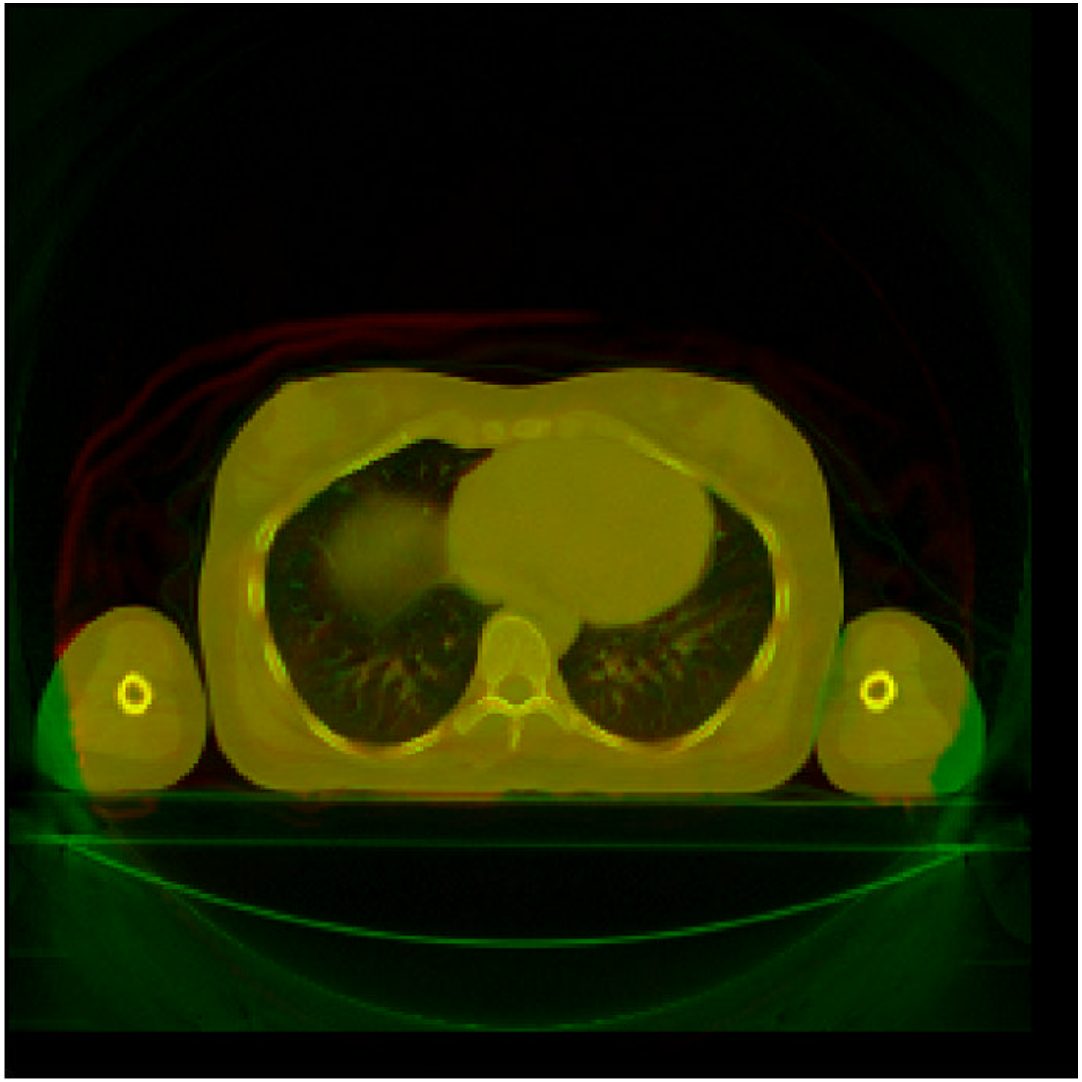
Treatment planning:

Radiotherapy
Hawkeye

Non-linear registered data sets



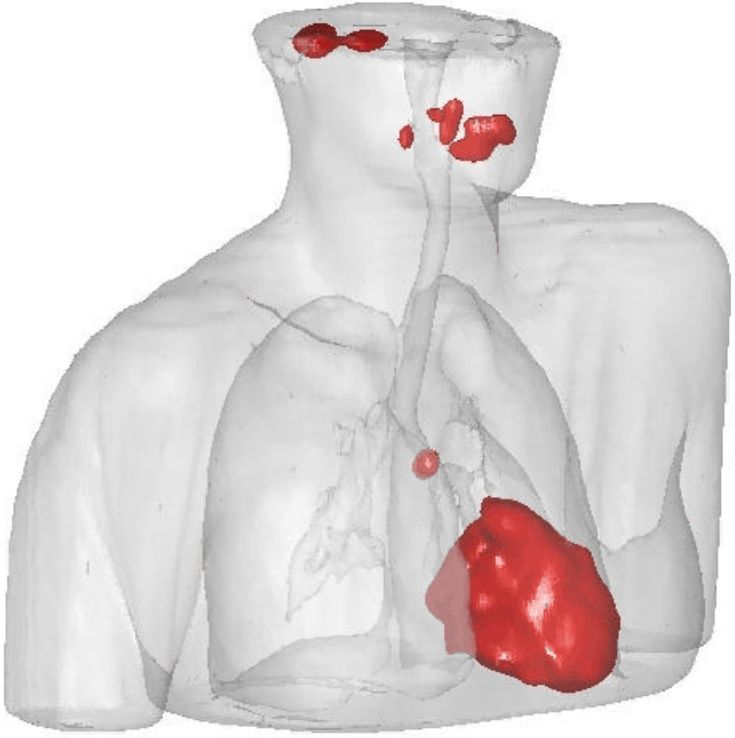




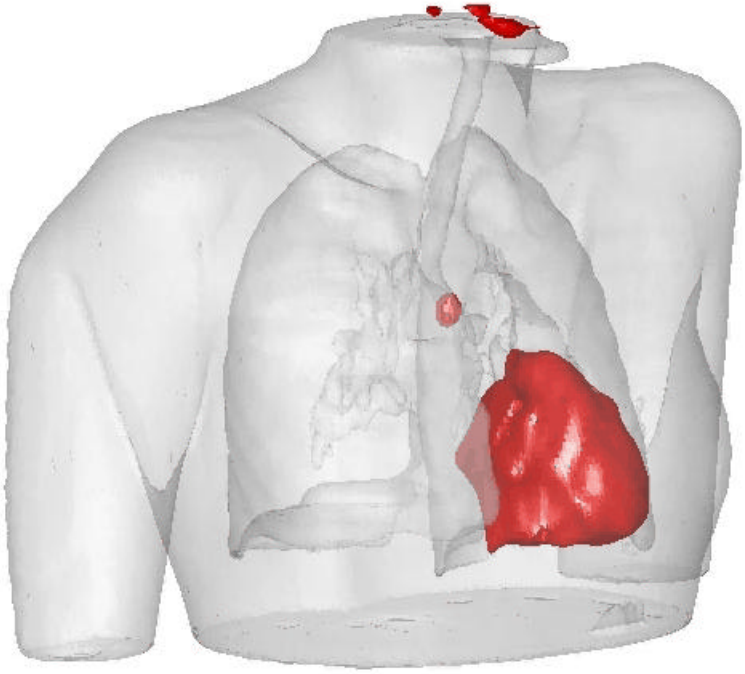
Treatment planning:

Applications also exist for enhanced visualisation and therefore more accurate tumour staging

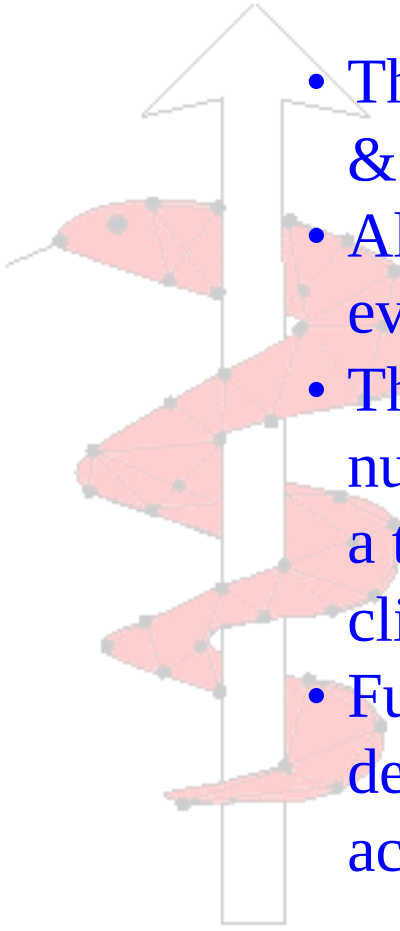
Pet scan mapped onto Hawkeye CT



Pet scan mapped onto Radiotherapy CT



Concluding Remarks



- The SimBio environment combines medical imaging & FEM techniques with up-to-date HPC technology
- All software components are in place and the final evaluation and validation phase is proceeding
- The evaluator applications show the impact of bio-numerics for improving medical understanding and as a tool for non-invasive diagnosis and planning of clinical procedures.
- Future trends: extended medical/clinical trials and demonstrations; using Grid technologies to provide access to such technologies