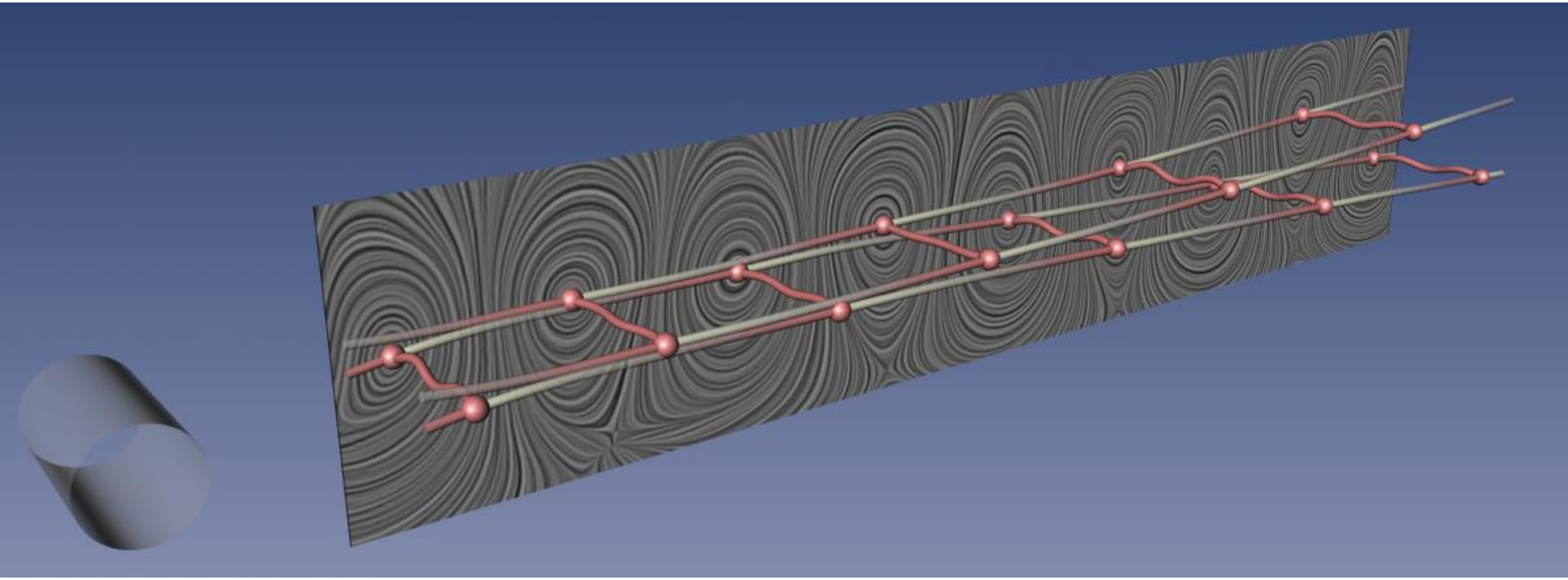
Feature-Based Flow Visualization



Tino Weinkauf

HPCViz, CSC, KTH Stockholm

- **Professor of Visualization**
  HPCViz, CSC, KTH Stockholm

- **Research Group Leader**, 2011 – 2014
  Max Planck Institute for Informatics,
  Saarbrücken, Germany

- **Adjunct Assistant Professor**
  Postdoc, 2009 – 2011
  Courant Institute of Mathematical Sciences,
  New York University

- **Researcher, PhD**, 2001 – 2009
  Zuse Institute Berlin / University of Magdeburg

- Studies: Computer Science at University of Rostock

Tino Weinkauf

Tino Weinkauf

Chris Peters

Mario Romero

Björn Thuresson

Professor

Associate Professors

VIC

PhD students

Engineer

Gregorio Palmas

Himangshu Saikia

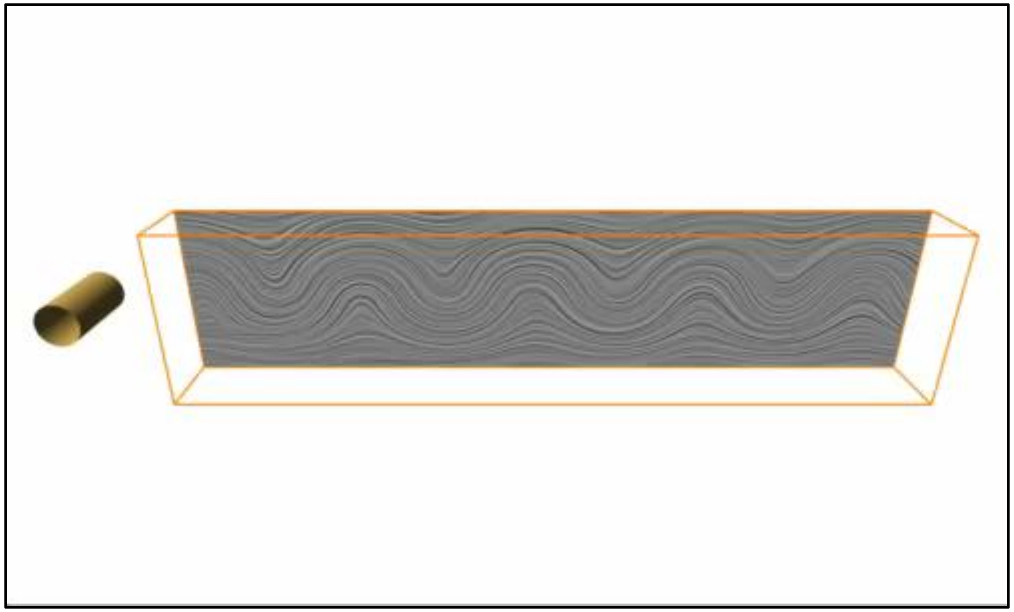
Zhongjie Wang
@ MPI

Henrik Edlund

- **Professor of Visualization**
  Linköping University
- **Research Group Leader**, 2012 – 2014
  DLR, Göttingen, Germany
- **Emmy Noether Group Leader**, 2006 – 2012
  Zuse Institute Berlin
- **Postdoc**, 2003 – 2006
  UC Davis, U.S.A.
- **PhD**, 1999 – 2003
  University of Kaiserslautern, Germany
- Studies: Physics at University of Munich

Ingrid Hotz


Milestones in Flight History
Dryden Flight Research Center
NASA
L-1011
Airliner Wing Vortice Tests at Langley
Circa 1970s



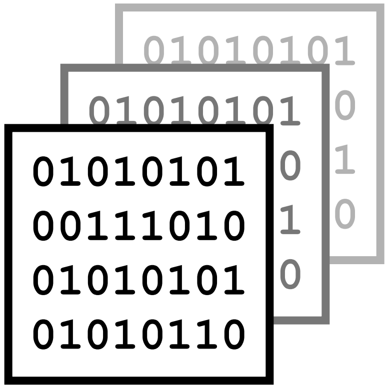
Flow behind a cylinder. Data courtesy of Bernd R. Noack (TU Berlin).

- mimicking real-world visualizations
- enhanced visualizations
- feature-based visualizations

Data

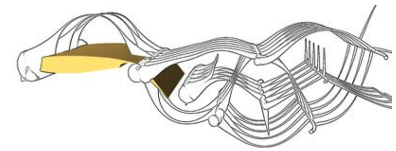
Visualization

Insight

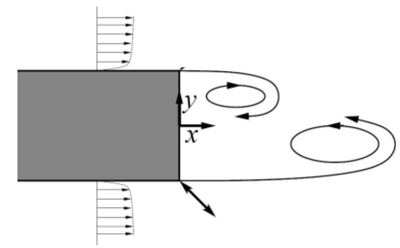


Large data sets,
multi-run simulations,
uncertainty,
noise, …

automated
target-oriented
objective



Descriptors



Conceptual models

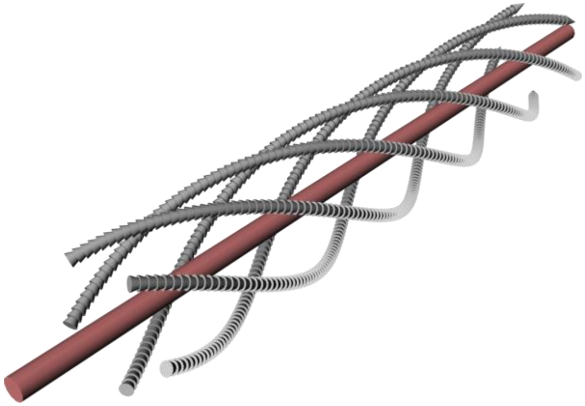
Feature-Based Visualization

reduction of information

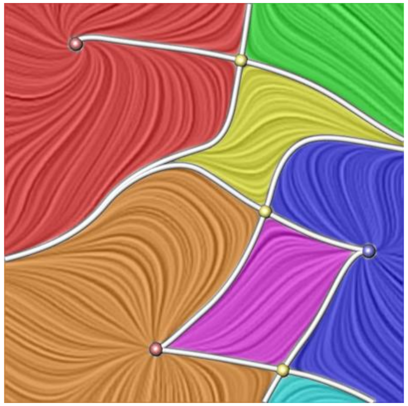
interactive visualization

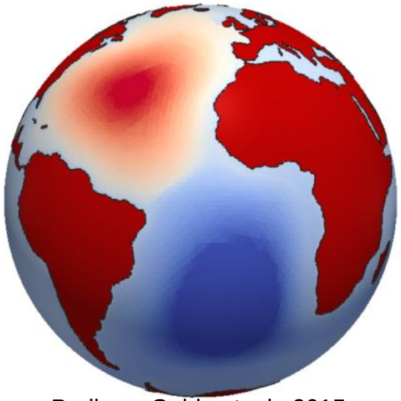
faster analysis

vortex structures



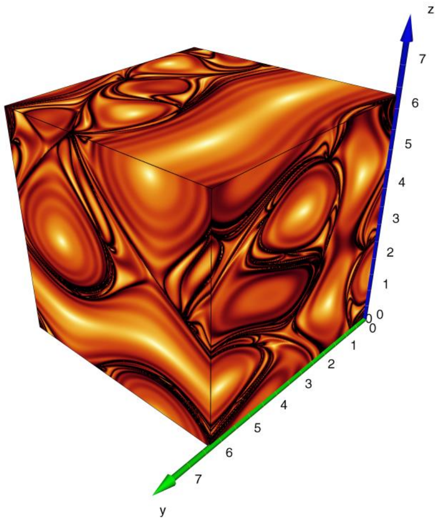
topological structures





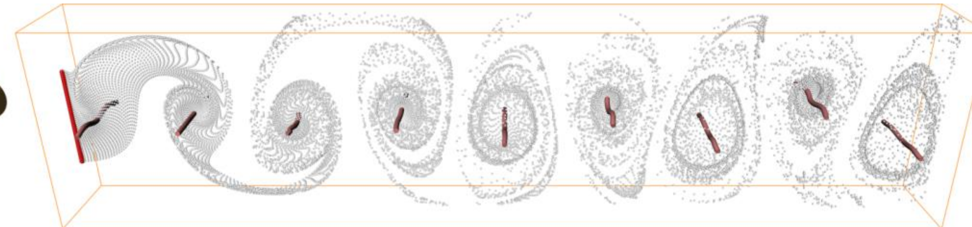
Padberg-Gehle et. al., 2015

almost-invariant sets



Lagrangian structures

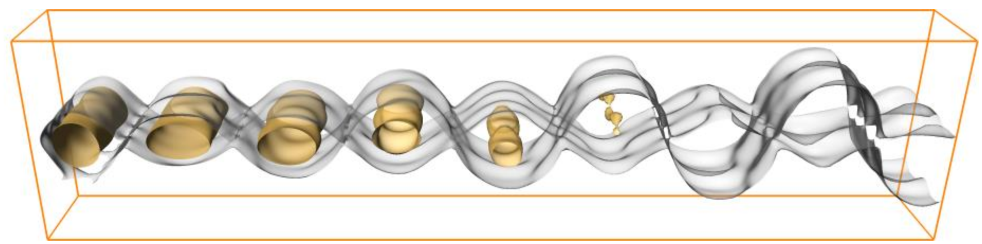
Cores of swirling motion
geometry of particle trajectories



Swirling motion cores for path lines

Vortex quantities

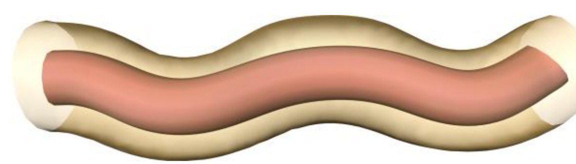
- λ_2, Okubo-Weiss, pressure, …



Isosurfaces of Okubo-Weiss parameter

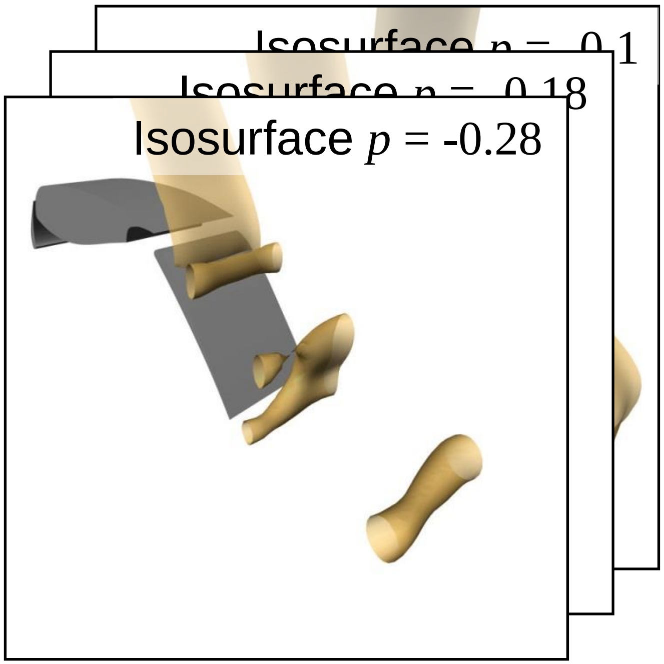
Vortex cores as extremal lines

- Height ridges/valleys
- Separatrices of the topological skeleton



Maximal line of Okubo-Weiss

Classic Visualization



user interaction required
full resolution required

Feature-based Visualization

automation possible

Simulation

data too large to
save in full resolution

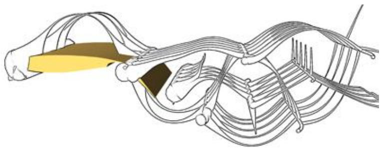
Feature Extraction

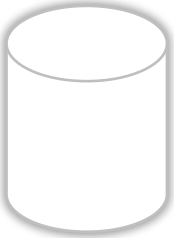
in-situ

versatile framework for defining features

notion of feature strength

track over time





Interactive Visualization

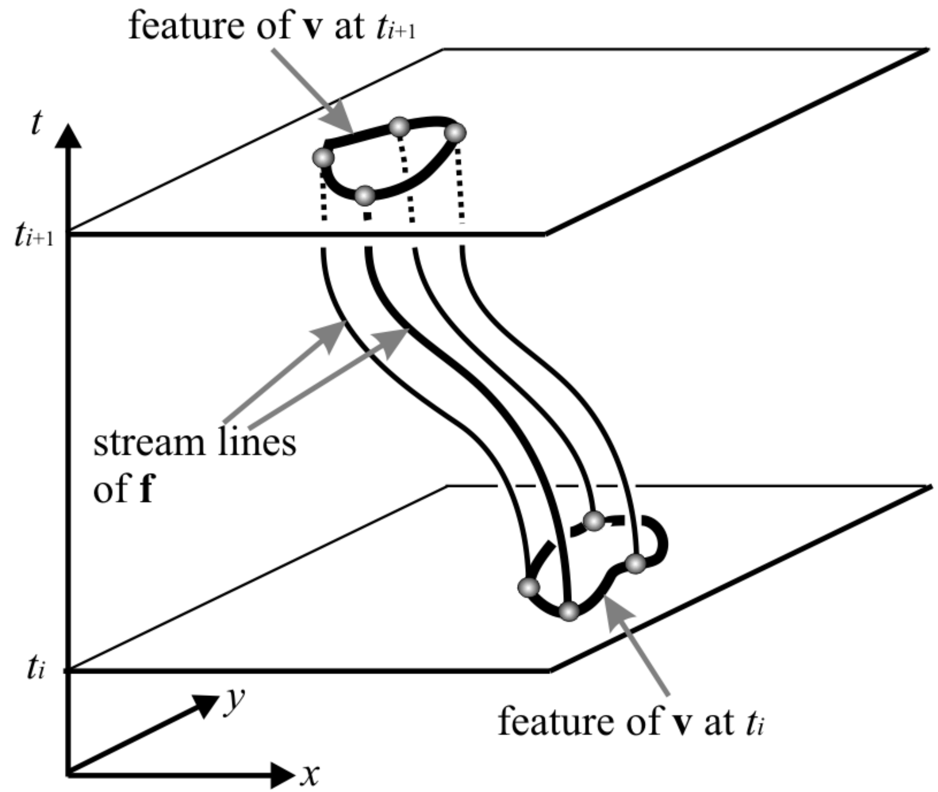
filter
comparison
hypothesis generation & testing
presentation

$$\mathbf{v}(x,y,t) = \begin{pmatrix} u(x,y,t) \\ v(x,y,t) \end{pmatrix}$$

$$\downarrow$$

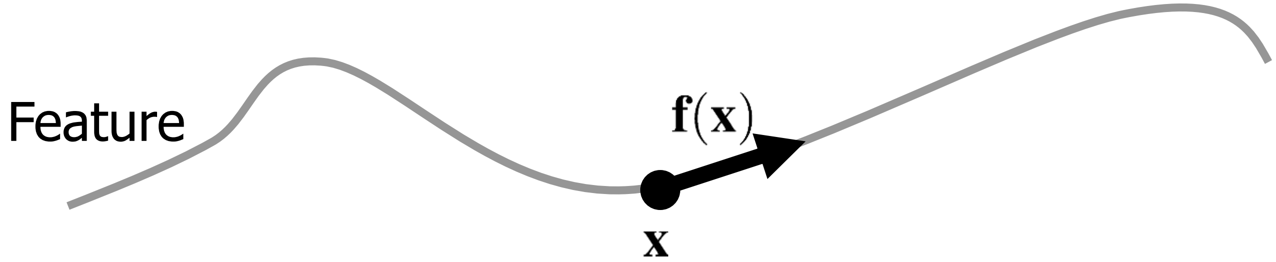
$$\mathbf{f}(x,y,t) = \begin{pmatrix} f(x,y,t) \\ g(x,y,t) \\ h(x,y,t) \end{pmatrix}$$

Feature Flow Field (FFF)



H. Theisel and H.-P. Seidel
Feature Flow Fields, VisSym 2003

- Feature Flow Field: vector field $\mathbf{f}$ at $\mathbf{x}$ pointing into direction where the feature continues



- Numerical stream line/surface integration is well-understood
- Stream object integration independent of underlying grid
- FFF gives theoretical tool for classifying local bifurcations

- **H. Theisel and H.-P. Seidel**
  Feature Flow Fields, VisSym 2003

- **H. Theisel, T. Weinkauf, H.-C. Hege, and H.-P. Seidel**
  Stream Line and Path Line Oriented Topology for 2D Time-Dependent Vector Fields, IEEE Vis 2004

- **T. Weinkauf, H. Theisel, H.-C. Hege, and H.-P. Seidel**
  Feature Flow Fields in Out-Of-Core Settings, TopoInVis 2005

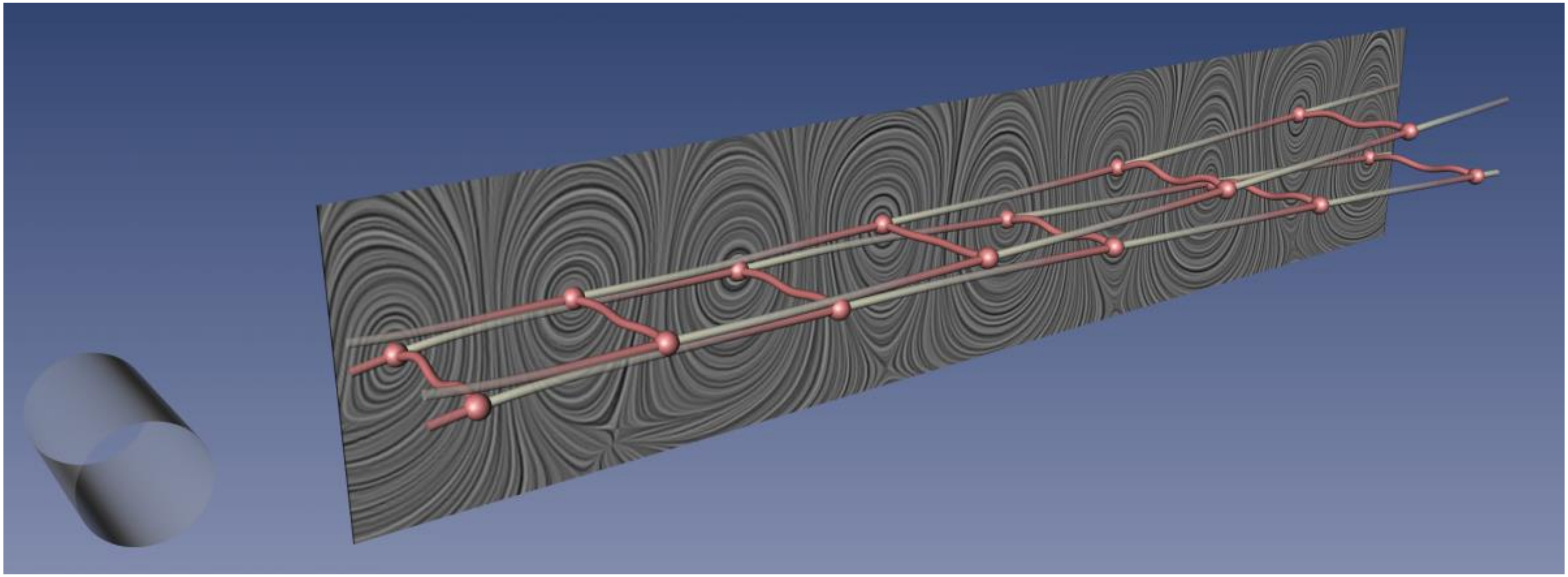
- **X. Zheng and A. Pang**
  Topological Lines in 3D Tensor Fields and Discriminant Hessian Factorization, TVCG 2005

- **H. Theisel, J. Sahner, T. Weinkauf, H.-C. Hege, and H.-P. Seidel**
  Extraction of Parallel Vector Surfaces in 3D Time-Dependent Fields and Application to Vortex Core Line Tracking, IEEE Vis 2005

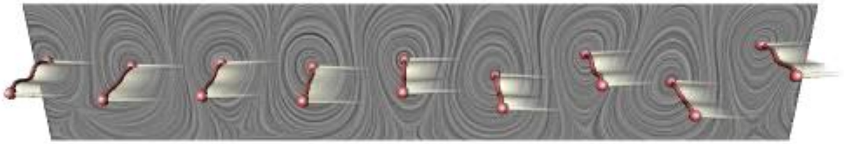
- **S. Depardon, J. J. Lasserre, L. E. Brizzi, and J. Borée**
  Automated topology classification method for instantaneous velocity fields, Experiments in Fluids 2007

- **J. Reininghaus, J. Kasten, T. Weinkauf, I. Hotz**
  Efficient Computation of Combinatorial Feature Flow Fields, TVCG 2012

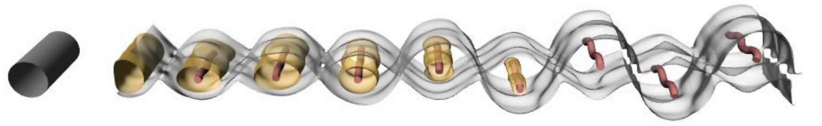
Data courtesy Bernd R. Noack



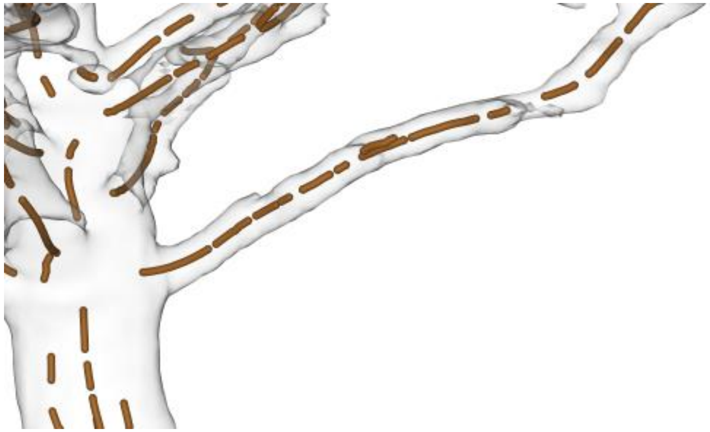
flow behind a cylinder – tracked vortex core lines



Sujudi/Haimes criterion



Okubo Weiss criterion



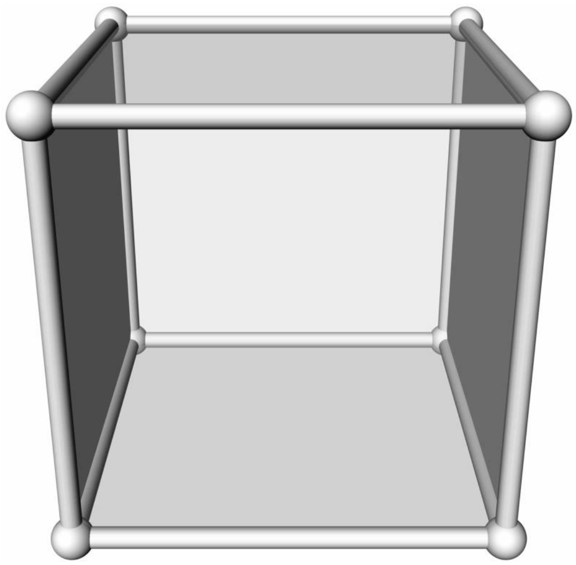
Continuous Methods

challenged by noise
derivation
interpolation

Discrete Methods

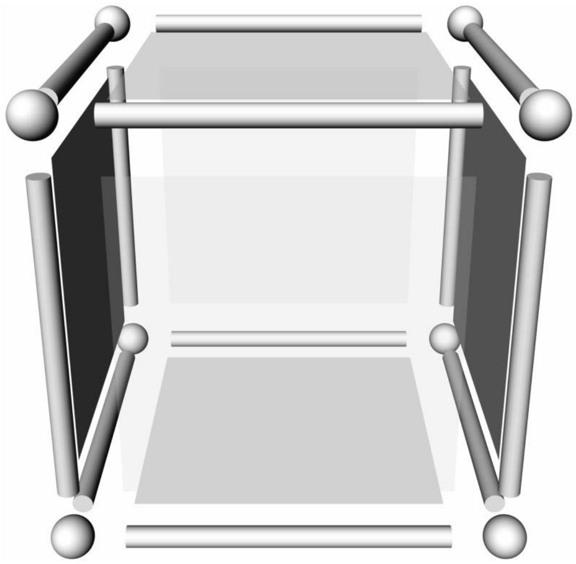
more robust
no derivation or interpolation
purely combinatorial

Discrete Morse Theory



Continuous Methods

challenged by noise
derivation
interpolation



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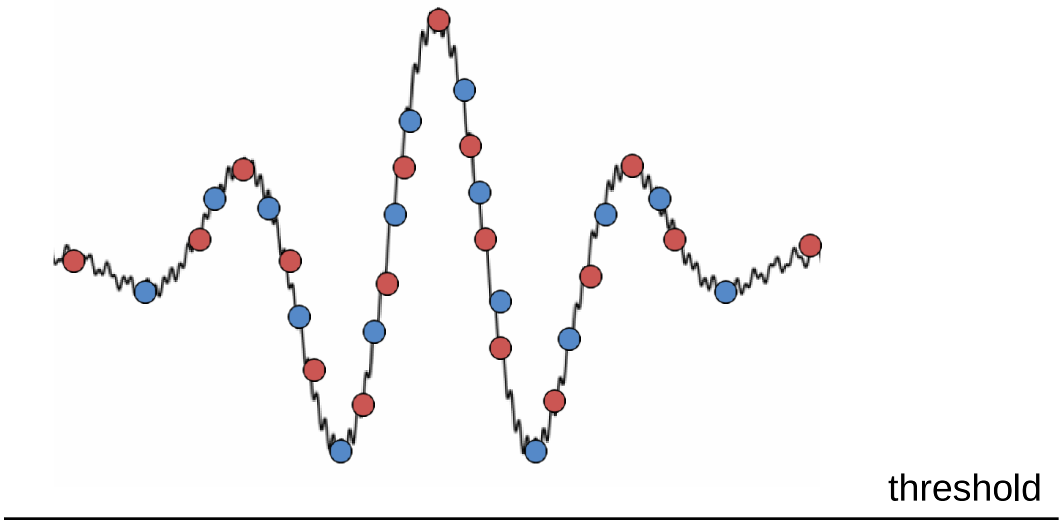
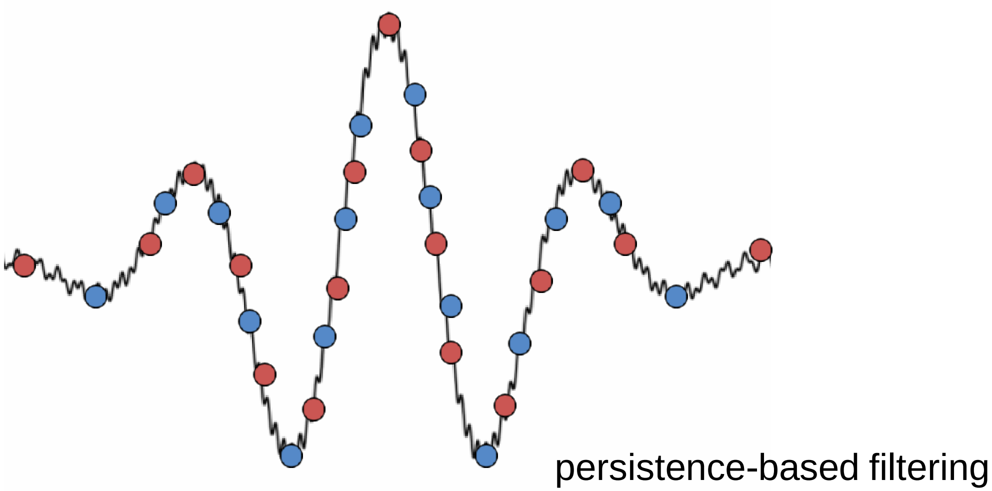
Discrete Morse Theory



Continuous Methods

challenged by noise
derivation
interpolation



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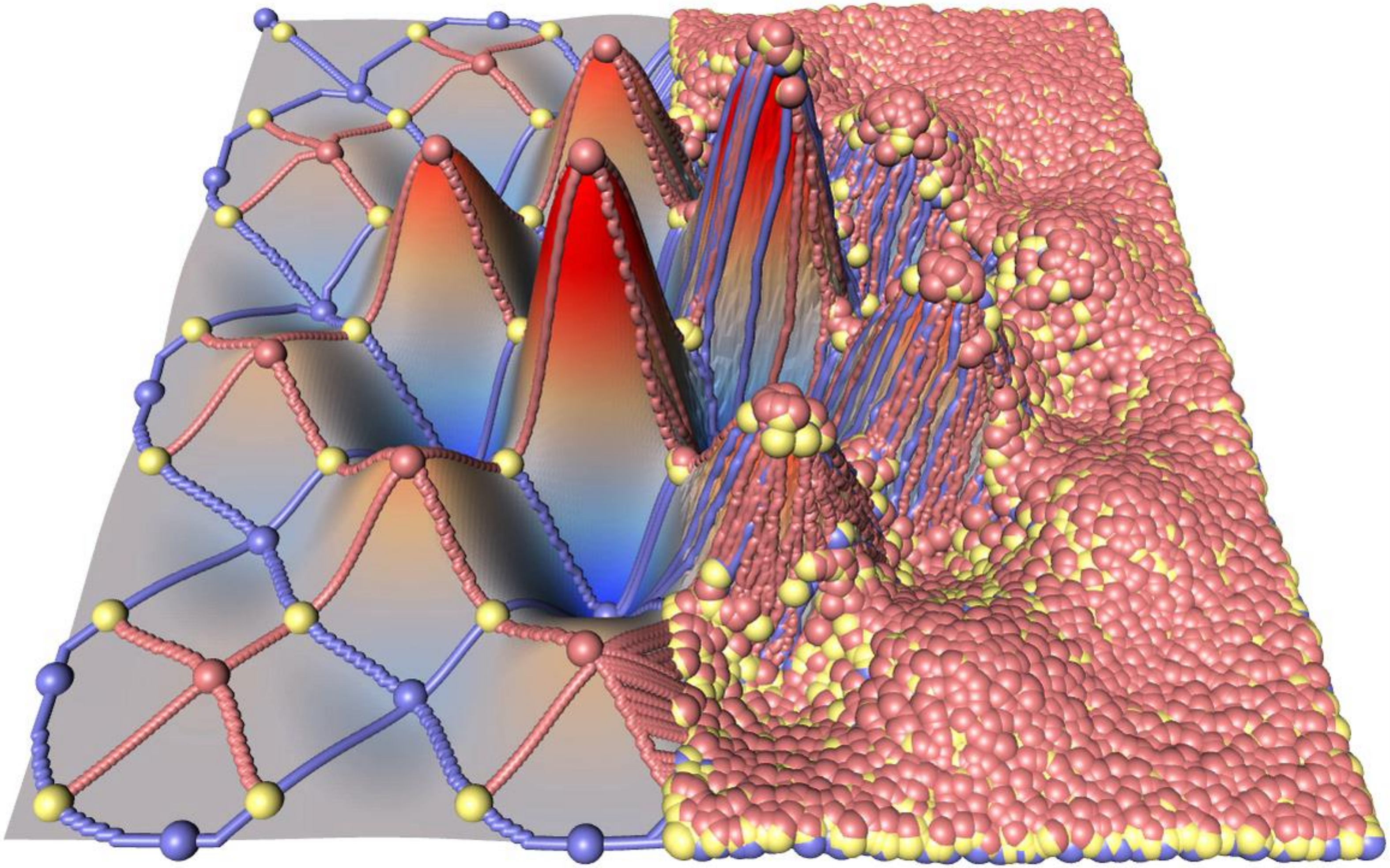
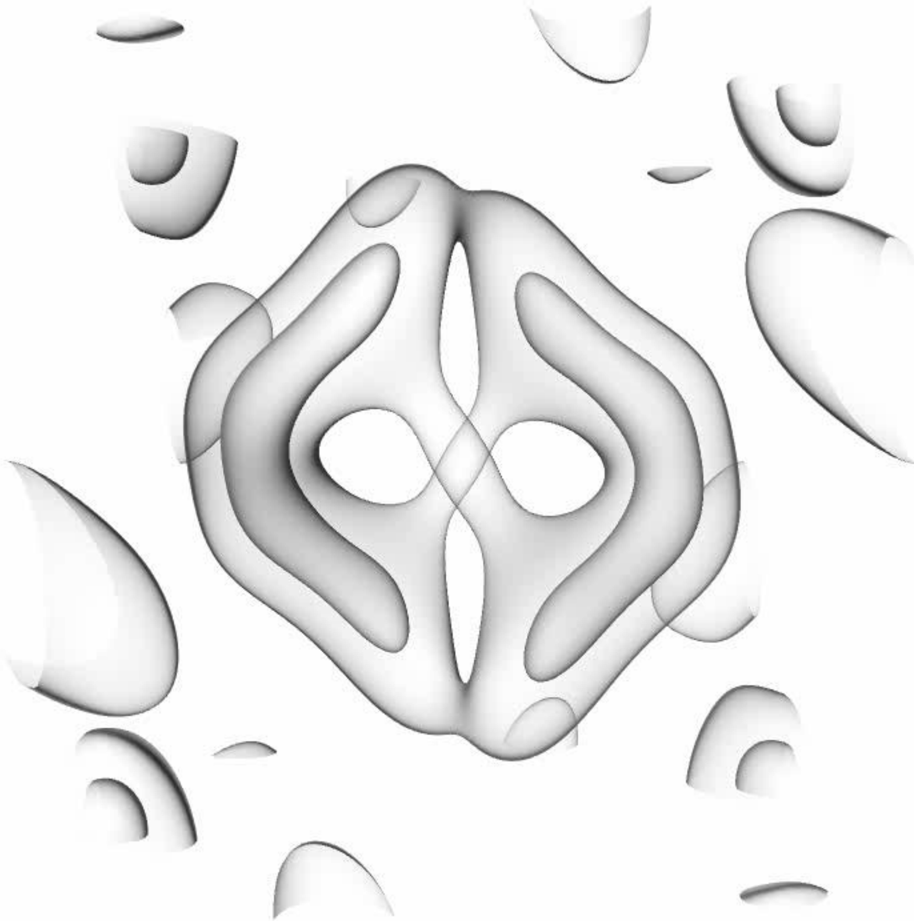
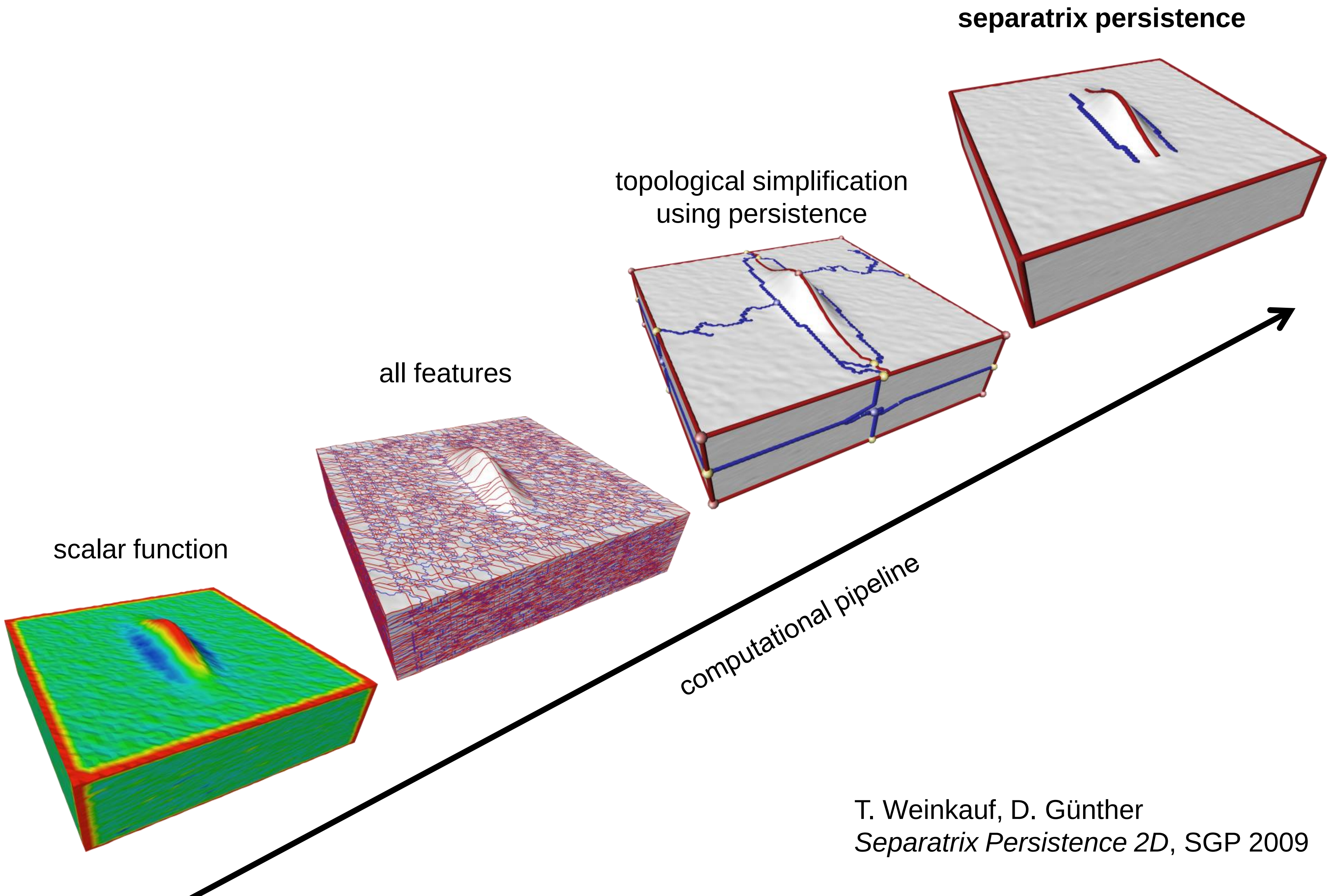
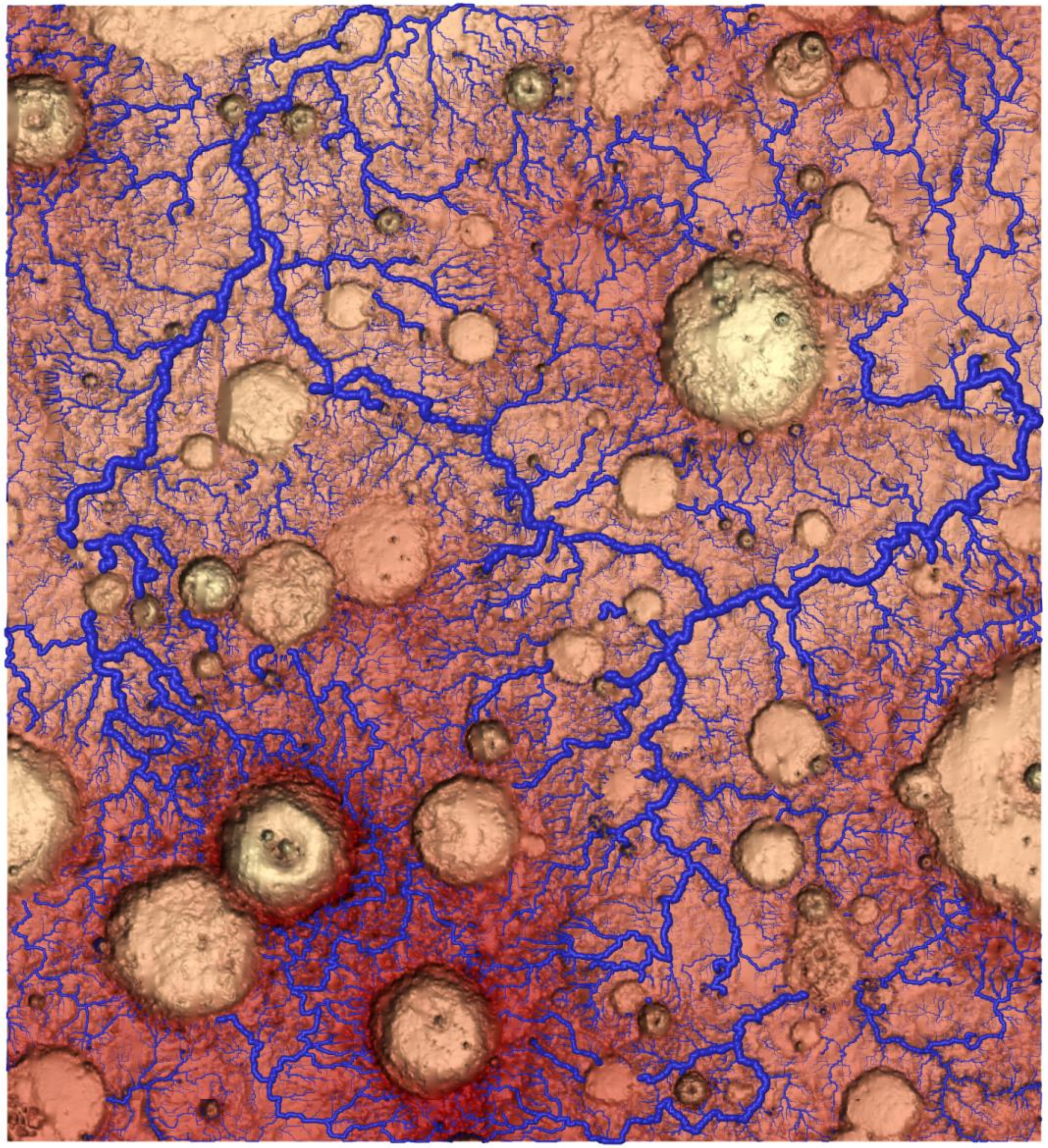






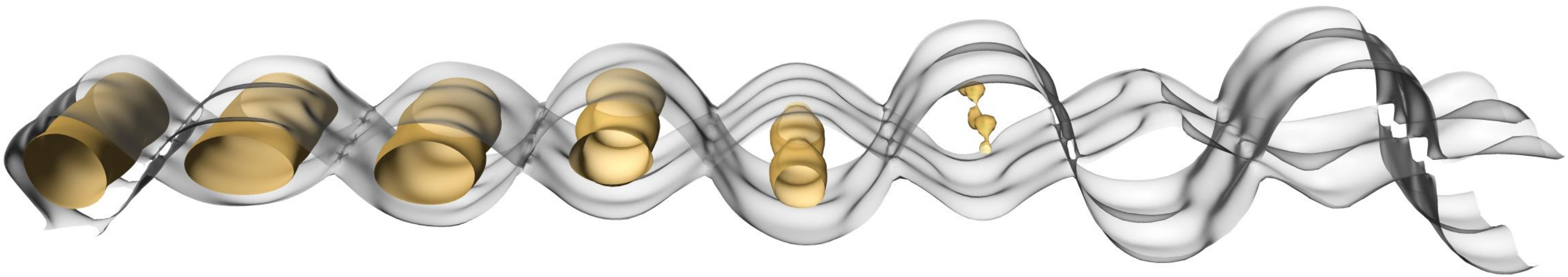
T. Weinkauf, D. Günther
Separatrix Persistence 2D, SGP 2009

D. Günther, H.-P. Seidel, T. Weinkauf
Separatrix Persistence 3D, CGF 2012

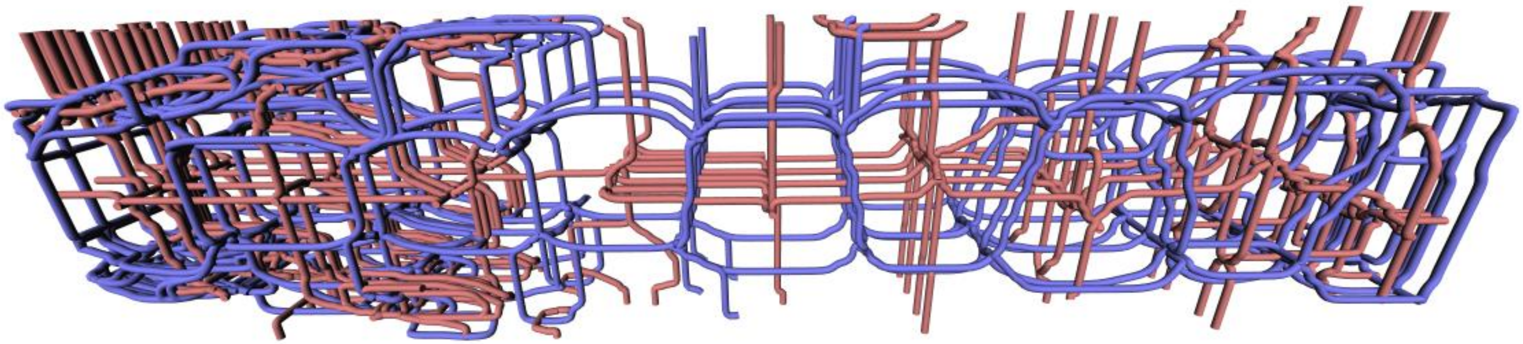


Valleys in a subregion of the Martian surface:

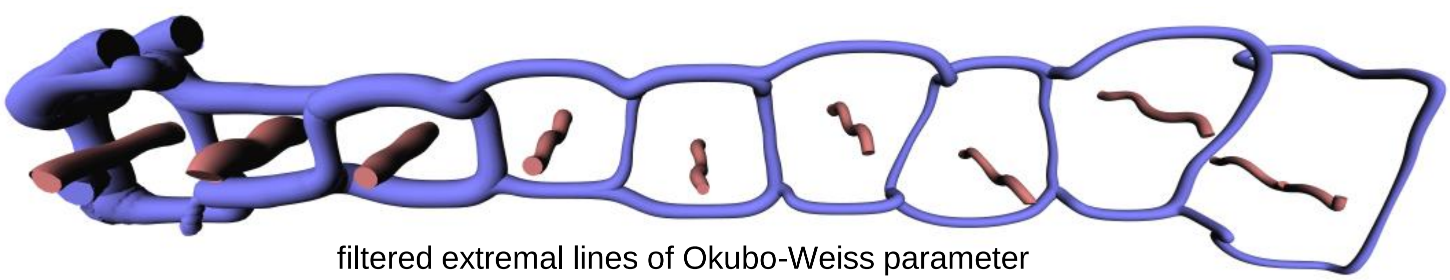
- Noisy data yields complex network
- Separatrix persistence allows differentiation between prominent and noise-induced valleys



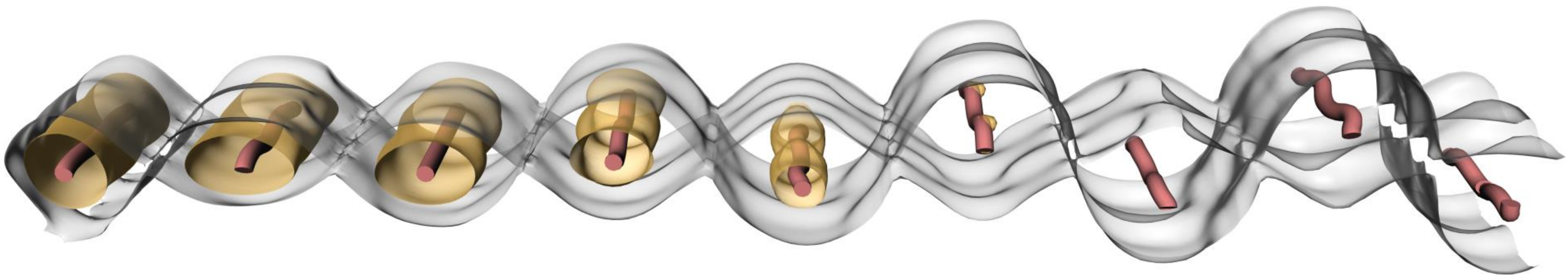
Flow behind a cylinder: isosurfaces of Okubo-Weiss parameter

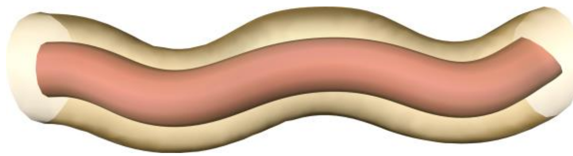


all extremal lines of Okubo-Weiss parameter

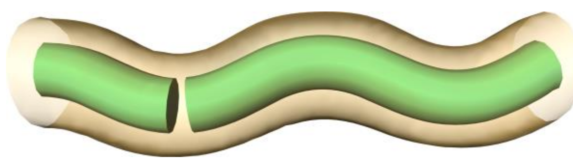


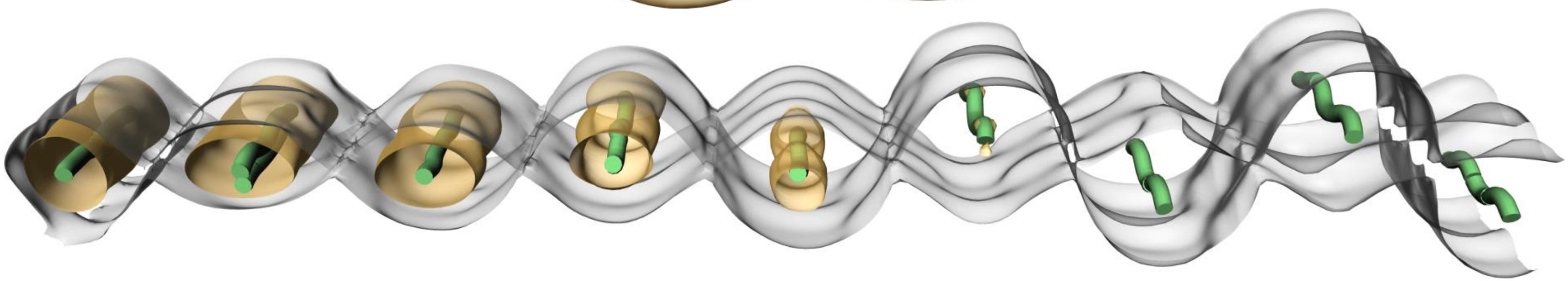
filtered extremal lines of Okubo-Weiss parameter



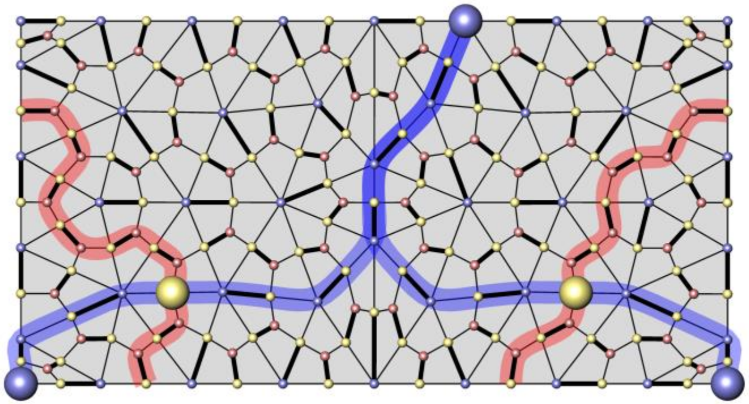


filtered extremal lines
(discrete Morse theory)





filtered extremal lines
(continuous model, height ridges)



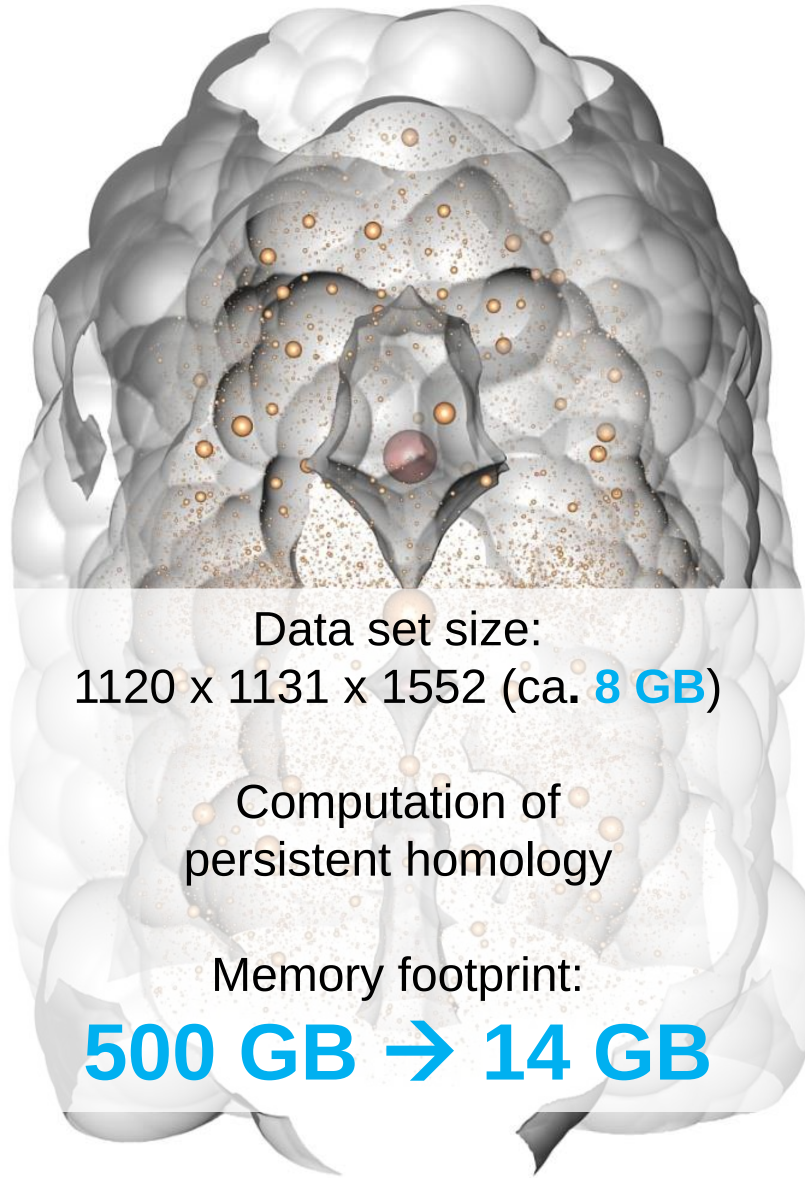
Graph Matching Problem

Volumetric data

Computation Morse-Smale complex
$O(n^3) \rightarrow O(n^2)$

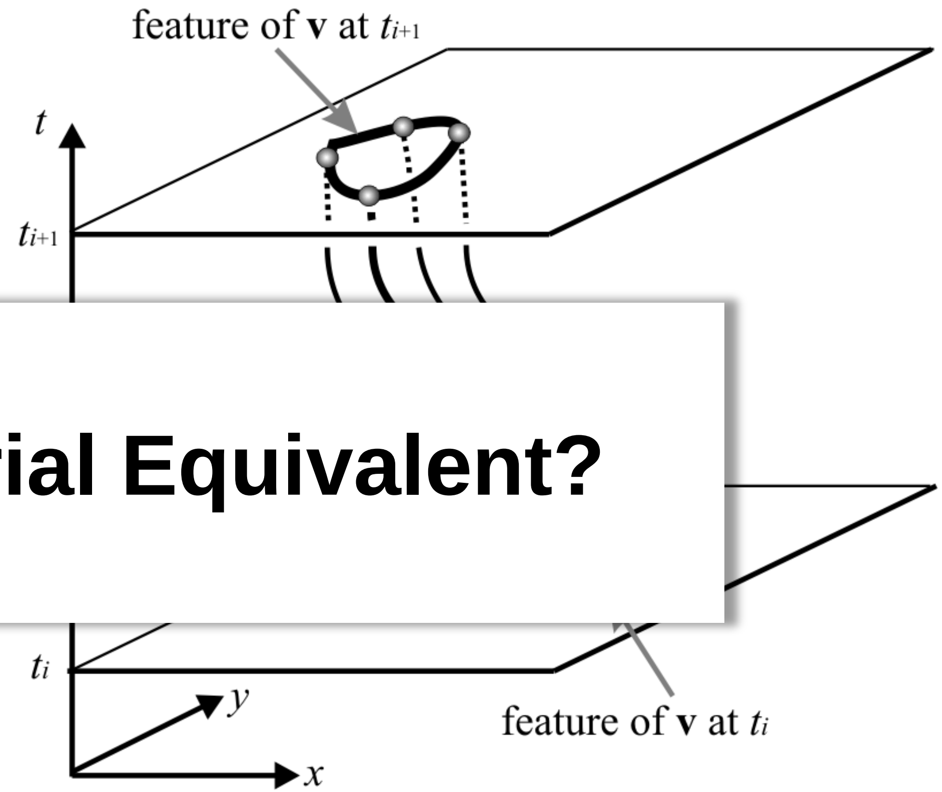
Significantly smaller memory footprint
for simplification
and persistent homology

Dissertations:
David Günther (Advisor: Tino Weinkauf)
Jan Reininghaus (Advisor: Ingrid Hotz)



Data courtesy: ZIB, Daniel Baum
Distance field of a Chaperon protein

$$\mathbf{v}(x,y,t) = \begin{pmatrix} u(x,y,t) \\ v(x,y,t) \end{pmatrix}$$

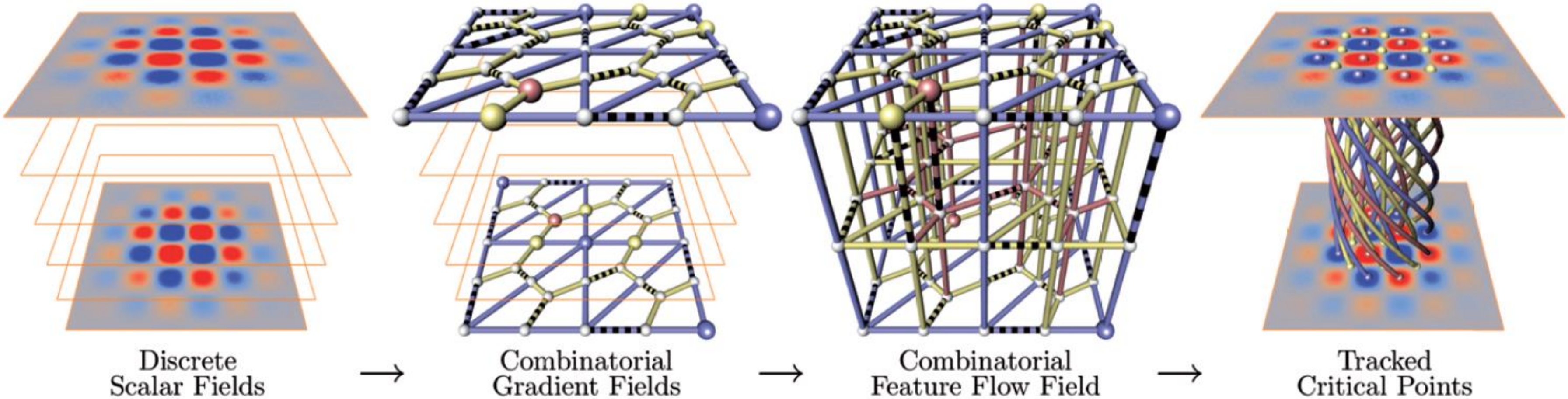


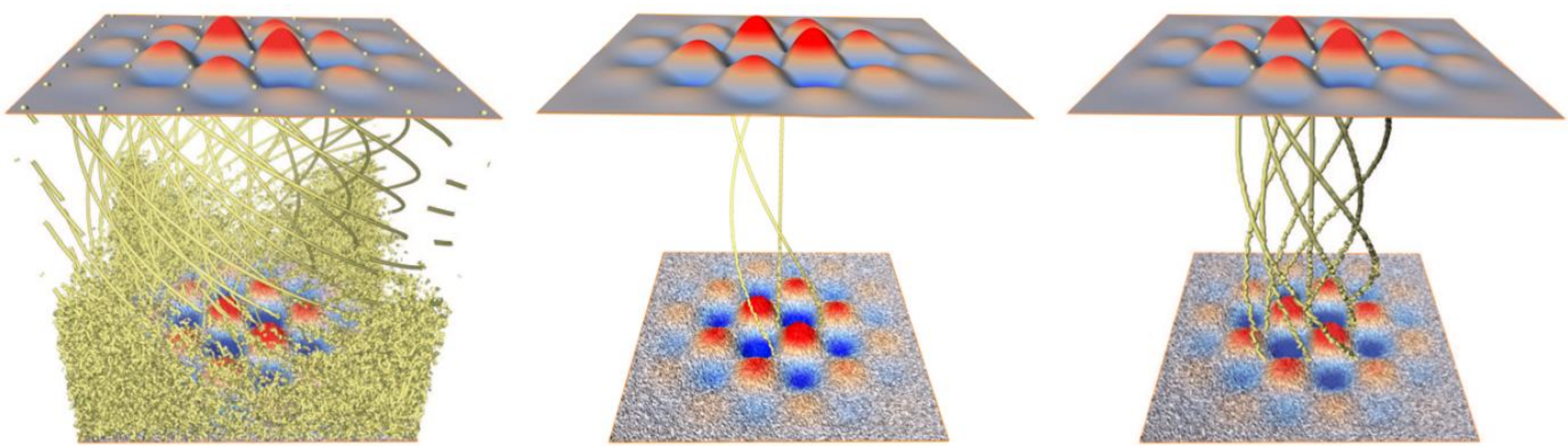
Combinatorial Equivalent?

$\mathbf{f}(x,$

Feature Flow Field (FFF)

H. Theisel and H.-P. Seidel
Feature Flow Fields, VisSym 2003



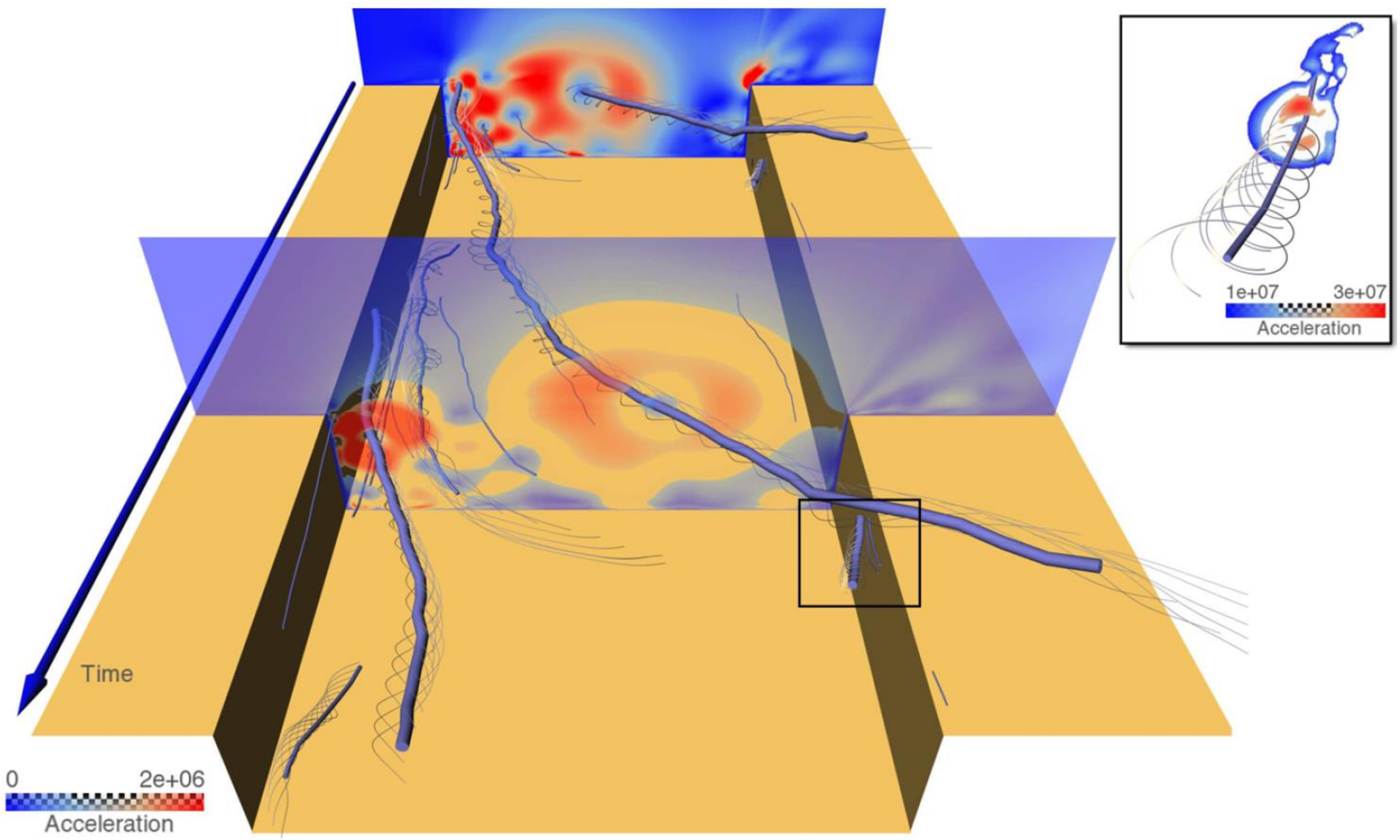


continuous feature flow fields

combinatorial FFF

J. Reininghaus, J. Kasten, T. Weinkauf, I. Hotz
Combinatorial Feature Flow Fields, TVCG 2012

Combinatorial Feature Flow Fields`: Tracked Vortices in a Cavity Flow



J. Reininghaus, J. Kasten, T. Weinkauf, I. Hotz
Combinatorial Feature Flow Fields, TVCG 2012

Simulation

data too large to
save in full resolution

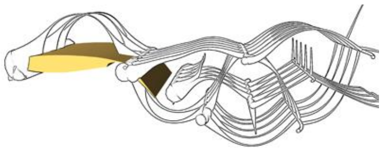
Feature Extraction

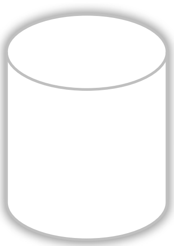
in-situ

versatile framework for defining features
- *discrete Morse theory*

notion of feature strength
- *(separatrix) persistence*

track over time
- *Feature Flow Fields*





Interactive Visualization

filter
comparison
hypothesis generation & testing
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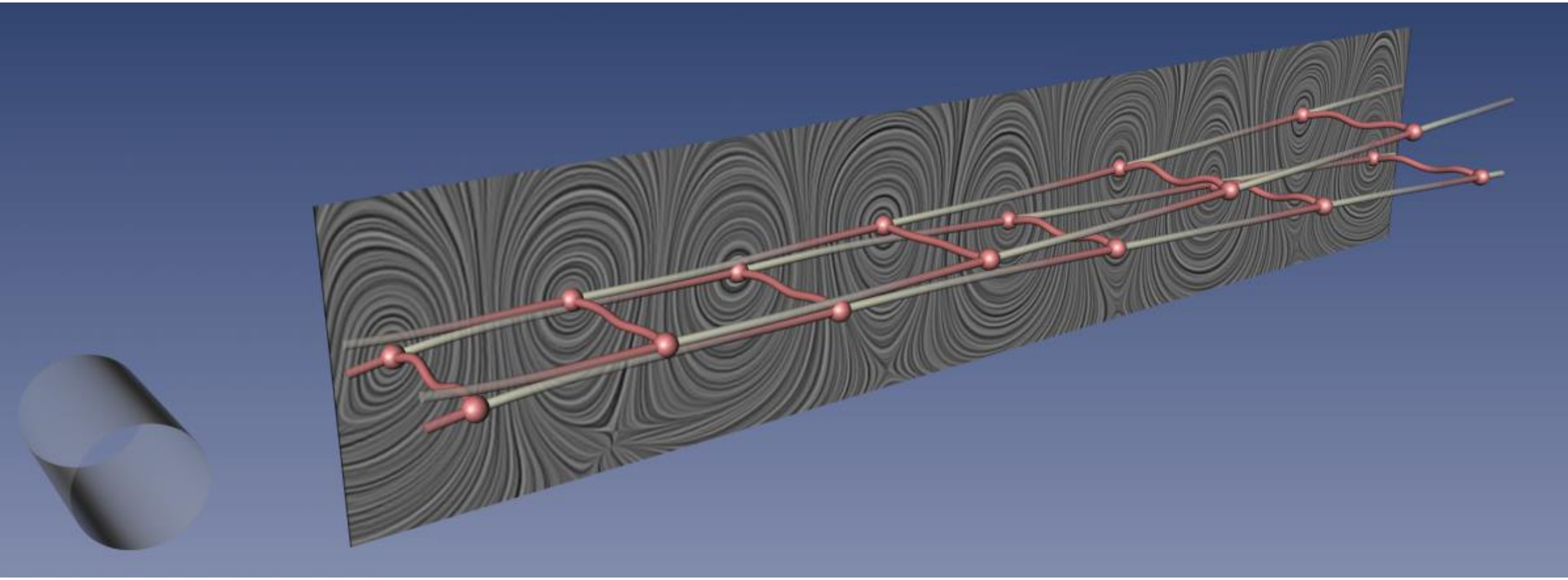
Feature-Based Flow Visualization



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