

Finite Element Analyses for Head Biomechanics

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in Bio-Informatics & Medical Applications

Overview

The Finite Element Method

Head Bio-mechanics - Motivation and Overview

The NEC/MPI Model for the Individual Patient

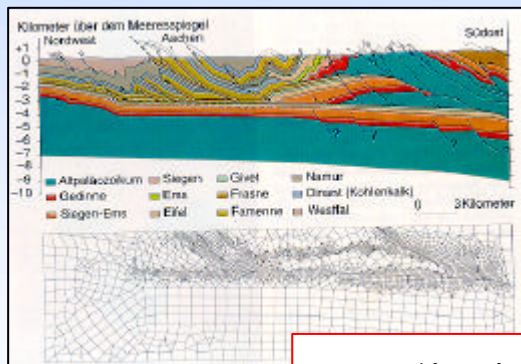
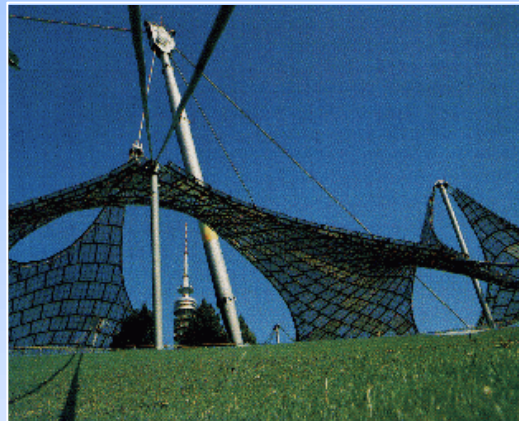
Two Test Applications

Future Planning

NEC

The Finite Element Method (FEM)

Application Fields

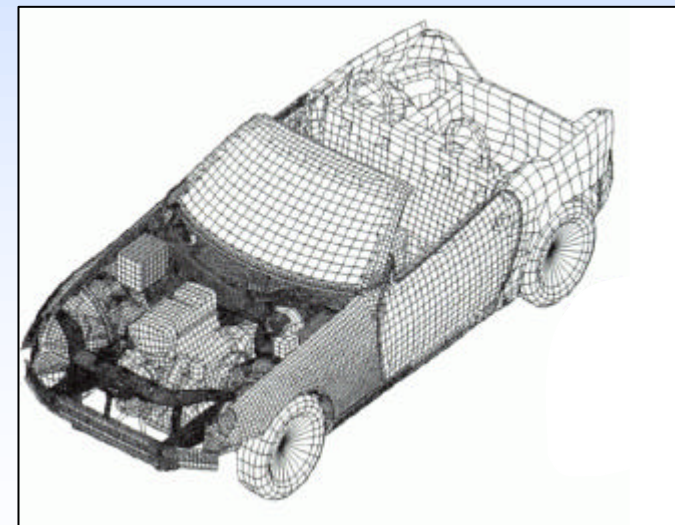


Construction

Prediction

FEM

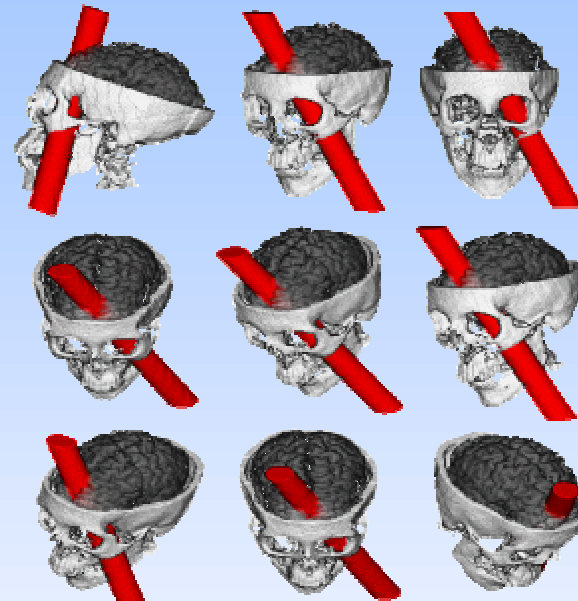
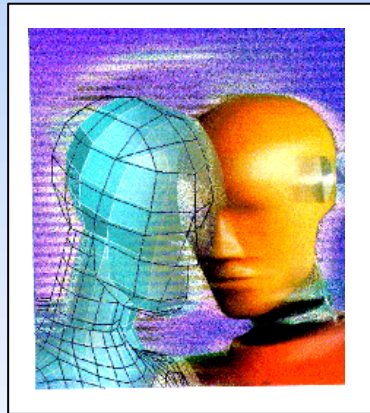
Optimisation



NEC

Computational Head Biomechanics

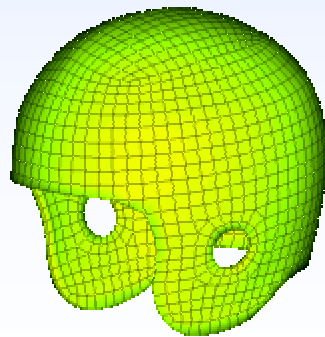
Examples



Courtesy of U Hamburg



Accident Reconstruction



Courtesy of WSU

Prevention

Surgical Planning

NEC

Computational Head Biomechanics

Head Impact Bio-mechanics

Dynamic problem, high velocity

Surgery Bio-mechanics

(Quasi)-static problem, middle/low velocity

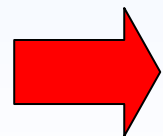
Statements on Head Injury

- With the advent of the airbag the number of head injuries has been greatly reduced.

- **BUT:** Still there are 700.000 head injuries/year in the USA
10 % of them are severe injuries!

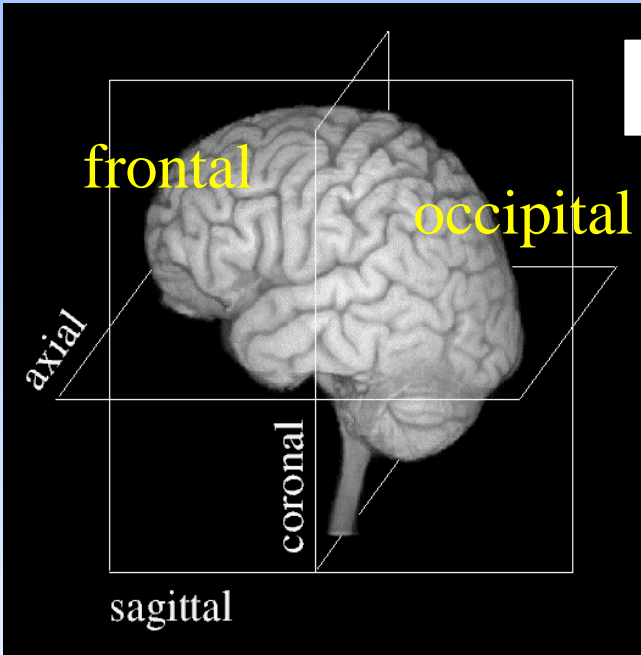
- Motorcyclists, pedal cyclists and pedestrians are still in danger.

- Optimisation of head protection in sports is of high relevance.

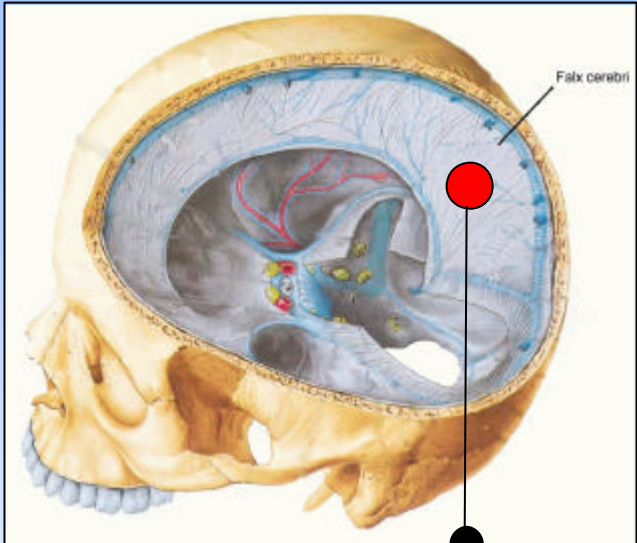


Head injury modelling is an important issue!

Basics of Head Anatomy



Definitions



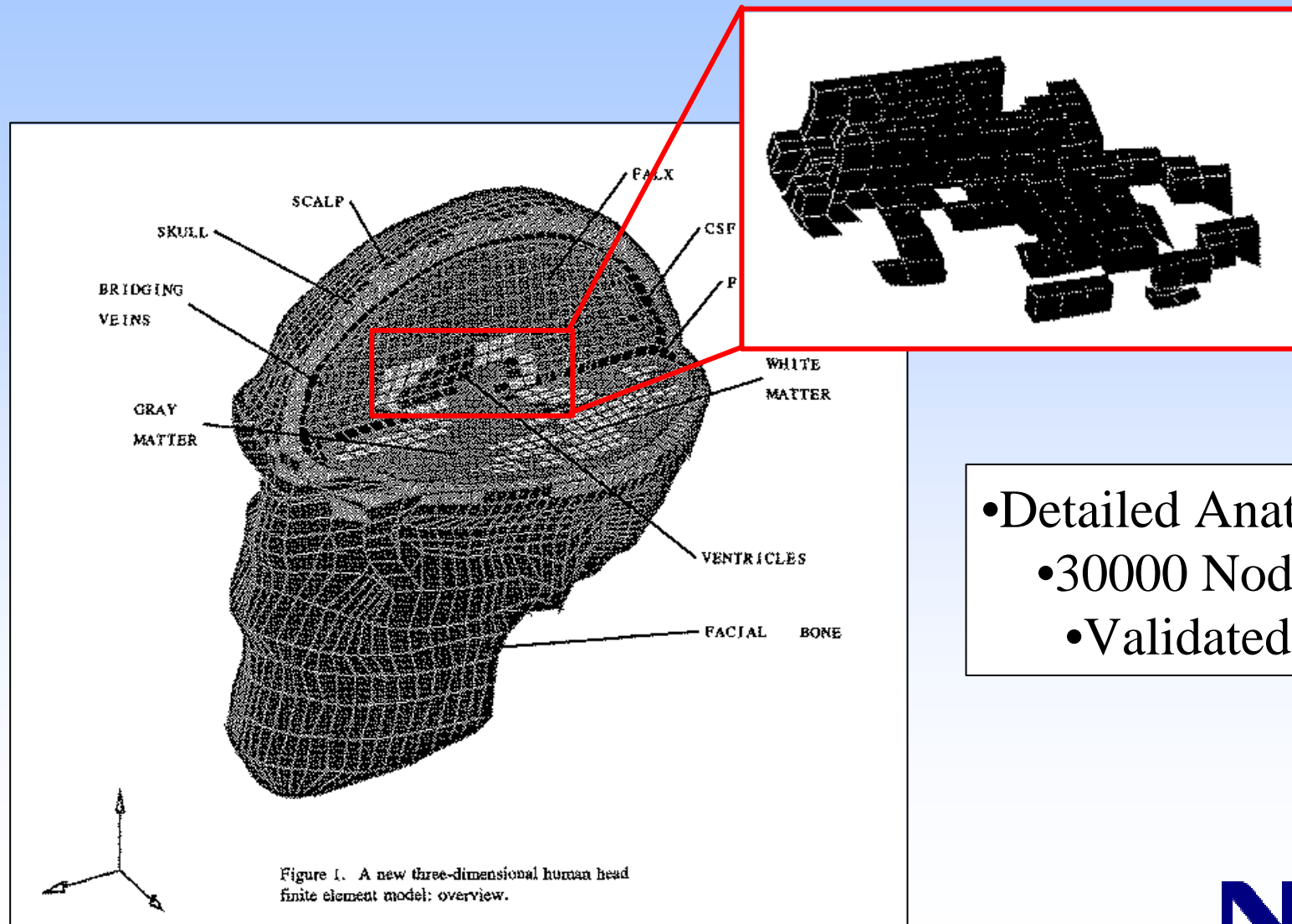
A Brain Membrane



Ventricles

A Sagittal MR Slice

Head Models - The WSU/ESI model



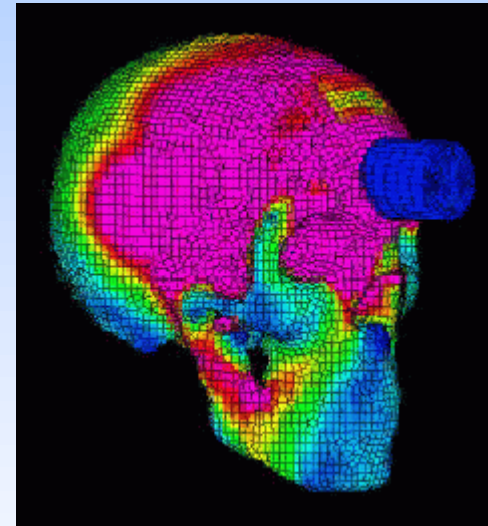
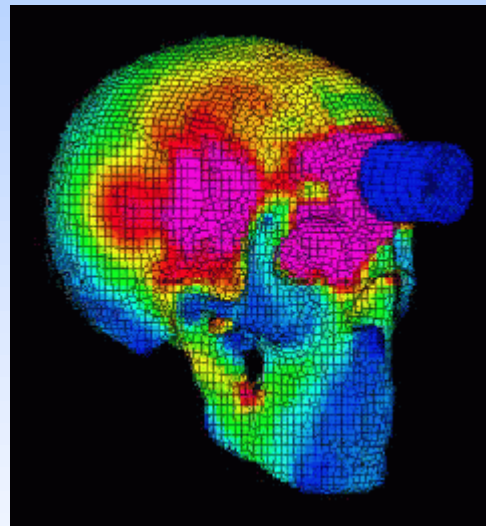
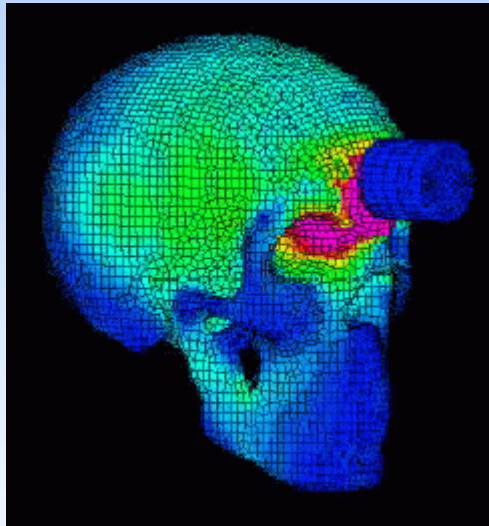
- Detailed Anatomy
- 30000 Nodes
- Validated!

Head Models - The Tübingen Model

Video show?

Head Models

Krabbel, Müller (TU Berlin, ETH Zürich, 1998)



- PAM-CRASH FE code
 - 20000 Nodes
- “Visible Human” Data
 - Brain & Skull only

Statements on Surgery Planning

- Image Guided Neurosurgery is a well established technique.

- **BUT:** Brain Shift endangers validity of pre-surgical images.

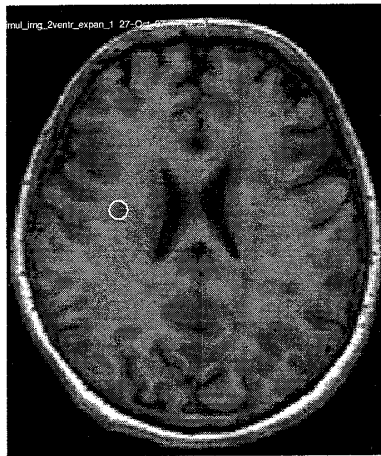
- Mechanical consequences of tumor growth are of medical interest.

- Planning of Facial Surgery is desired.

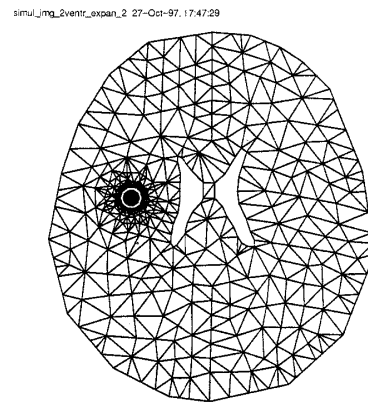
 Head models will become supportive tools for the surgeon.

Head Models - Simulating Tumor Growth

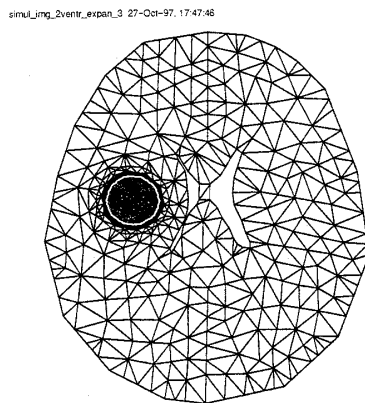
Kyriacou 1997



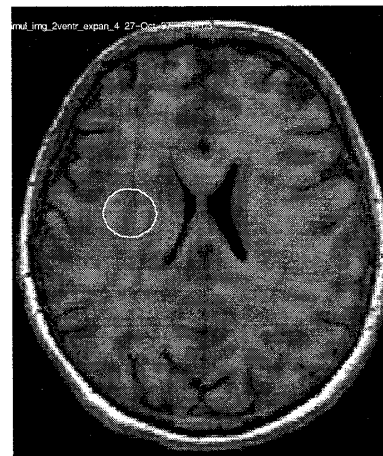
(A)



(B)



(C)



(D)

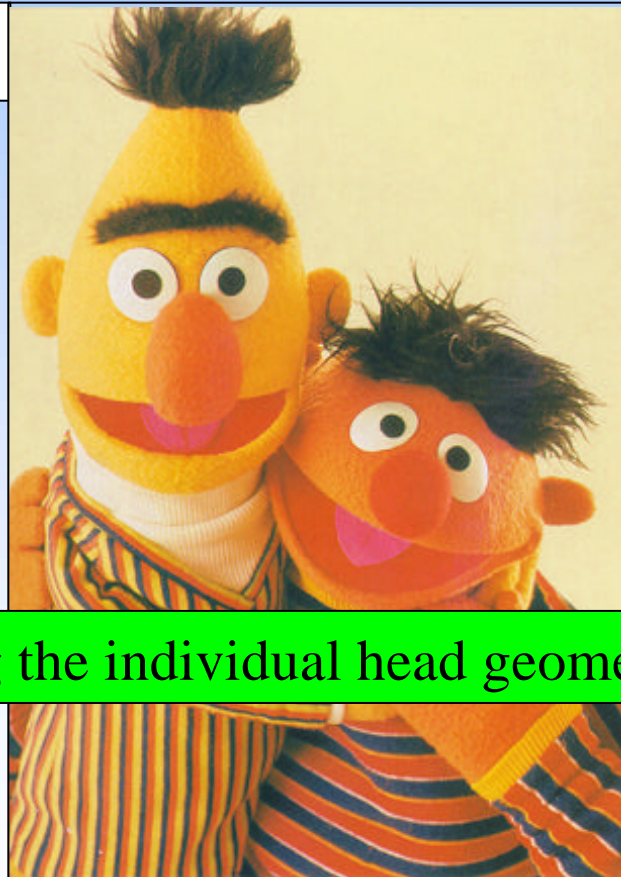
- 2D Model
- a Few Hundred Nodes
- Validated!

NEC

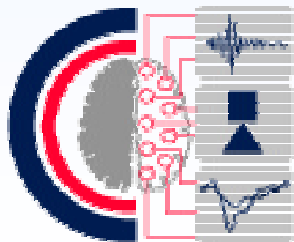
The NEC/MPI Model for the Individual Patient

Head Geometry Shows High Variability!

A famous example:



→ A model reflecting the individual head geometry becomes necessary.



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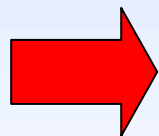
NEC

The NEC/MPI Head Model

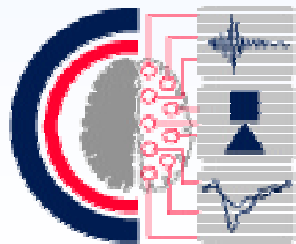
Requirements

A very **precise** geometry description of neuroanatomical structures.

A highly flexible approach enabling a **fast** setup of individual models.



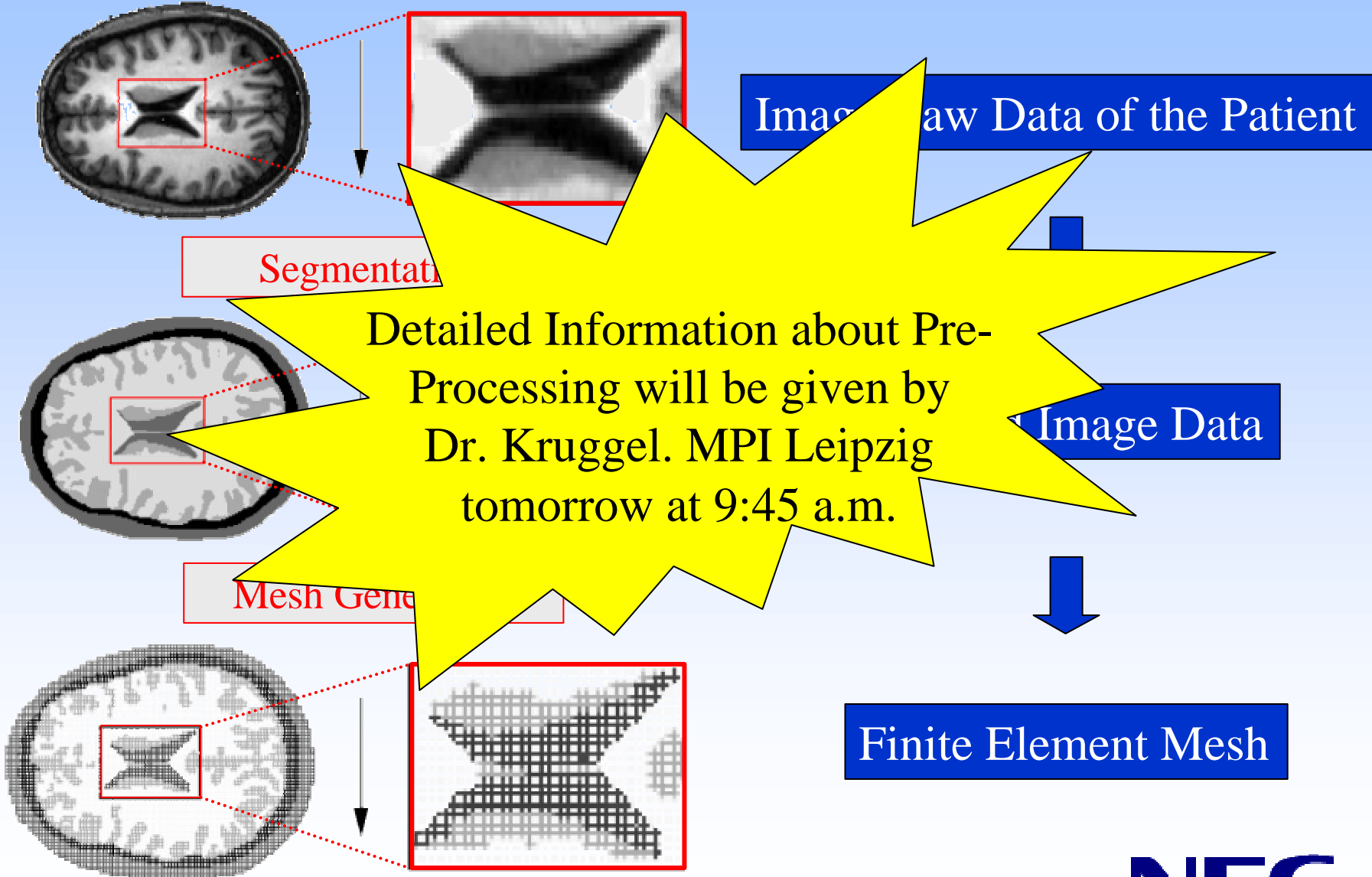
Head modelling becomes a supercomputer application!



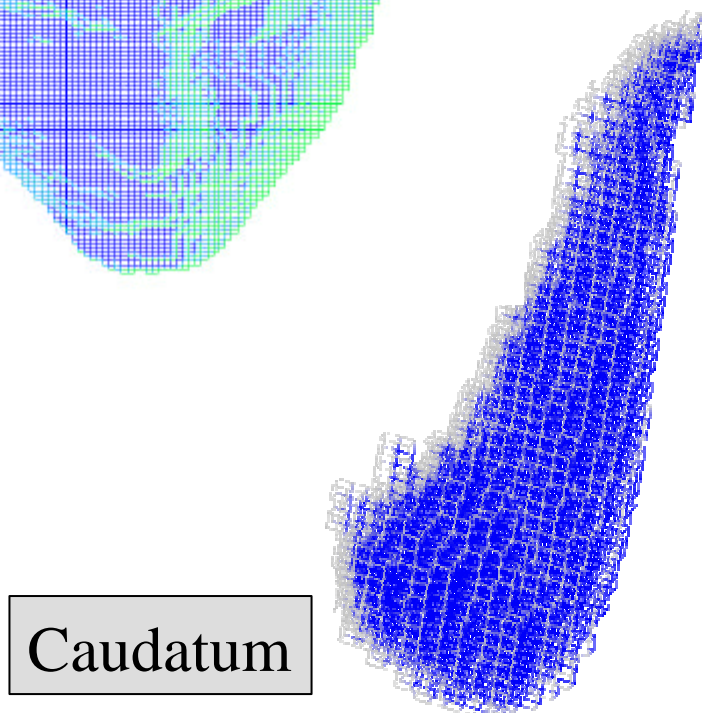
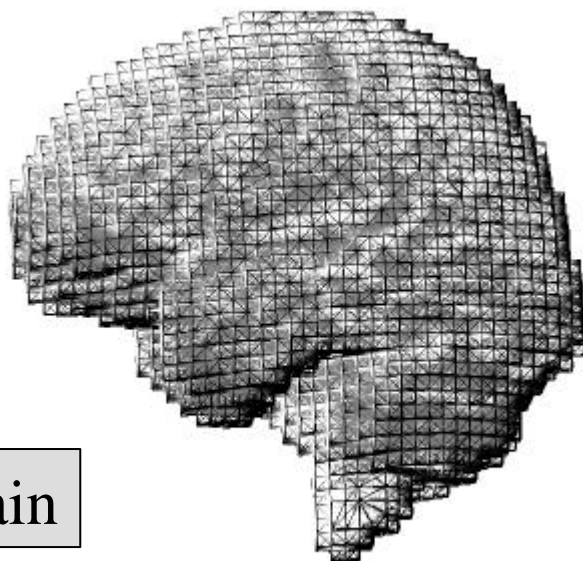
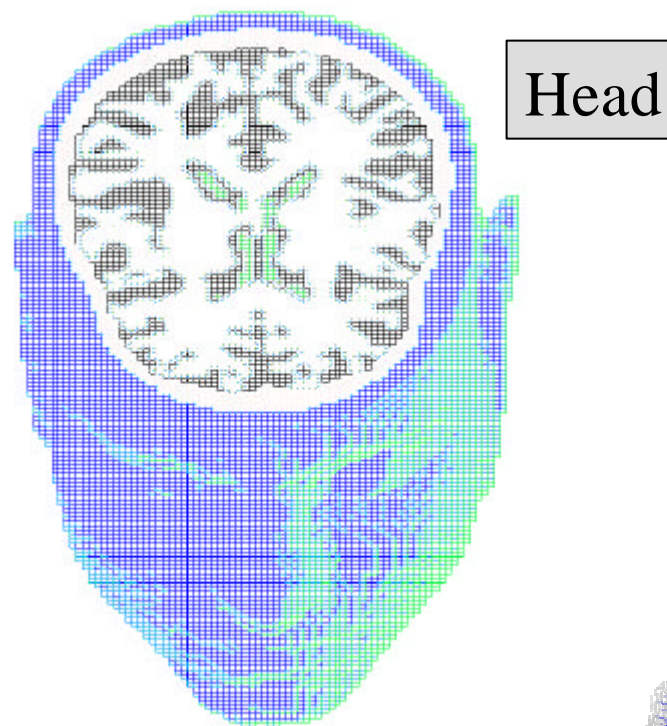
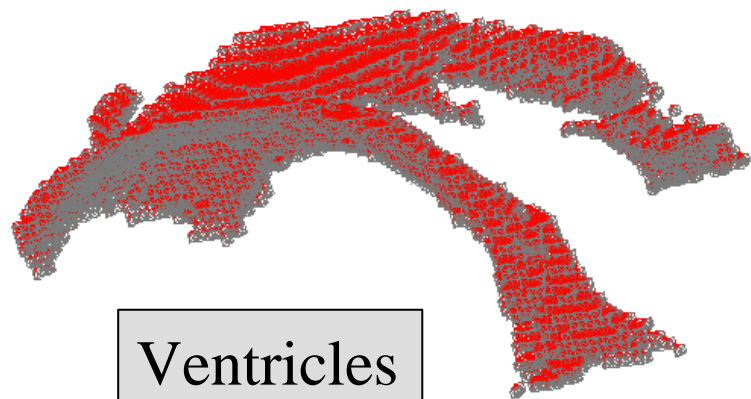
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Preprocessing of Medical Scan Data



Neuroanatomical FE Meshes



Parallel FE Code HEAD-FEM

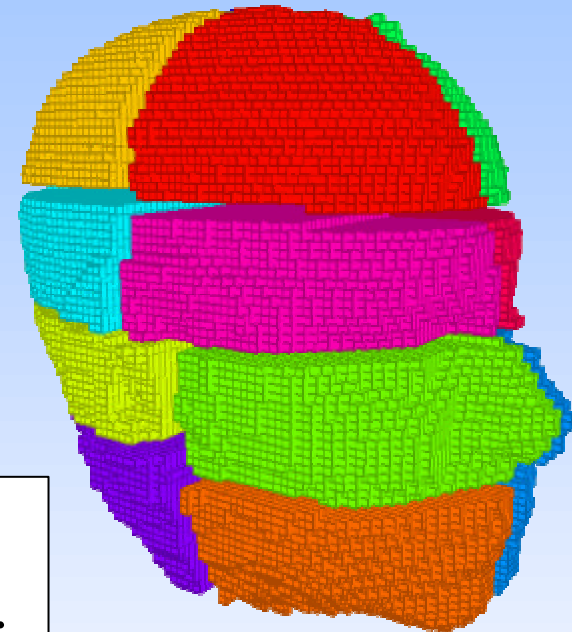
HEAD-FEM is a fully parallel linear finite element code for special bio-mechanical applications

A partitioned FE mesh is the distributed input for HEAD-FEM

HEAD-FEM currently exploits the linear solvers implemented in the AZTEC library.

A typical calculation time for a static FE analysis is 5min on 32 processors of the NEC Cenju-4.

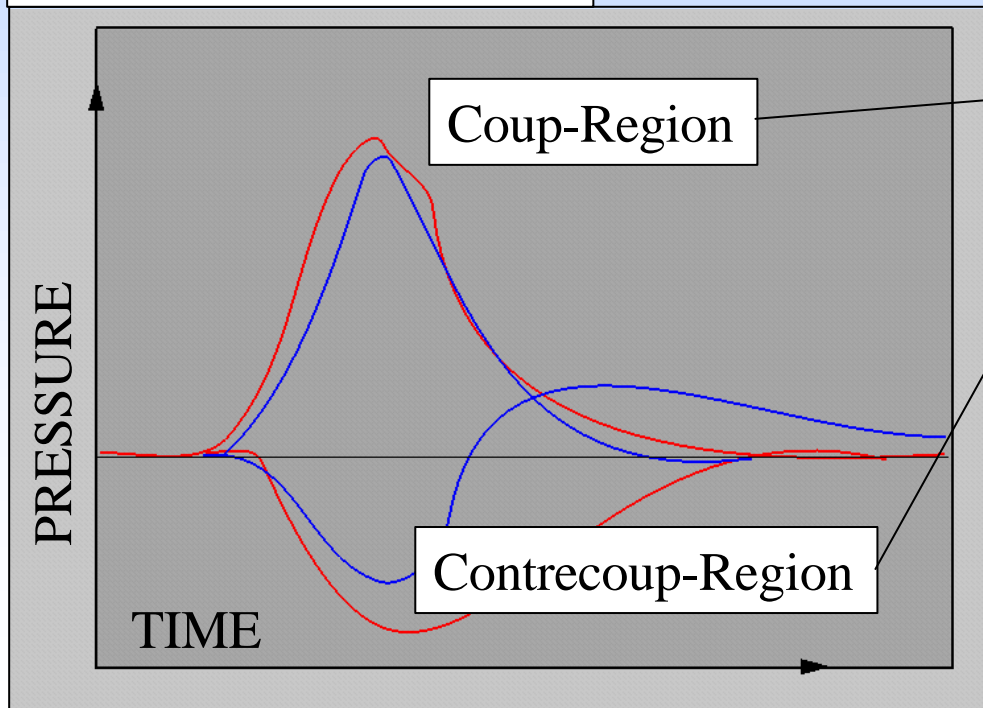
A typical calculation time for a dynamical FE analysis is 30min.



Application: Head Impact Bio-mechanics

A Validation Study

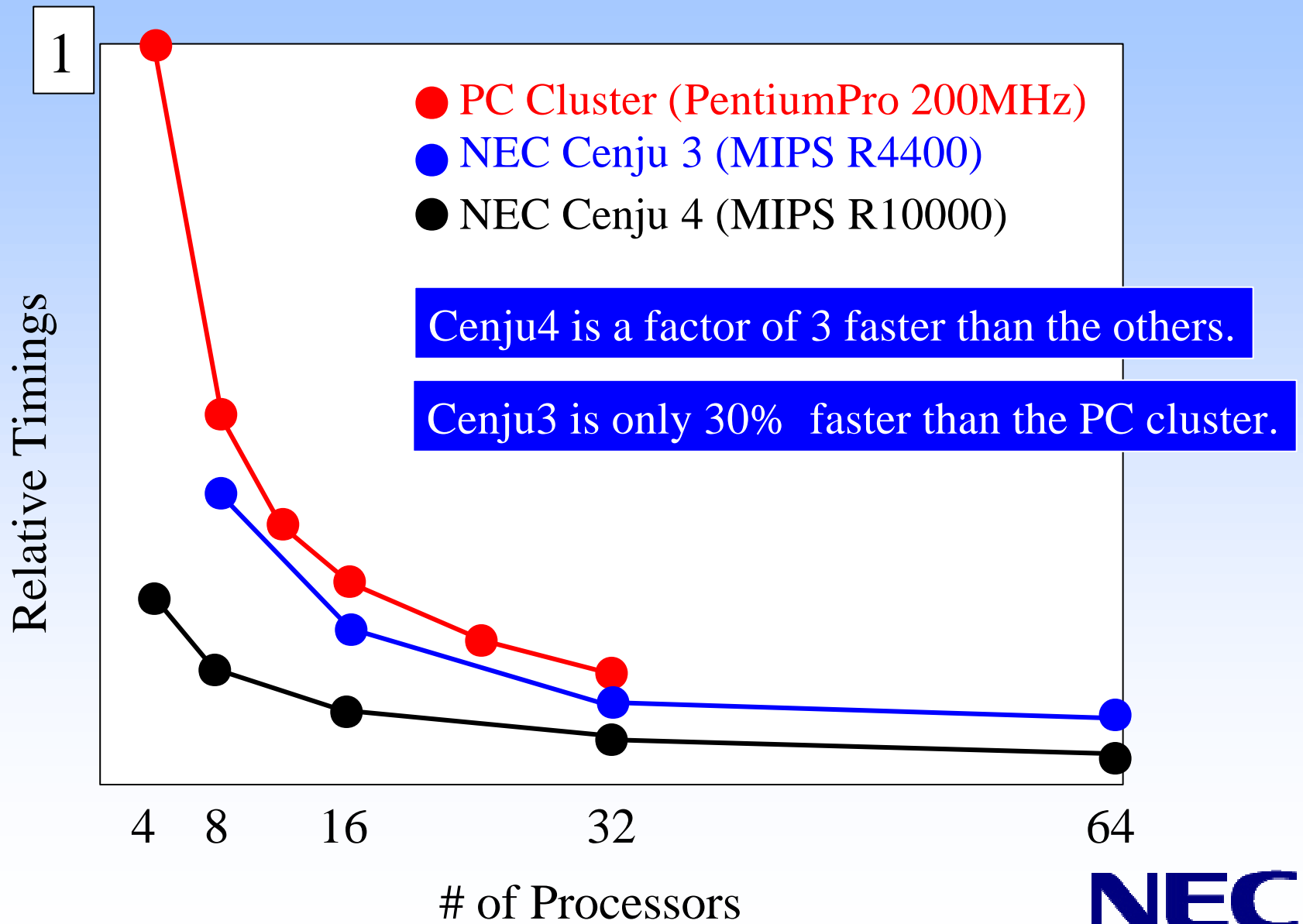
— Experiment
— Simulation



Pressure Distribution



HEAD-FEM on Parallel Architectures



Application: Maxillo-Facial Bio-mechanics

Motivation

University of Leipzig, Department of Oral & Maxillofacial Plastic Surgery



Pre-surgical situation



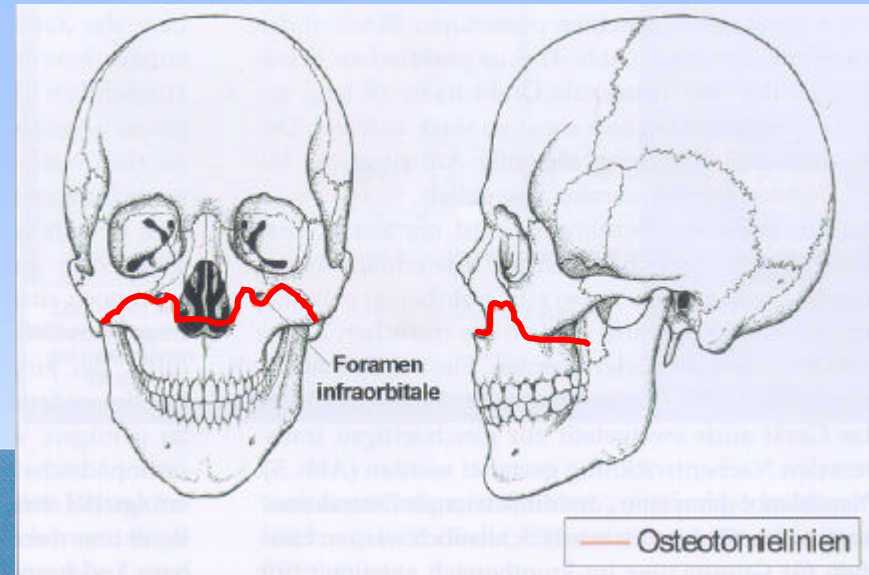
Post-surgical situation



Maxillo-Facial Bio-mechanics

Operation Technique

The "Halo" Frame



Cutting Lines

Maxillo-Facial Bio-mechanics

Two Project Phases:

PHASE I

Simulation of skull displacement due to “halo” forces.

PHASE II

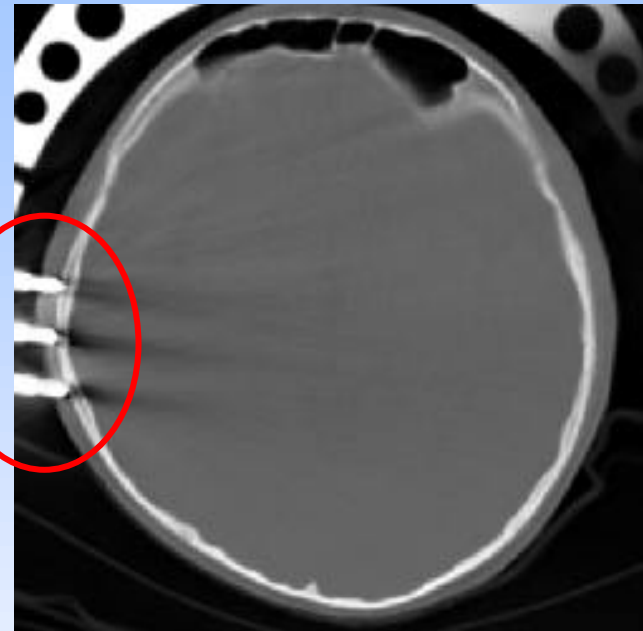
Simulation of soft tissue re-arrangement.



Surgery Bio-mechanics (Phase I)

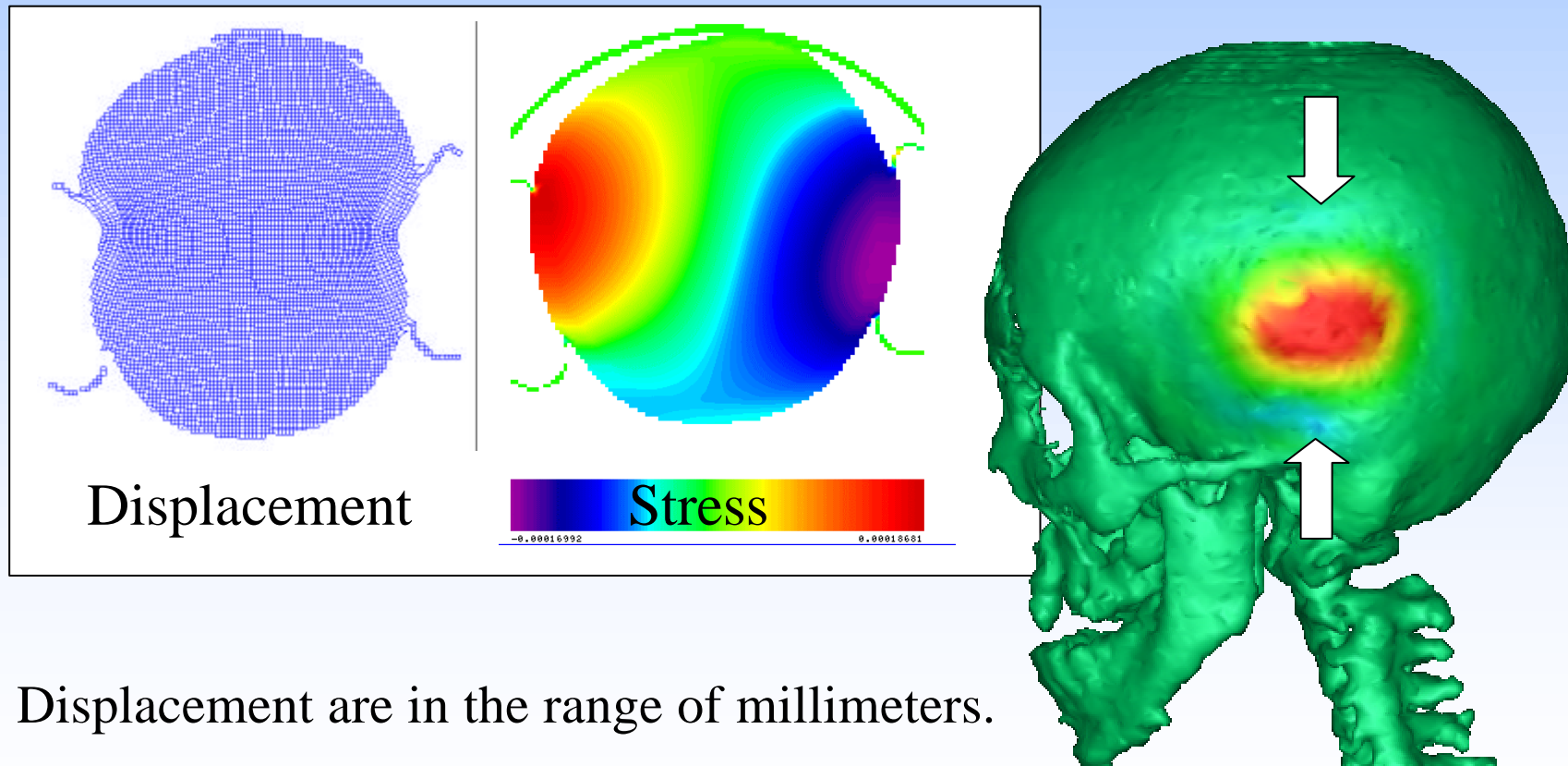
Halo Screws

The forces applied to the skull are exactly known



Maxillo-Facial Bio-mechanics (Phase I)

Static skull mechanics



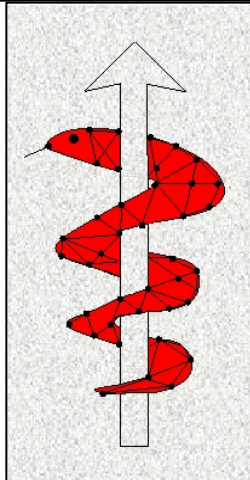
Displacement are in the range of millimeters.

Future Planning

Technical Developments



<http://www.simbio.de>



Extension of HEAD-FEM

- Coupling with DRAMA
 - Simple Crack Model
- Geometric Non-linearity
 - Visco-elasticity

Project in Planning Simulation & Validation in Head Traumatology

Consortium:
University of Tübingen
NEC CCRLE,
DaimlerChrysler, ...

Extension of HEAD-FEM

- Explicit Solvers
- Contact Algorithms

Discussion

Material Properties

The limiting factor for the quality of FE head models is the lack of **reliable material properties** of human soft tissue!

One aspect of the SimBio project is to significantly **improve** this situation (Prof. Grebe, Université de Compiègne, France)

With all these improvements FE head models might become a **supportive tool** for the medical user.