Overview January 2013

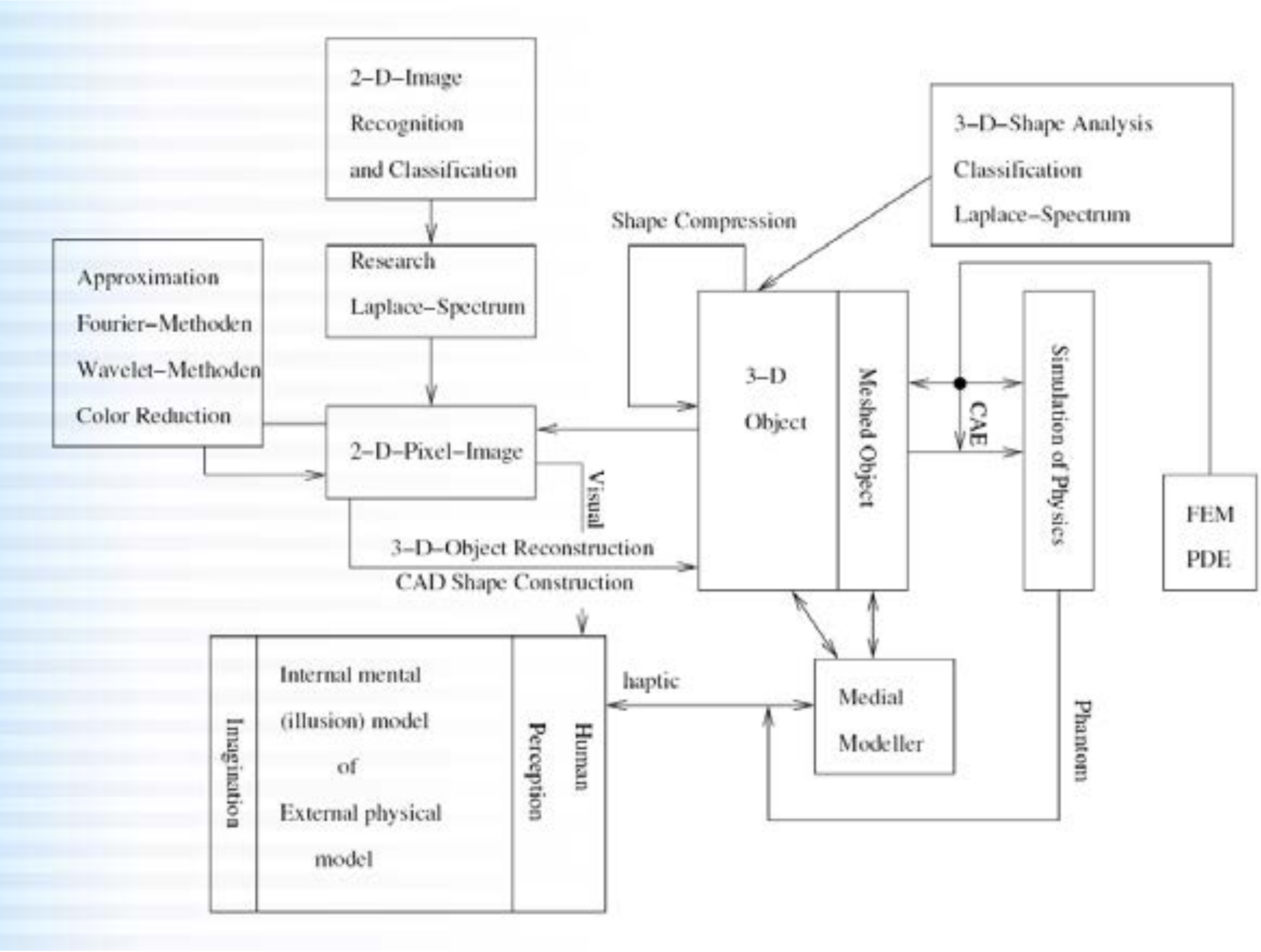
Structure of Doctoral-Research at the Welfenlab

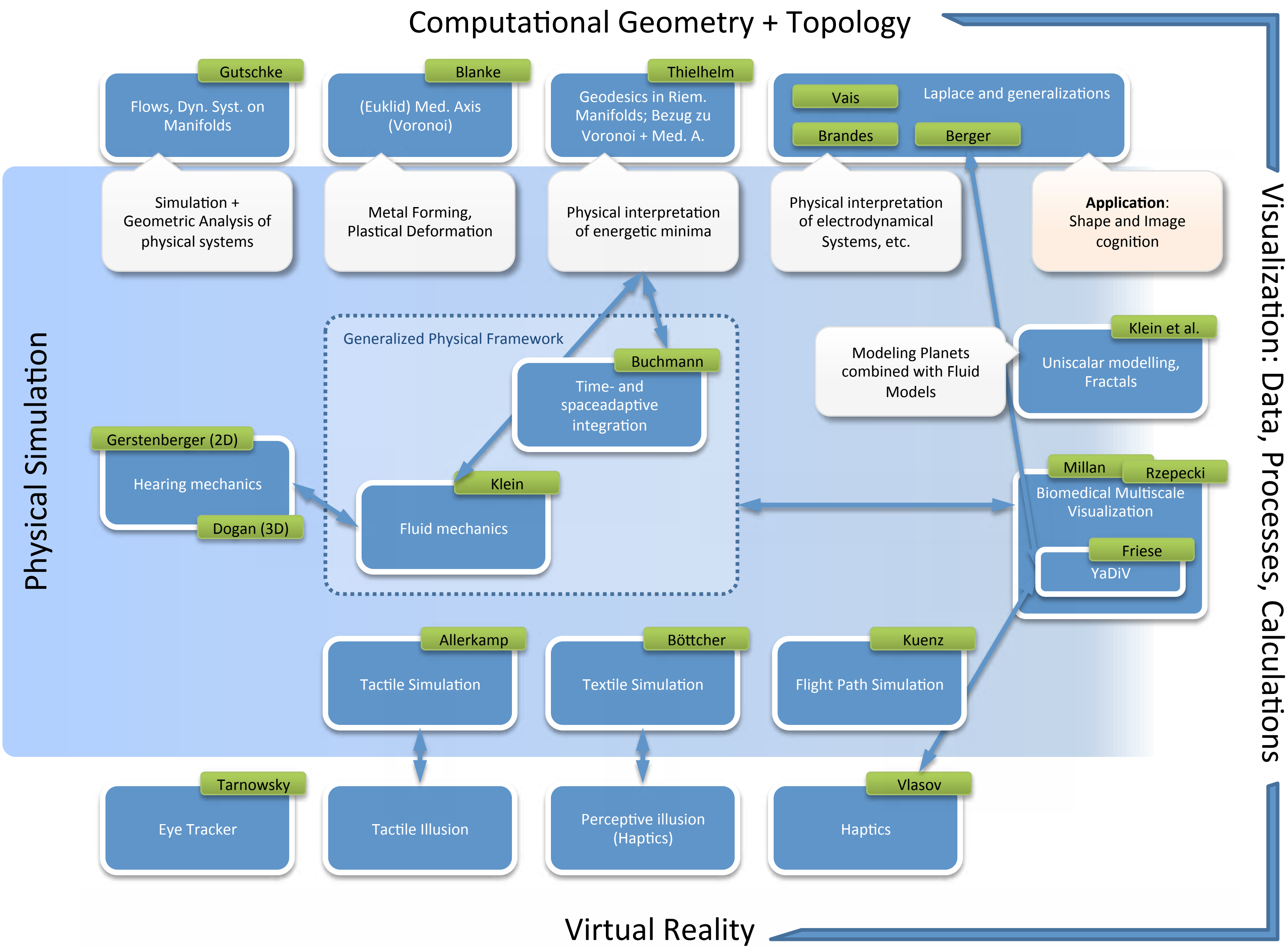
F.-E. Wolter

Welfen Laboratory

Institute of Man-Machine-Communication
Leibniz University of Hannover

RELATION OF CONCEPTS (AROUND 2003)





Computational Geometry + Topology
Gutschke
Flows, Dyn. Syst. on Manifolds
Blanke
(Euklid) Med. Axis (Voronoi)
Thielhelm
Geodesics in Riem. Manifolds; Bezug zu Voronoi + Med. A.
Vais
Laplace and generalizations
Brandes
Berger
Simulation + Geometric Analysis of physical systems
Metal Forming, Plastical Deformation
Physical interpretation of energetic minima
Physical interpretation of electrodynamical Systems, etc.
Application: Shape and Image cognition
Physical Simulation
Generalized Physical Framework
Buchmann
Time- and spaceadaptive integration
Modeling Planets combined with Fluid Models
Klein et al.
Uniscalar modelling, Fractals
Gerstenberger (2D)
Hearing mechanics
Dogan (3D)
Klein
Fluid mechanics
Millan
Rzepecki
Biomedical Multiscale Visualization
Friese
YaDiV
Allerkamp
Tactile Simulation
Böttcher
Textile Simulation
Kuenz
Flight Path Simulation
Tarnowsky
Eye Tracker
Tactile Illusion
Perceptive illusion (Haptics)
Vlasov
Haptics
Visualization: Data, Processes, Calculations
Virtual Reality

Welfenlab Research

0. Preface: Dynamical Systems

Dynamical Systems

General form: e.g.

$$x''(t) = M^{-1} \cdot F(x(t), x'(t))$$

e.g.: used in Haptex simulations cf. slide 23

Böttcher, G.: Haptic Interaction with Deformable Objects: Modelling VR Systems for Textiles. Springer Series on Touch and Haptic Systems, Springer (2011).

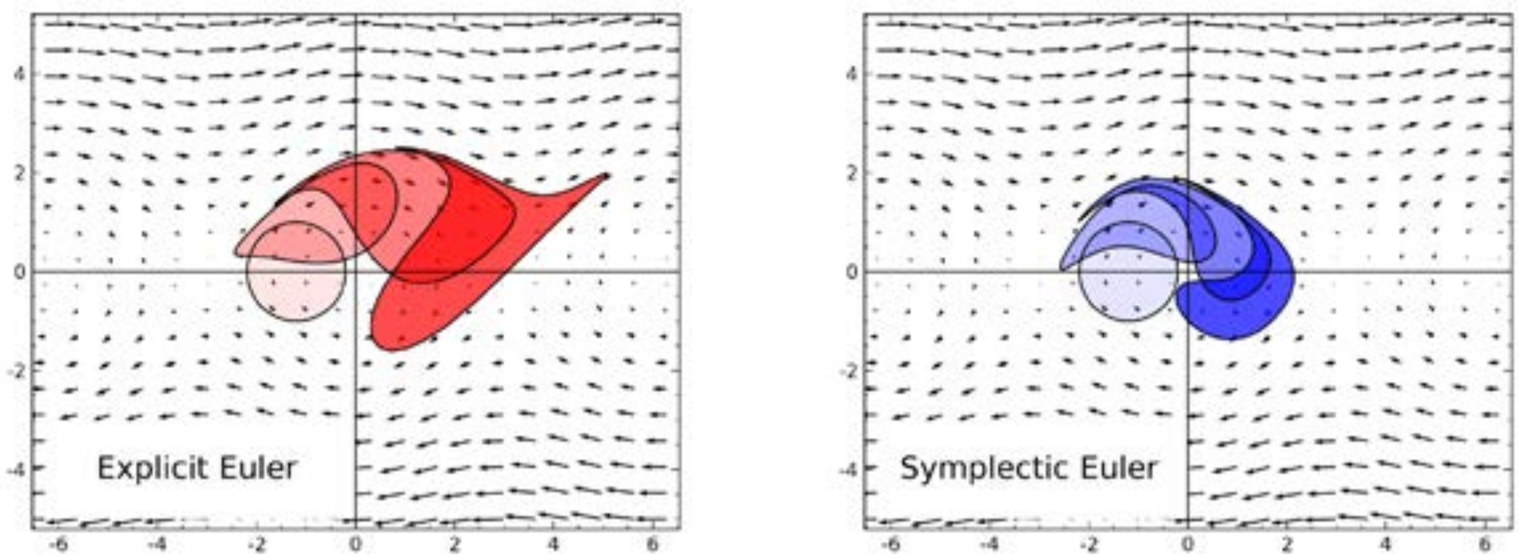
Dynamical Systems

General form: e.g.

$$x''(t) = M^{-1} \cdot F(x(t), x'(t))$$

Example: Pendulum

- Energy (area) should be conserved
- Result quality depends on chosen integration method



Welfenlab Research

1. Computational Geometry and Topology

Dynamical Systems on Submanifolds in Euclidean Space

Problem Statement

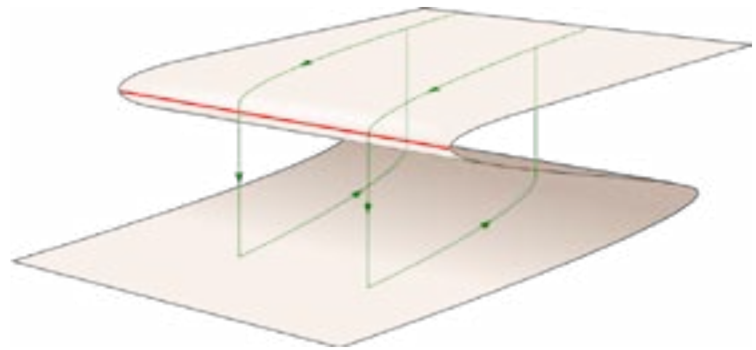
- Study Solutions (Flow Map) $\varphi(x,t)$ of $y' = G(x,t)$

  $t \mapsto \varphi(x,t)$ with $\frac{d}{dt}\varphi(x, t) = G(\varphi(x, t), t)$
- Analyze dynamical system with orbits on submanifold S
- S defined implicitly by $F(x) = c$
- Following a point controlled by this system
- Point moves slow while on S and fast while not on S.

DYNAMICAL SYSTEMS ON SUBMANIFOLDS IN EUCLIDEAN SPACE

Applications

- Analyzing Physical Systems,
  - electrical cicuit system
  - Mechanical and biological systems
- Helpful studying periodic orbits



Gutschke, M., Vais, A., Wolter, F.-E.: Differential geometric methods for examining the dynamics of slow-fast vector fields. The Visual Computer. 31, 169–186 (2015).

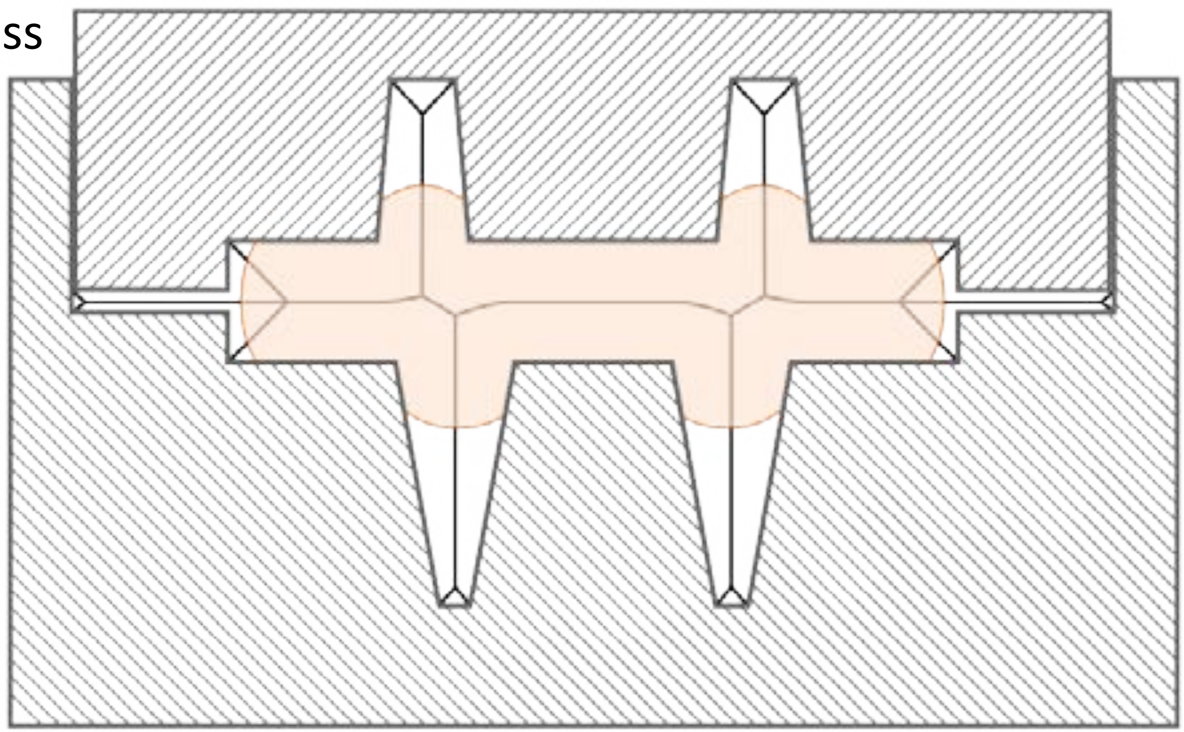
SPECIAL PLASTIC DEFORMATIONS & MEDIAL AXIS

Problem Statement

- Compute the inverse φ^{-1} of a computable Flow map $\varphi(x, t)$
- Interesting in Metal Forming process

- This problem turns out to be very difficult, see:
  - *"Current theoretical approaches to collective behavior of dislocations"*, G. Ananthakrishna
  - *"Plastic Deformations and Dynamical Systems"*, Kubin, L.P., Fressengeas, C., Ananthakrishna, G. (2002)

Behrens, B.A., Blanke, P., Hadifi, T., Wolter, F.-E., Santangelo, A.: Fast 3D inverse simulation of hot forging processes via Medial Axis Transformation: An approach for preform estimation in hot die forging. Prod. Eng. 7, 409–416 (2013).



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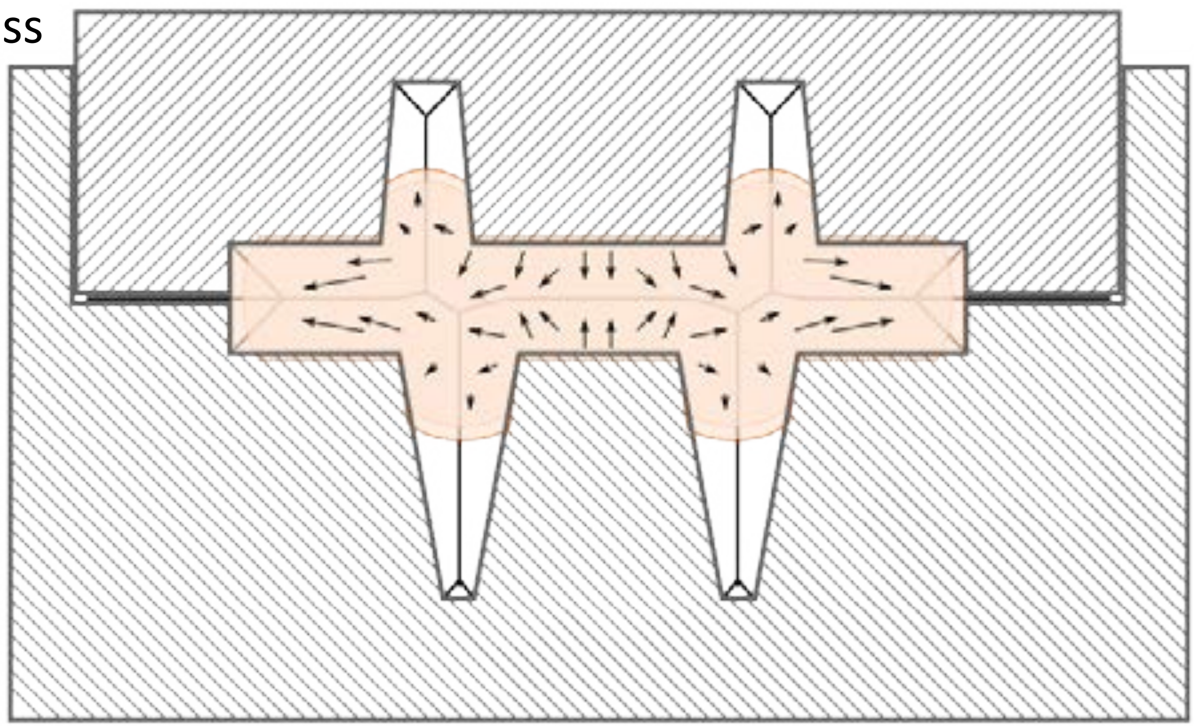
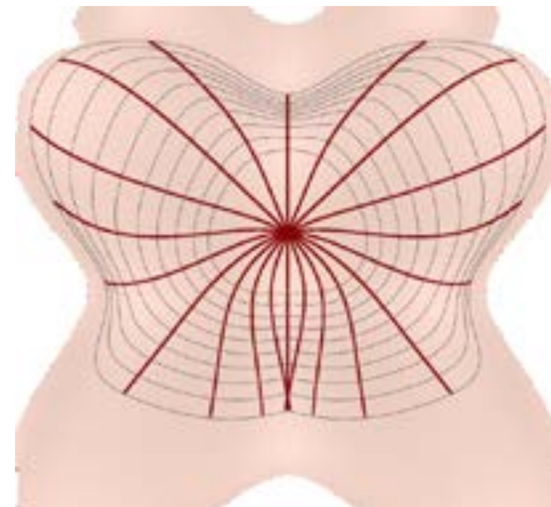


Geodesics in Riemannian Manifolds

- Described by special dynamical systems defined by the geometry of the manifold
- Differential equation: $y' = \Gamma(y, t)$
- Special flow maps: Offset/Exponential maps $O(y, t)$ offset geometries
- More specialized notation:
  $\exp(x, t)$, inverse: $\exp^{-1}(\exp(x, t))$



- Study Focal Sets, i.e. where $D\exp$ has not maximal rank
- Study Flow Map, its inverse and singularities
  - Use it to analyze the distance geometry of a Riemannian Manifold

Wolter, F.-E., Blanke, P., Thielhelm, H., Vais, A.: Computational differential geometry contributions of the Welfenlab to GRK 615. modelling, simulation and software concepts for scientific-technological problems. pp. 211–235. Springer (2011).

Thielhelm, H., Vais, A., Wolter, F.-E.: Geodesic bifurcation on smooth surfaces. Visual Computer. 31, 187–204 (2014).

Geodesics in Riemannian Manifolds

Physical interpretation

- Geodesic $g(t)$ from p to q is local minimizer (stationary point) of energy $\int \left| g'(t)^2 \right|$ by comparison with close neighbor paths joining p and q.

LAPLACE

- Use computations in the context of Laplace operator or its generalizations and modifications to analyze and classify geometry of
  - shapes
  - images

Reason:

Laplace operator and its eigenfunctions and eigenvalues are related to shape of geometric objects.

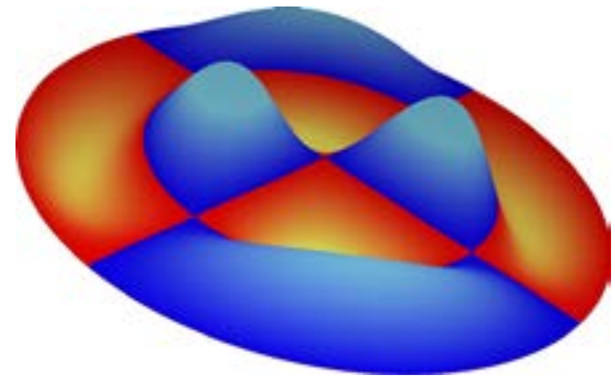
LAPLACE

Wave equation: $u_{tt}(t, x) = \Delta_x u(t, x)$

Heat equation: $u_t(t, x) = \Delta_x u(t, x)$

Separation of variables: $u(t, x) = \upsilon(x) \cdot T(t)$

Eigenvalue equation: $\Delta \upsilon = \lambda \upsilon$



Eigenvalues (spectrum): $\lambda_1, \lambda_2, \ldots$

Eigenfunctions: $\upsilon_1, \upsilon_2, \ldots$

Heat Kernel:

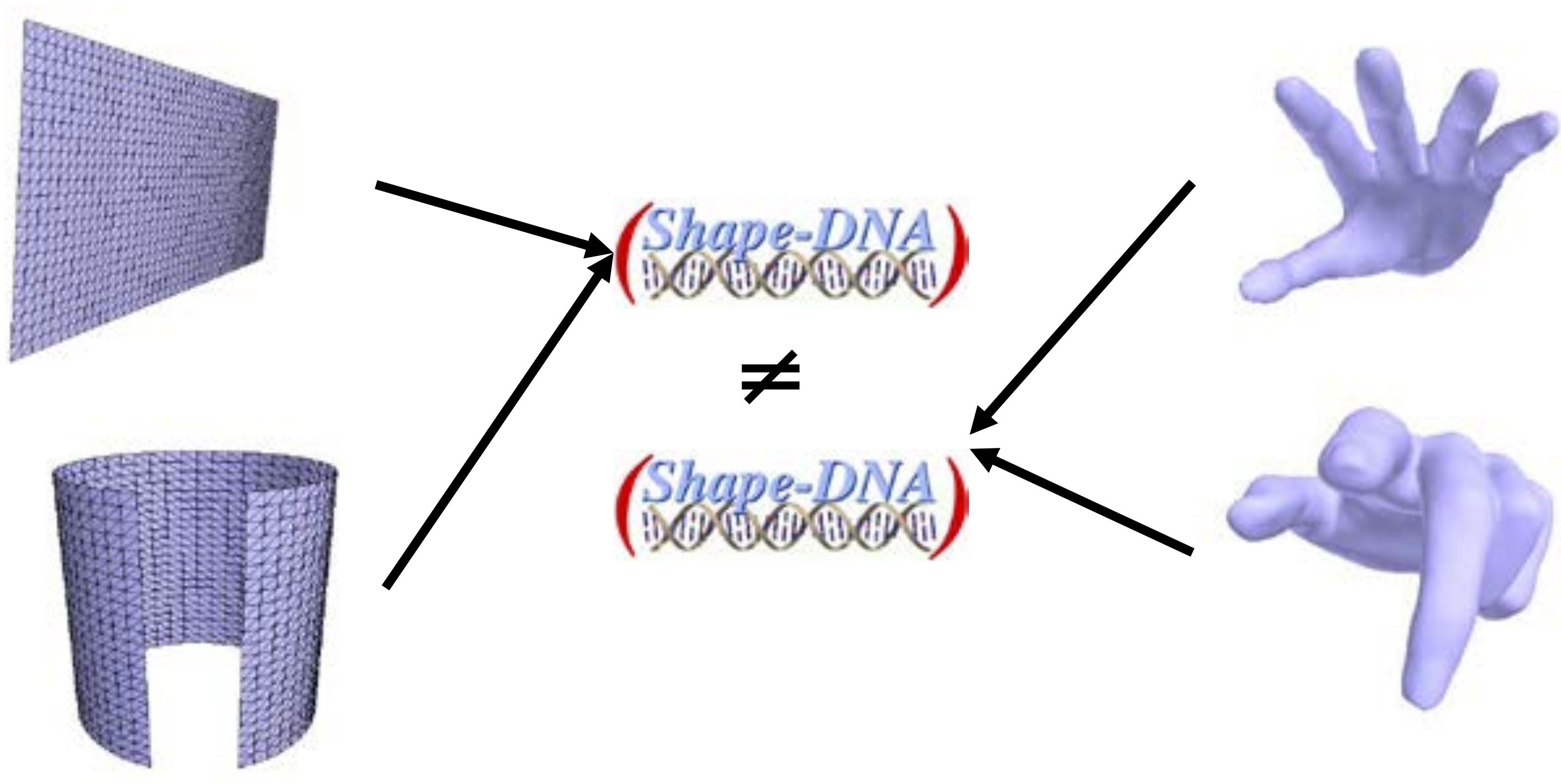
$$K(t, x, y) = \sum_{i=1}^{\infty} e^{-\lambda_i t} \upsilon_i(x)\, \upsilon_i(y)$$

Heat Trace:

$$\int_M K(t, x, y) = \sum_{i=1}^{\infty} e^{-\lambda_i t} \xrightarrow{t \to 0} A_S(c_0, c_1, c_2, t)$$

LAPLACE SPECTRA AS SHAPE-DNA

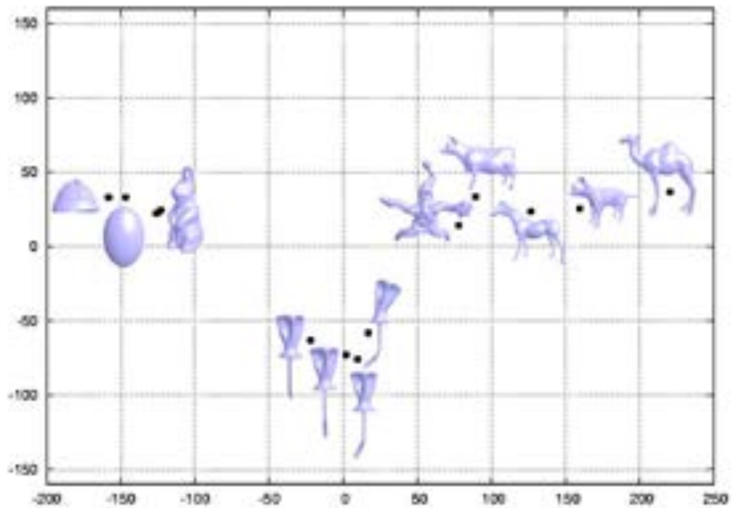
- **Theorem**: Isometric shapes => Same Laplace spectra



Wolter, F.-E., Peinecke, N., Reuter, M.: A Method for the Characterization of Objects (Surfaces, Solids and Images). Patent application (2005).

"Shape-DNA" of surfaces and solids. Comput.-Aided Des. 38, 342–366 (2006).

Shape-DNA for geometry



Applicable for:

- 2D surfaces
- 3D volumetric data

Shape-DNA for images

Applicable for:

- Monochromatic images
- Greyvalue images
- RGB images
- 3D (Voxel) images

Peinecke, N., Wolter, F.-E., Reuter, M.: Laplace spectra as fingerprints for image recognition. Comput.-Aided Des. 39, 460–476 (2007).

LAPLACE: SPECTRAL INFORMATION

Eigenvalues/Heat Trace determine:

- Volume
- Volume of boundary
- Curvature integrals
- Euler characteristic
- …

Spectrum can be used as „Shape-DNA" for

- Surfaces
- Solids
- Images
- …

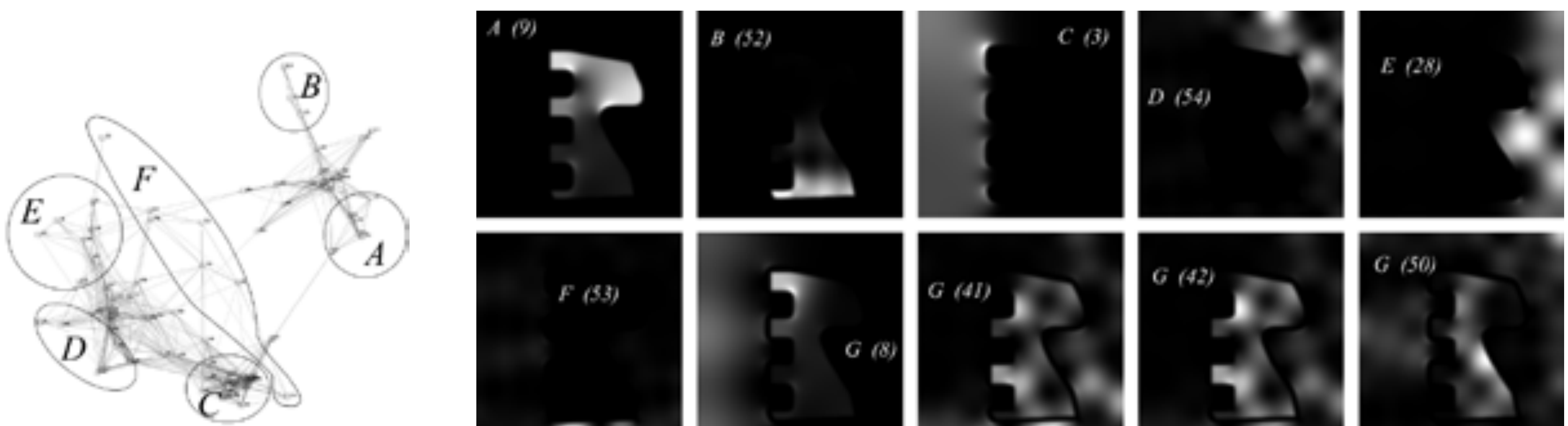
Wolter, F.-E., Peinecke, N., Reuter, M.: A Method for the Characterization of Objects (Surfaces, Solids and Images). Patent Apllication (2005).

GENERALIZATIONS AND CURRENT RESEARCH

- Laplacians on vectorbundles
  - Zero-sets of eigenfunctions
  - Hyperbolic manifolds

Vais, A., Brandes, D., Thielhelm, H., Wolter, F.-E.: Laplacians on flat line bundles over 3-manifolds. Comput. Graph. 37, 718–729 (2013).

- Extended descriptors (partial matching, …)



Berger, B., Vais, A., Wolter, F.-E.: Subimage sensitive eigenvalue spectra for image comparison. Vis. Comput. 1–17 (2014).

Welfenlab Research

2. Virtual Reality

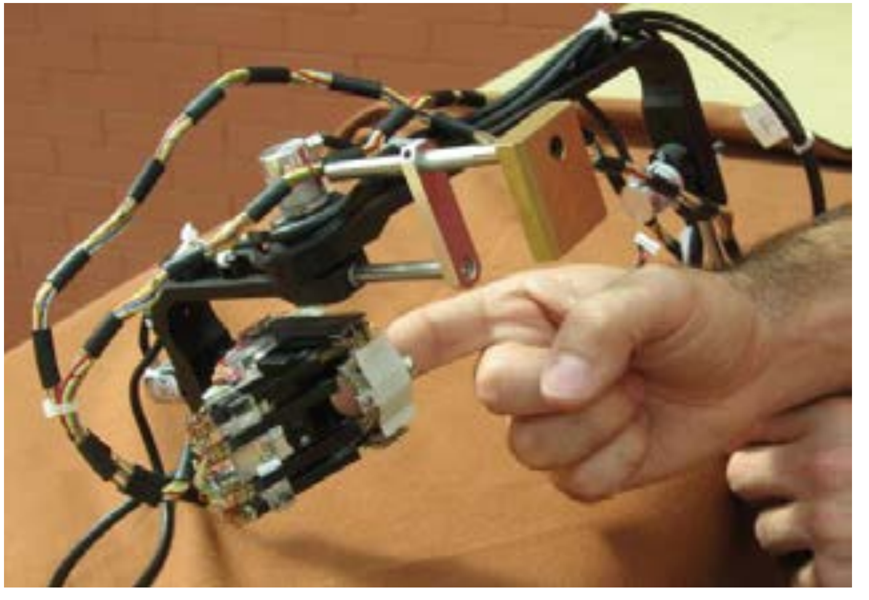
Virtual Reality: Basics

Three important areas for realistic Virtual Worlds

A. Visual
B. Tactile
C. Haptic

Tactile Simulation

Physical Simulation Tactile Signal



- Physical Models yields relevant Tactile Data T(t)
- Signal (usually) created by a Tactile array
- Relevant class of Signals to create illusion (Tactile Color)

Allerkamp, D., Böttcher, G., Wolter, F.-E., Brady, A.C., Qu, J., Summers, I.R.: A vibrotactile approach to tactile rendering. Vis. Comput. 23, 97–108 (2007).

Allerkamp, D.: Tactile Perception of Textiles in a Virtual-Reality System. Cognitive Systems Monographs,Springer (2010).

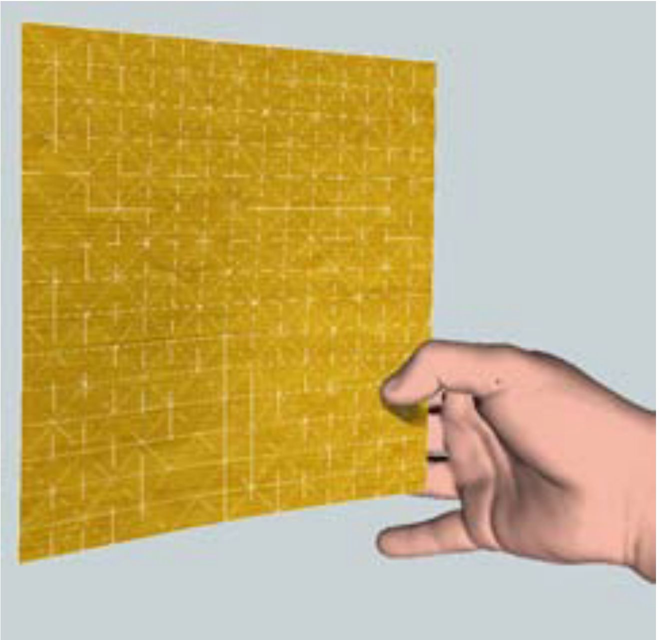
HAPTIC SIMULATION

- Solve a Dynamical System

$$M \cdot x''(t) = F(x(t),\, x'(t))$$

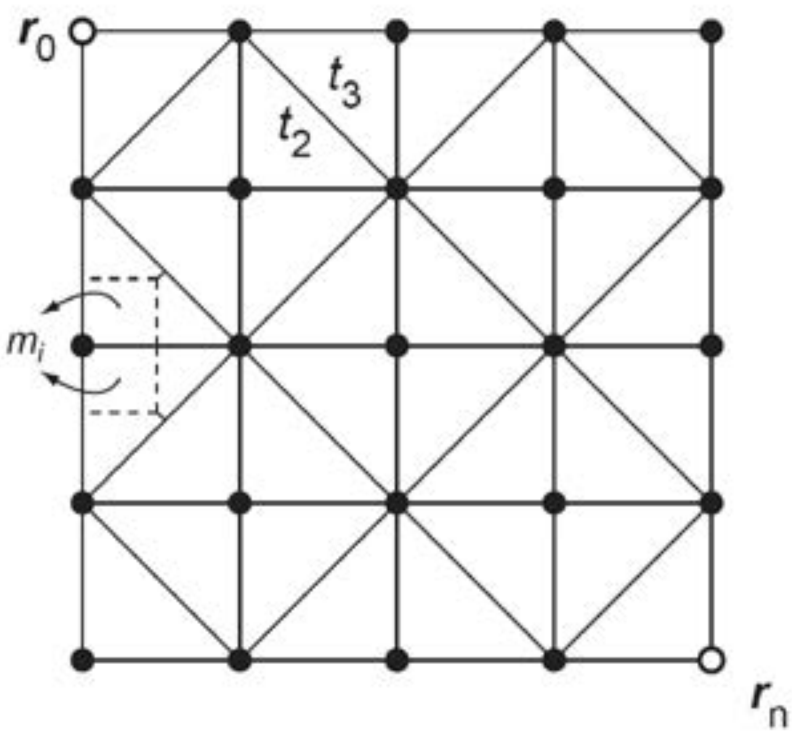
$$x''(t) = M^{-1} \cdot F(x(t),\, x'(t))$$

- Appropiate Integration needed
- Usually fast methods are required to achive 1000Hz



Böttcher, G.: Haptic Interaction with Deformable Objects: Modelling VR Systems for Textiles. Springer Series on Touch and Haptic Systems, Springer (2011).

HAPTIC SIMULATION



- Interpretion as a particle system
- Second order ODE:

$$r''(t) = F(r, r')M^{-1}$$

- Numerical integration of a *6n x 6n* matrix

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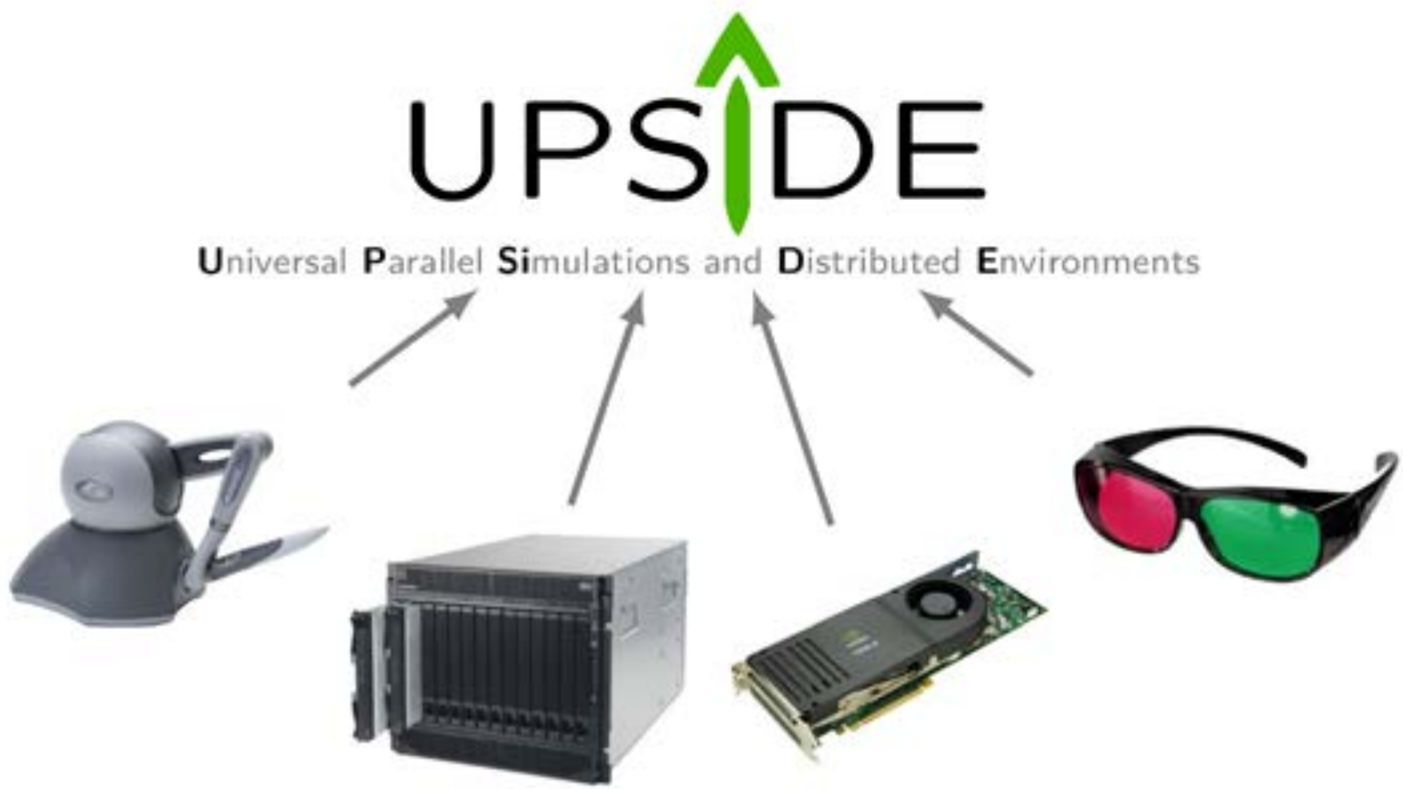
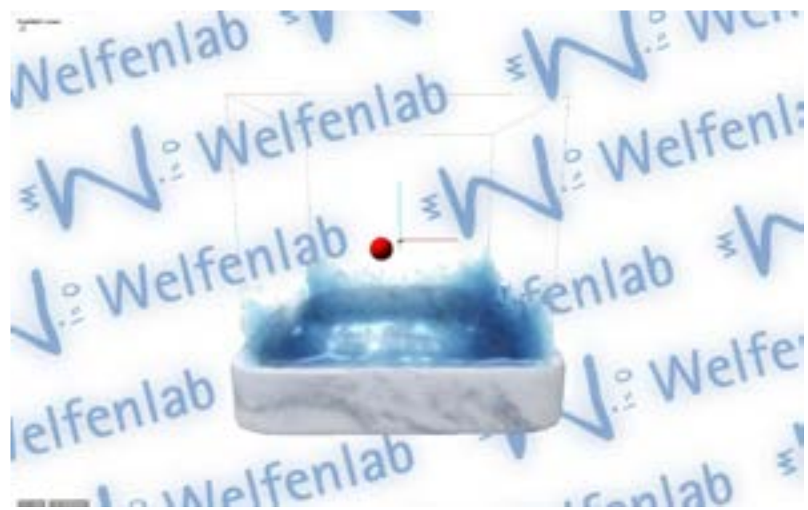
3. Physical Simulation

General extendable Physical Simulation Framework



COMPUTATIONAL METHODS FOR FLUID DYNAMICS

- Examination of different computational paradigms
  - Grid based (esp. Adaptive multigrid solvers)
  - Particle based (SPH, WCSPH, PCISPH, ISPH…)
- Research on fluid structure interaction (focussing on haptics)
- Relations to Riemannian Geometry as in *"Geometrical theory of Fluid Flows and dynamical systems"*, Tsutomu Kambe



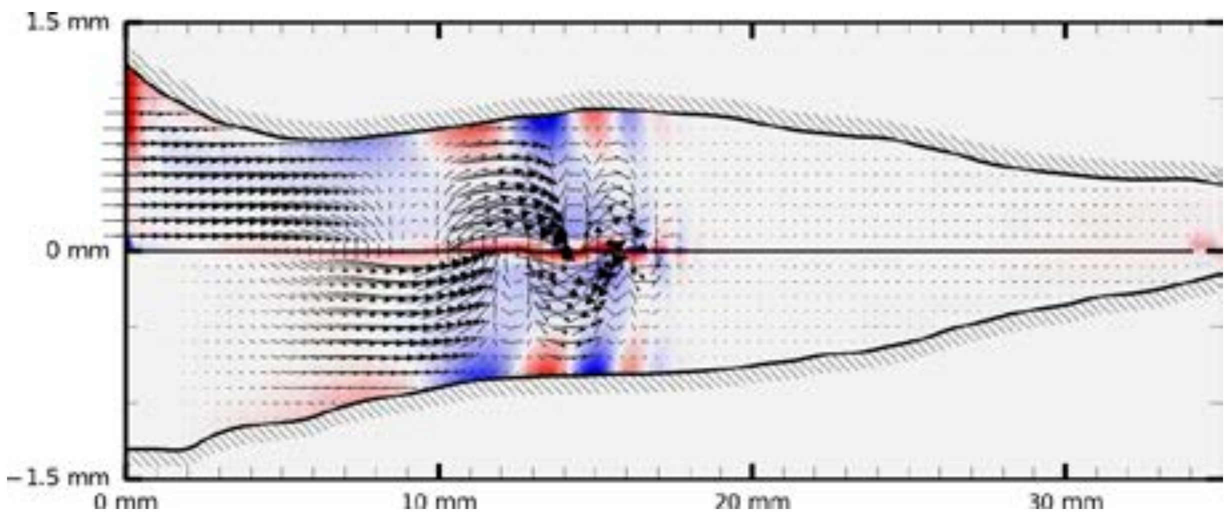
Kambe, T.: Geometrical theory of fluid flows and dynamical systems. Fluid Dyn. Res. 30, 331–378 (2002)

HEARING MECHANICS

2D Simulation

- Accustic streaming analysis
- FEM solution for cochlea mechanics in every single time step (involving Navier-Stokes, etc.)
- Solving a huge dynamical system

$$M(t)\ u''(t) + H(t)\ u'(t) + K(t)\ u(t) = F(t)$$

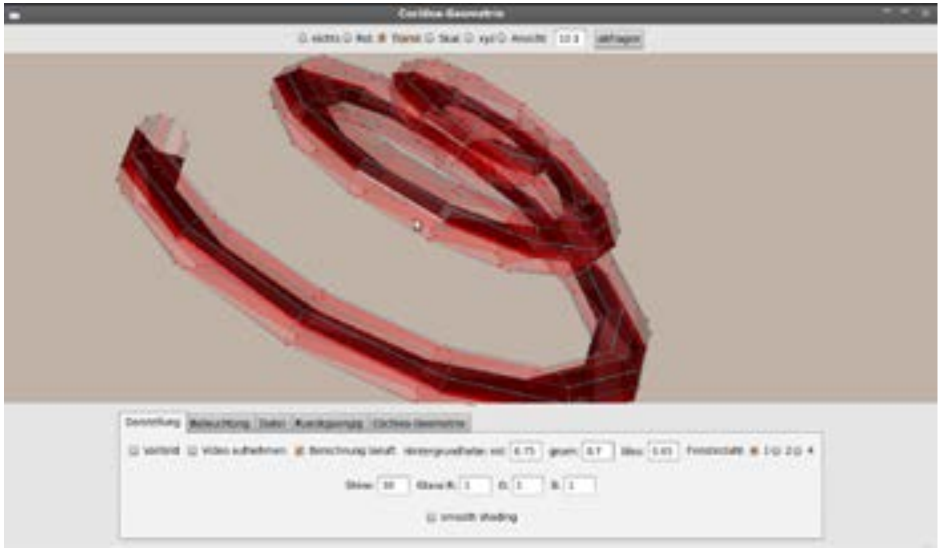


Gerstenberger, C., Wolter, F.-E.: Numerical Simulation of Acoustic Streaming Within the Cochlea. Journal of Computational Acoustics. 21, 1350019 1–37 (2013).

Hearing Mechanics

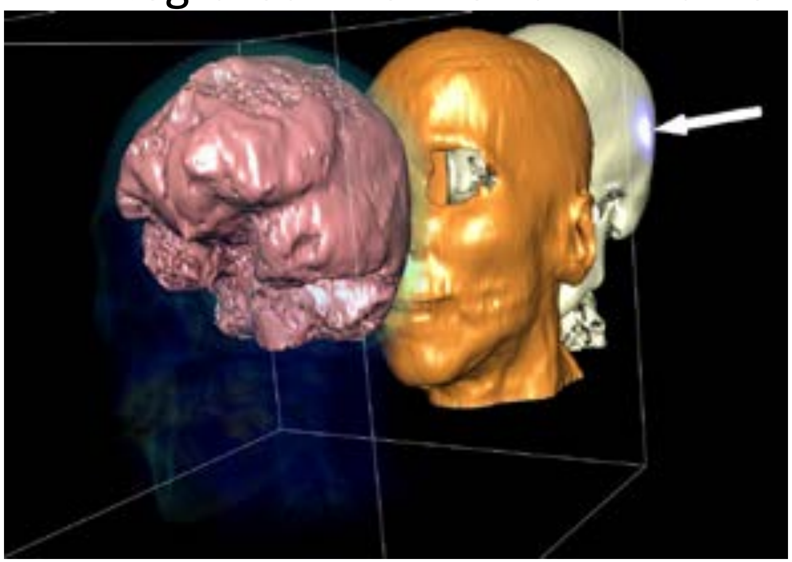
3D Simulation

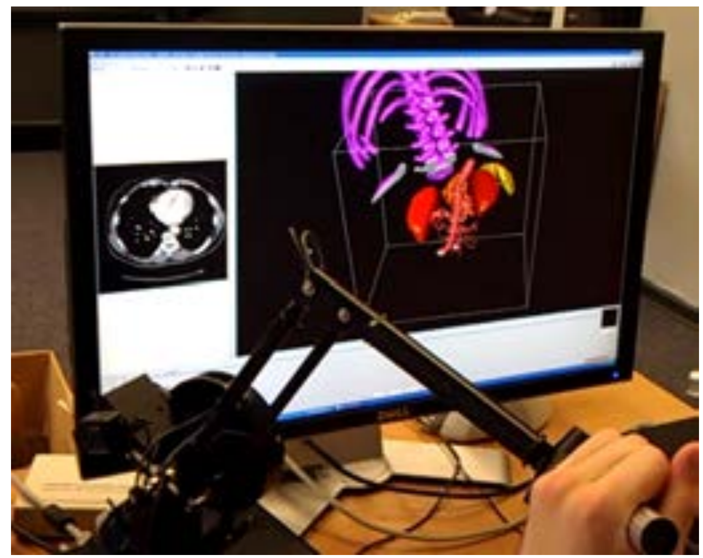
- Extension to the 3D case
- Non-FEM approach (FDM / Lattice Boltzman)
- Use Cluster for calculations



Haptic Interaction with 3D Voxel Data

- Haptic Realtime Challenge
- Similar to "normal Haptic Simulation"
- Use raycasting to check for contacts
- Allow interactive deformations with haptic feedback
- Integrated into the YaDiV framework





Vlasov, R., Friese, K.-I., Wolter, F.-E.: Haptic rendering of volume data with collision detection guarantee using path finding. Transactions on Computational Science XVIII. pp. 212–231. Springer (2013).

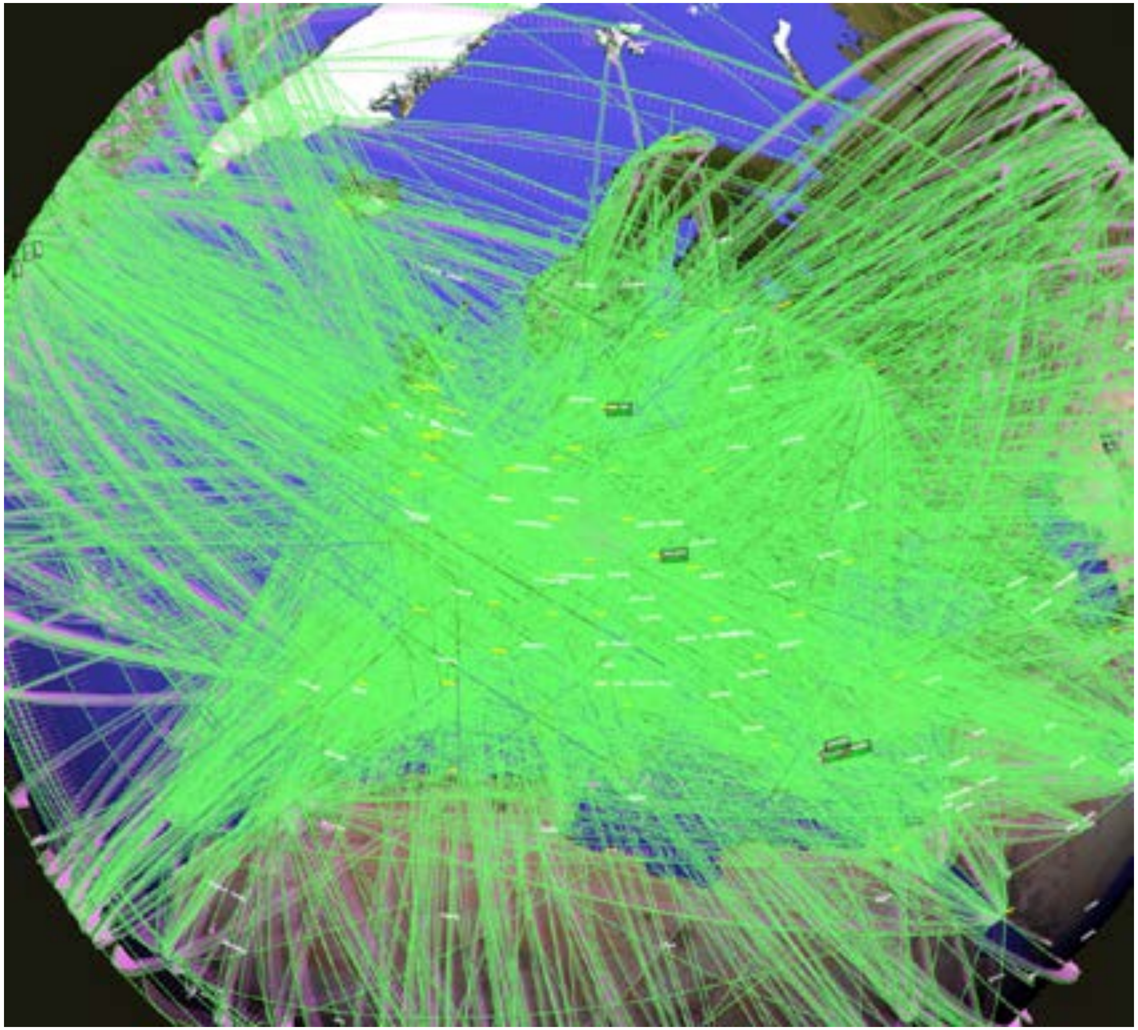
Vlasov, R., Friese, K.-I., Wolter, F.-E.: Haptic rendering of volume data with collision determination guarantee using ray casting and implicit surface representation. Cyberworlds (CW), 2012 International Conference on. pp. 91–98. IEEE (2012).

Vlasov, R., Friese, K.-I., Wolter, F.-E.: Ray casting for collision detection in haptic rendering of volume data. Proceedings of the ACM SIGGRAPH Symposium on Interactive 3D Graphics and Games. pp. 215–215. ACM, New York, NY, USA (2012).

FLIGHT PATH SIMULATION

Problem statement:

Many simultaneous flights



[Kuenz, A., Schwoch, G., Wolter, F.-E.: Individualism in global airspace-user-preferred trajectories in future ATM. Digital Avionics Systems Conference (DASC), 2013 IEEE/AIAA 32nd. pp. 1E1–1E13. IEEE (2013).]

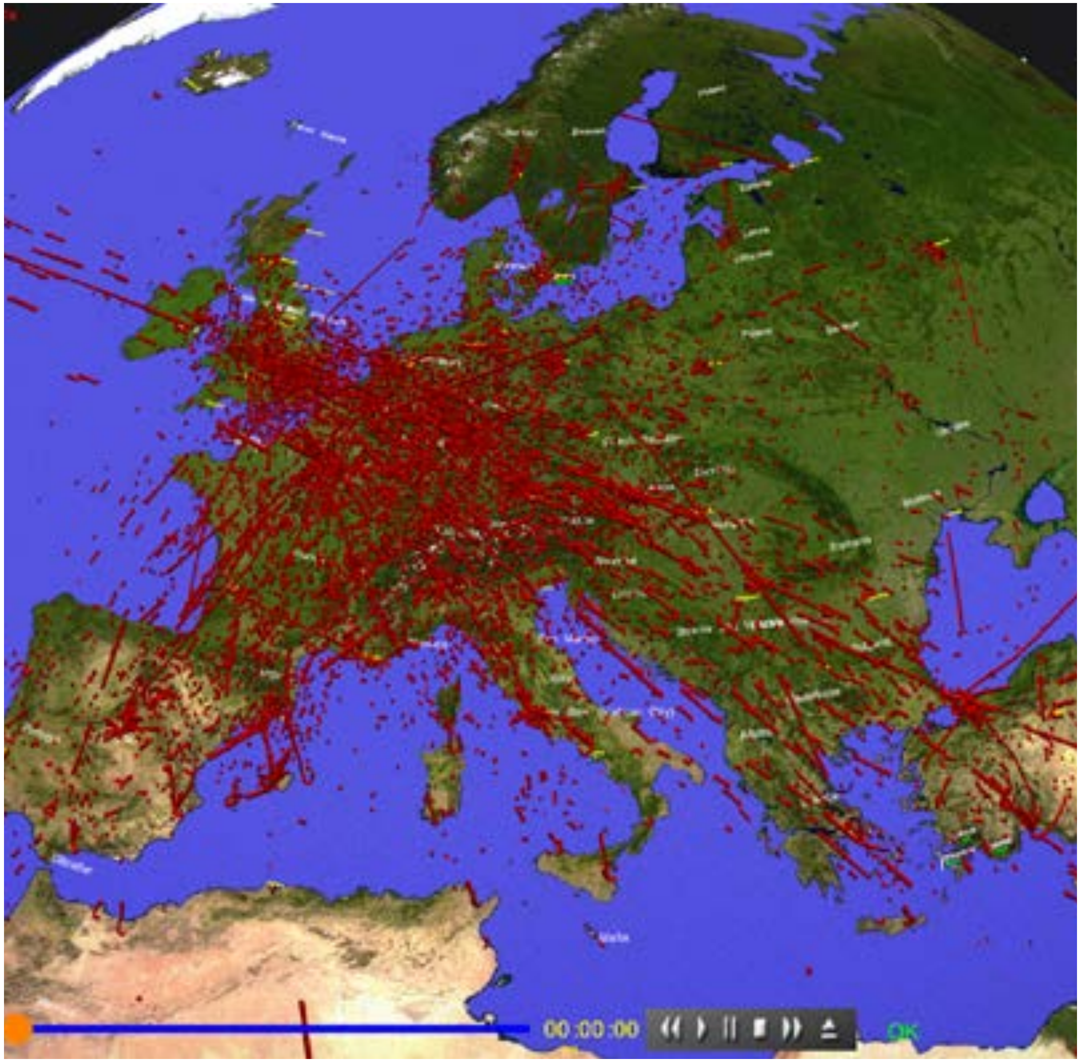
FLIGHT PATH SIMULATION

Problem statement:

Many simultaneous flights

Get a collision free dynamical system

- Use a 4 dimensional description (Hexadecimal Tree)
- Search adaptively in the 4 dimensional space



FLIGHT PATH SIMULATION

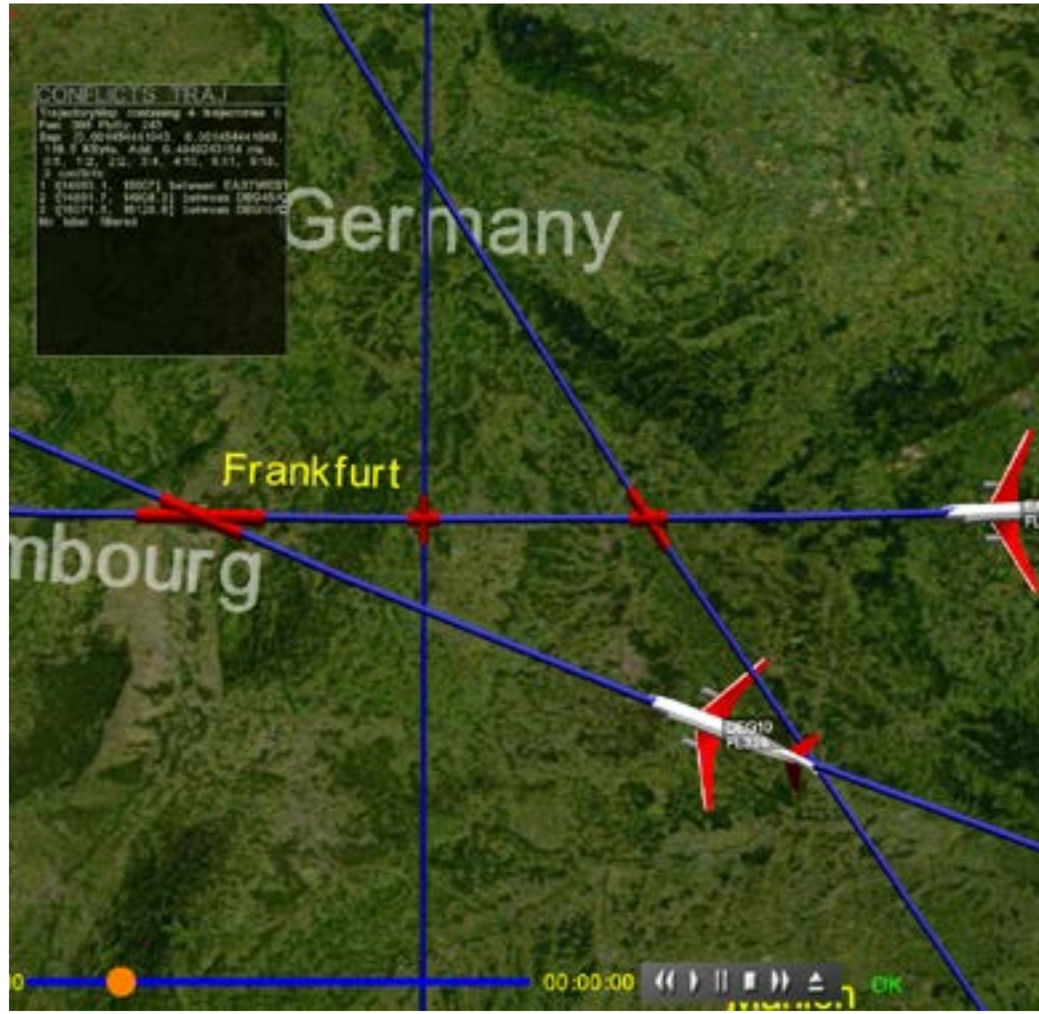
Problem statement:

Many simultaneous flights

Get a collision free dynamical system

Consider delaying flights to avoid collisions

The system has to be very fast to be of use



Welfenlab Research

4. Visualization

Visualization based on Fractal Models

- Discrete dynamic system generated by a self similar map

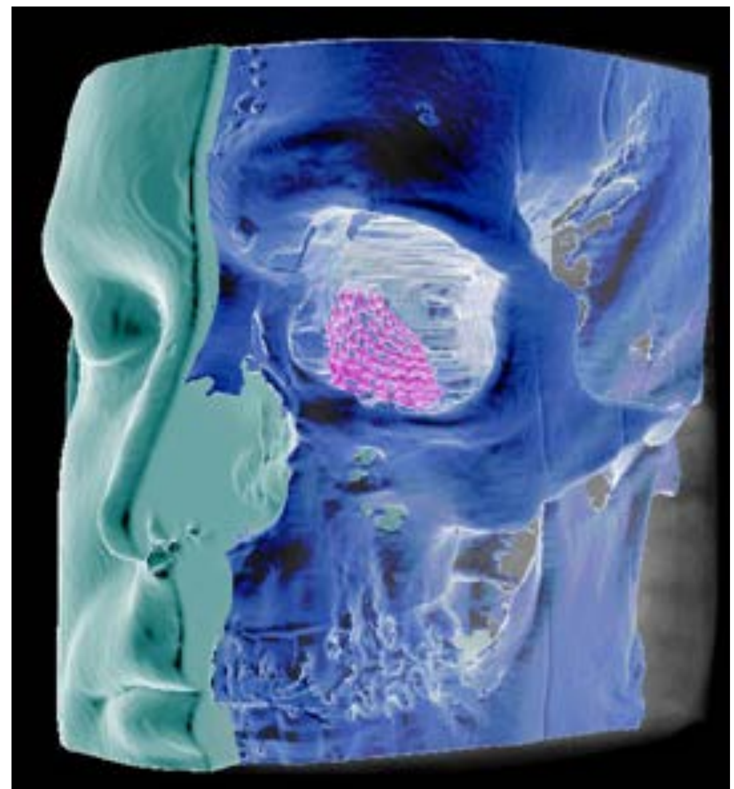
$$\lim(S^n(I))$$

  with being a initial seed set.
- Limit set → fractal
- Used to generate visualization data

Haase, F., Klein, M., Tarnowsky, A., Wolter, F.-E.: Interactive fractal compositions. Proceedings of the 11th ACM SIGGRAPH International Conference on Virtual-Reality Continuum and its Applications in Industry. pp. 181–188. ACM (2012).

3D Voxel based-Volume Visualization

- A function $\mathrm{P}(\mathrm{x})$ defined on 3D Voxel data
- Visualization of intensity data of this function (YaDiV)



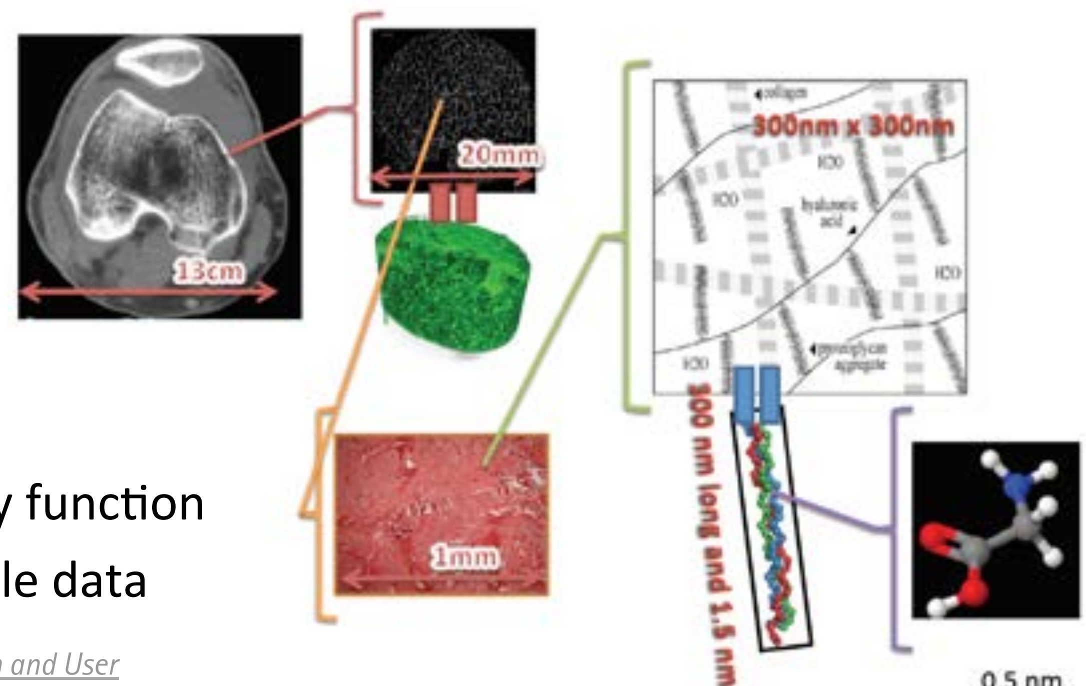
Friese, K.-I., Blanke, P., Wolter, F.-E.: YaDiV—an open platform for 3D visualization and 3D segmentation of medical data. Vis. Comput. 27, 129–139 (2011).

Biomed. Multi Scale Visualization

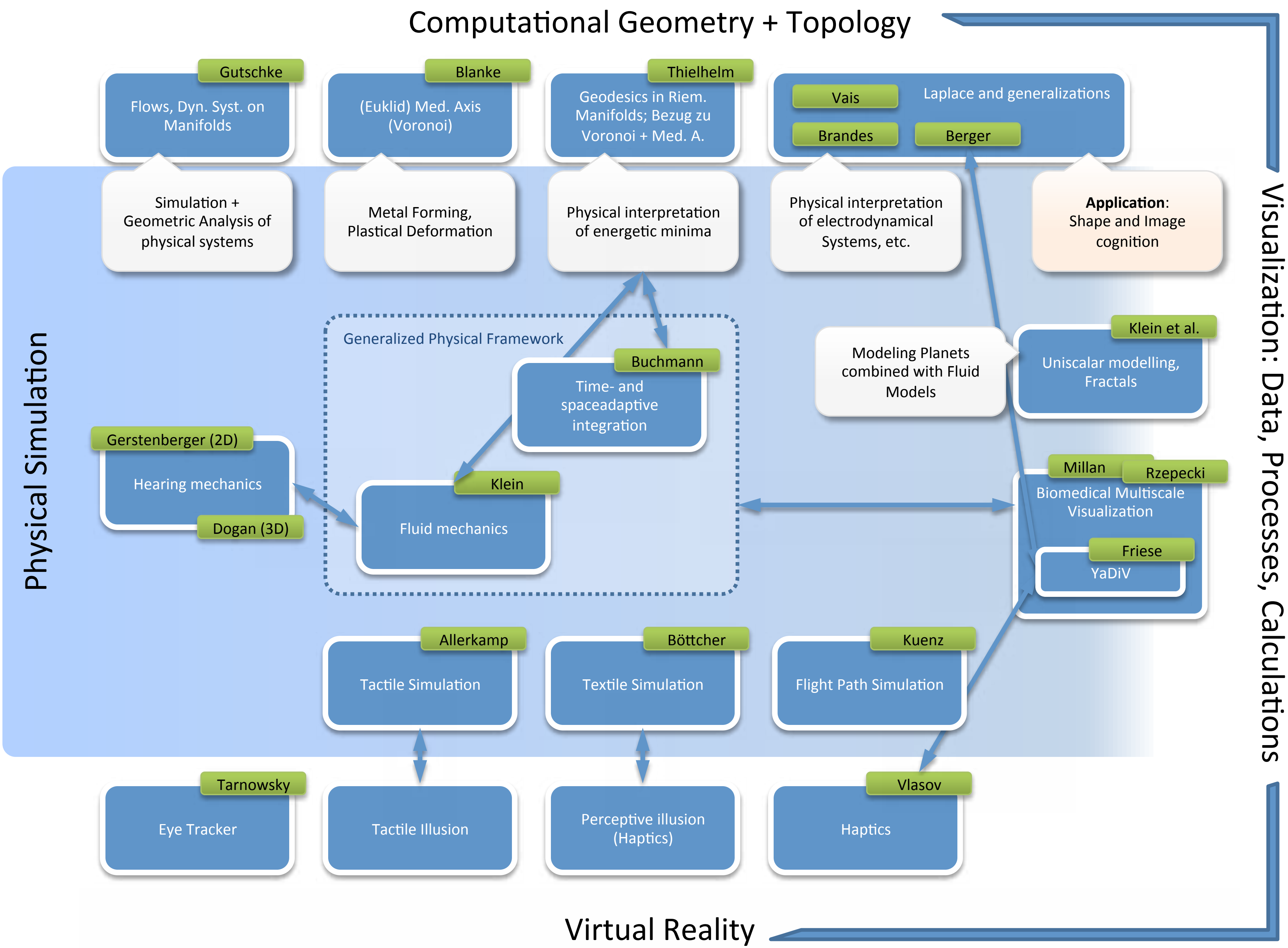
- Some of the 3D biomedical data can be visualized with YaDiV
- Important to handle processes that change over time on different time and length scales
- Visualized data
  - Computational results
  - Appropriate physical models involved

Example

- Biomedical CT-Data
  - Radon transform density function
  - Segmentation visualizable data



Millan, R., Rzepecki, J., Friese, K.-I., Wolter, F.-E.: Visualization and User Interaction Methods for Multi- Scale Biomedical Data. Multiscale Biological Human - Multiscale Biological Modalities for Physiological Human Articulation. Springer-Verlag London (2014).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Perceptive illusion (Haptics)
Vlasov
Haptics
Virtual Reality
Visualization: Data, Processes, Calculations