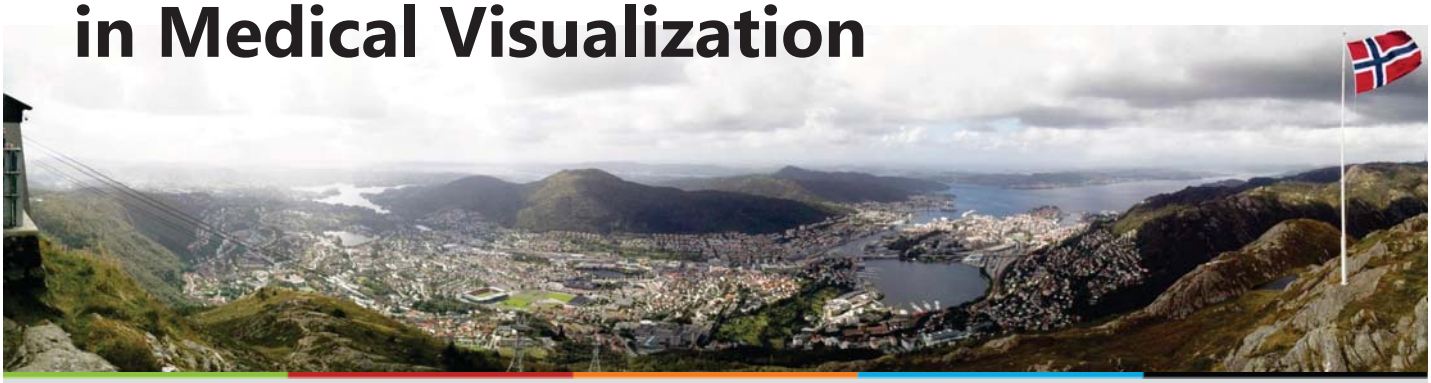
From Anatomy to Physiology in Medical Visualization



Helwig Hauser
University of Bergen

These 30 mins.

Motivation

Physiology

Capturing physiology

- data
- models

Selected examples

- hemodynamics in aneurysms (Preim et al.)
- tissue perfusion (Hauser et al.)
- functional brain studies (Lundervold et al.)
- protein–ligand binding (Byška et al.)

Challenges

Motivation

Medicine—it's about the *living* patient!

- focus on the physiological (dys-)function
- relates to anatomy, often, of course,
  but goes much further beyond

Visualization—substantial challenges!

- time-dependent phenomena
- multi-scale phenomena, both in space & time
- heterogeneous data (and models)
- multi-disciplinary

Physiology

Definition(s):

… the mechanical, physical, and biochemical functions
of humans, their organs, and the cells…

… specific characteristics and mechanisms
of the human body that make it a living being

… life processes

As compared to anatomy:

… the shape and structure of living things

Medical Physiology

Guyton and Hall Textbook:

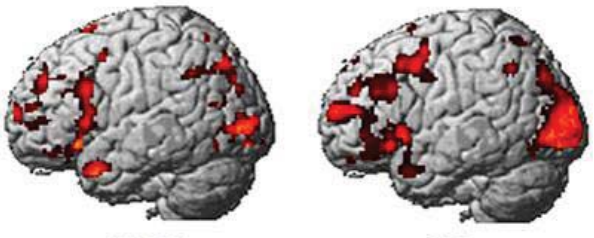
- Cell physiology
- Membrane, Nerve and Muscle physiology
- Metabolism and temperature regulation
- Heart physiology
- The circulation
- The body fluids and kidneys
- Blood Cells, Immunity, and Blood Clotting
- Respiration
- Aviation, Space and Deep-Sea-Diving physiology
- The Nervous System and Sensory physiology
- The Nervous System: The special senses
- Motor and Integrative neurophysiology
- Gastrointestinal physiology
- Endocrinology and Reproduction
- Sport physiology

Capturing Physiology

Data

- functional imaging like fMRI, PET, CEUS, …
- numerical simulation as from blood flow simulation

…



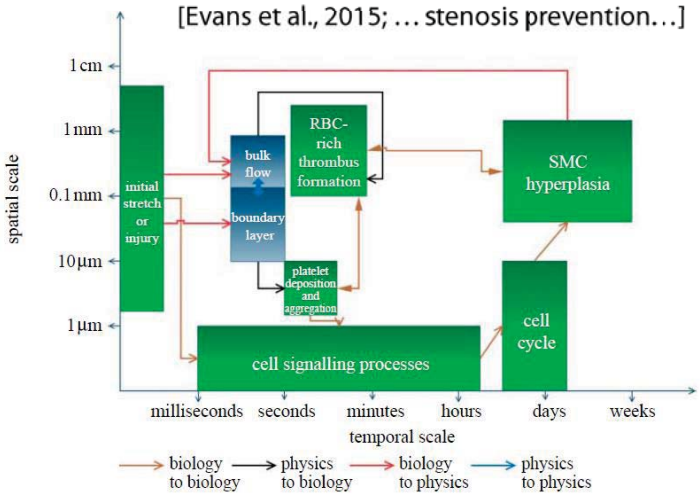
[Kassam et al., 2013; PLOS one]

Models

- physical models, e.g., kinematic models
- biochemical models, e.g., pathway models

…

[Evans et al., 2015; … stenosis prevention…]

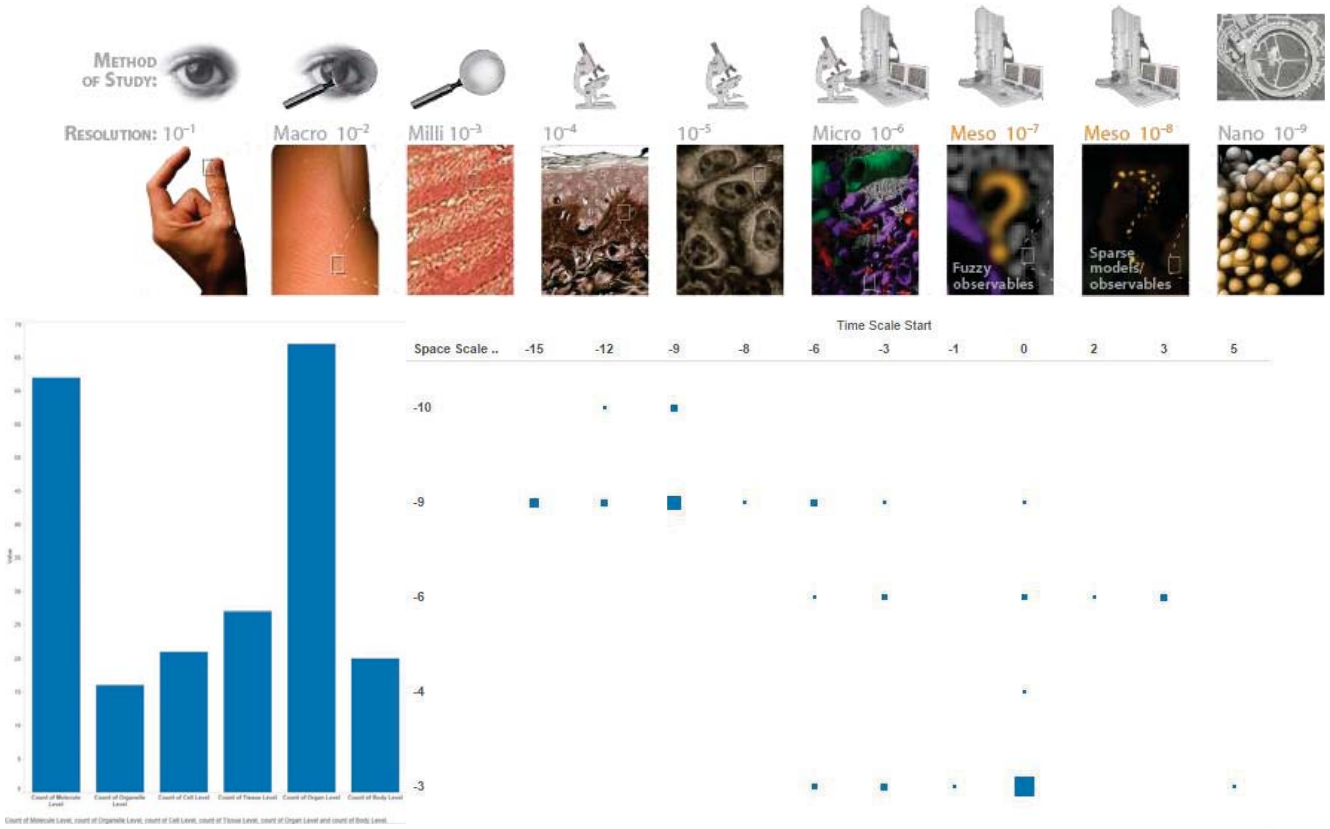


Data Acquisition—Functional Imaging

Cellular physiology	Nerve, muscle, membrane	Metabolism	Heart physiology	Blood circulation
Microscopy	Microscopy	Microscopy, PET, SPECT	Ultrasound, CT, MR, ECG, PET, SPECT	Ultrasound, MR, CFD
Micro circulation	Body fluids and kidneys	Blodd cells and immunity	Respiration	Gastro-intestinal
Ultrasound, MR, CT	MR	?	CT, MR, US	US, MR, CT
Brain	Endocrinology & reproduction	Sport physiology	Aviationn, space, deep-sea phys.	Kinematics
fMRI, EEG (PET/SPECT)	?	ECG, GPS, WattMeters, other sensors	?	Tracking sensors

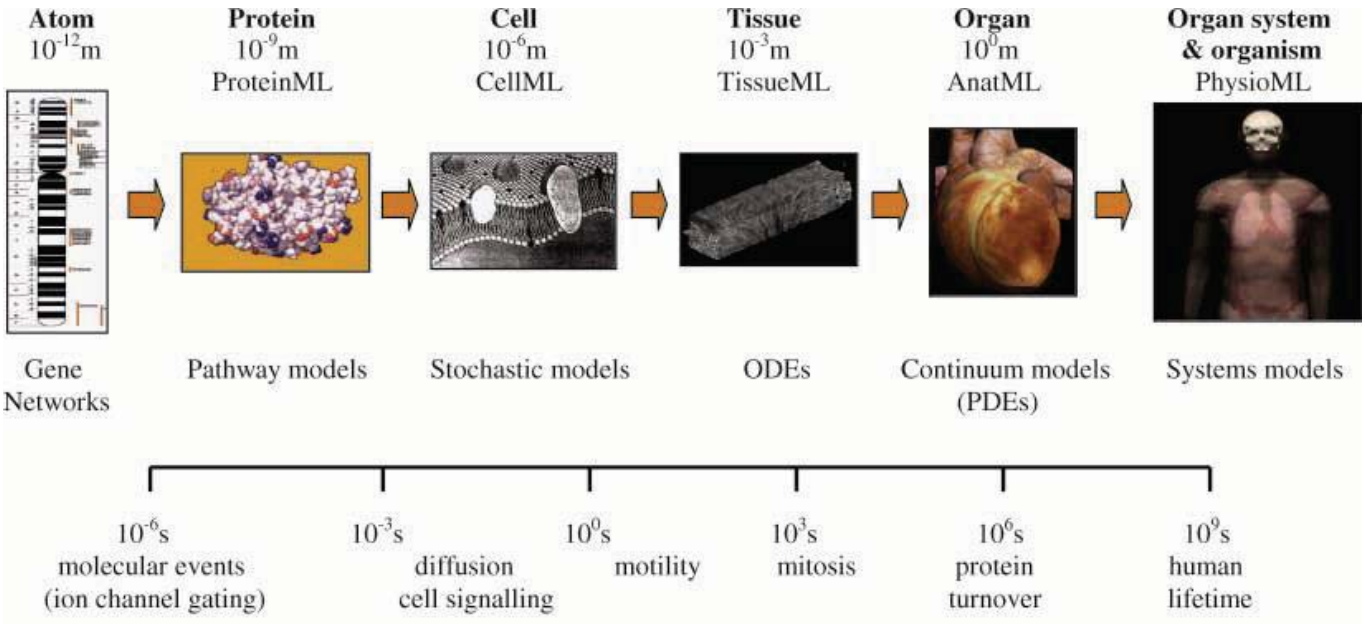
Data Acquisition—Functional Imaging

[Mesoscope.org, Johnson et al.]



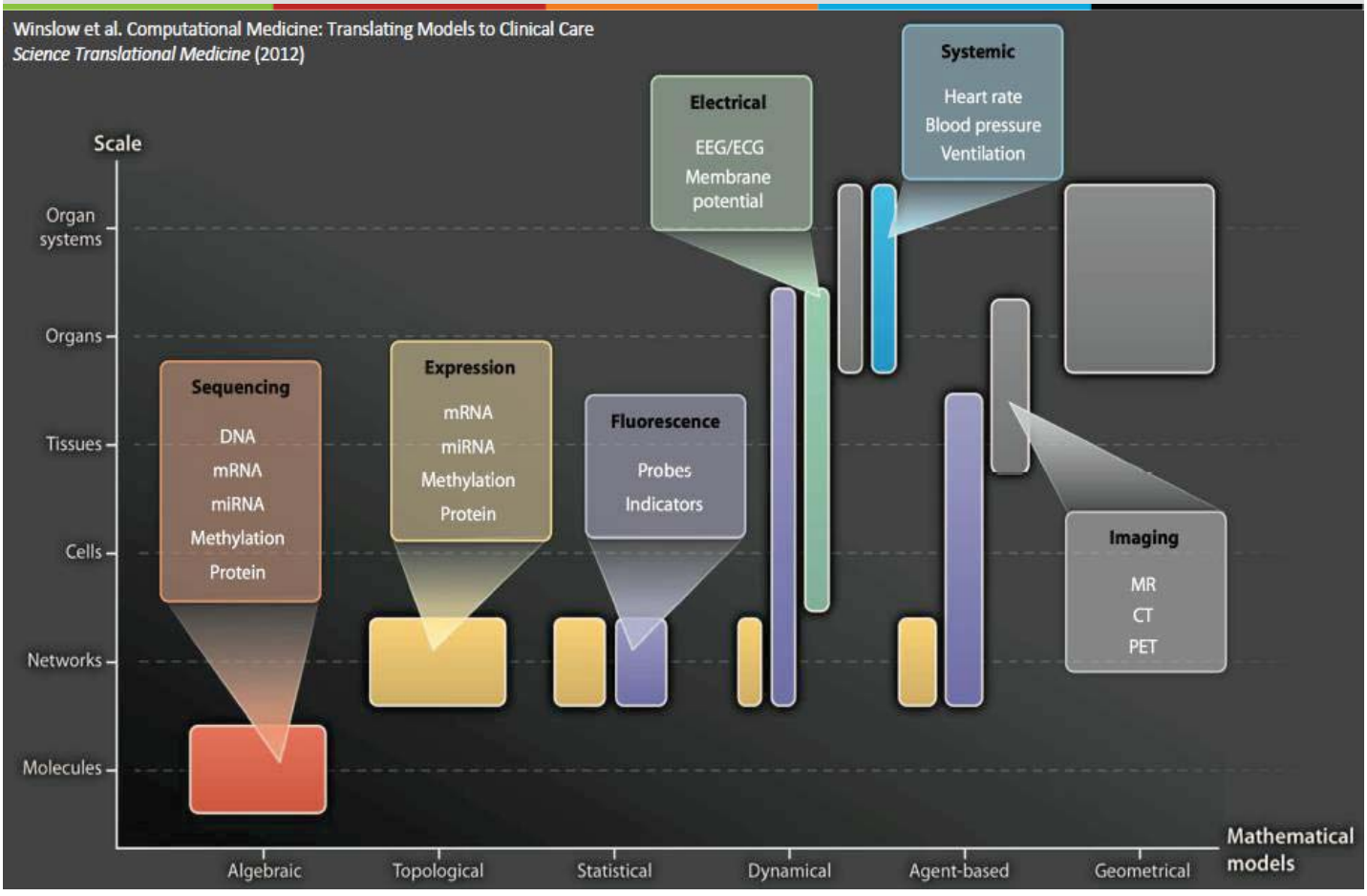
Modeling Physiology—Physiome

Multi-scale modeling of human phyisology



Hunter et al.., *2002*

Approaches vs. Scale



Physiological Modeling Pipeline

Imaging & visualization → mental model → model formalization → model definition → quantitative results

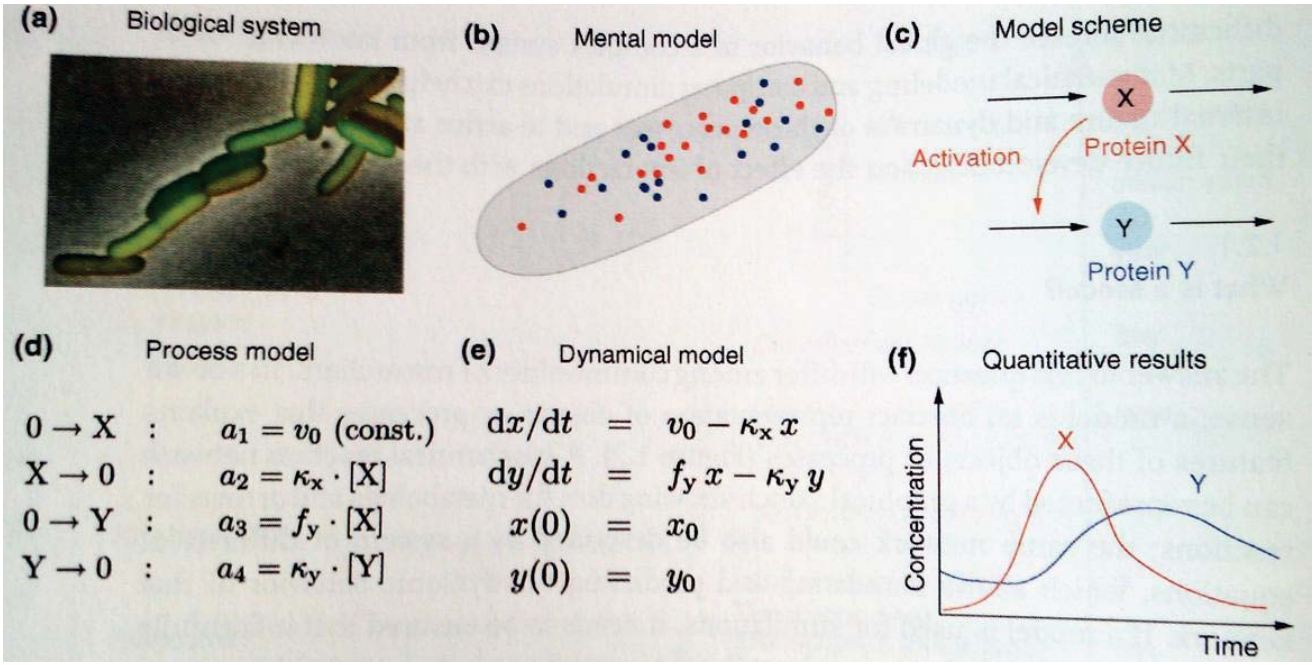


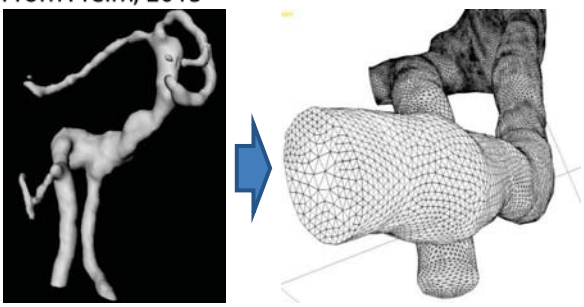
Image courtesy of Edda Klipp

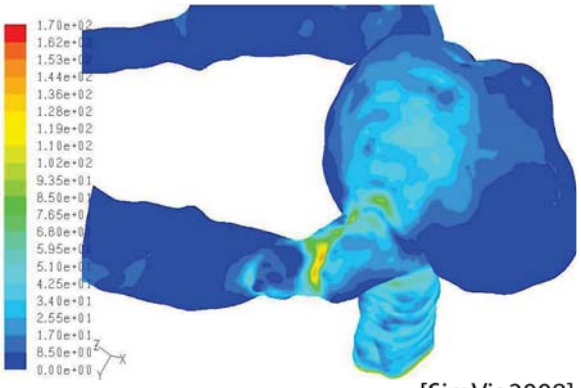
Example: Studying Aneurysms

Hemodynamics important for rupture risk assessment

- anatomical imaging
- geometric vessel reconstruction
- gridding & numerical simulation
- joint visualization

From Preim, 2015



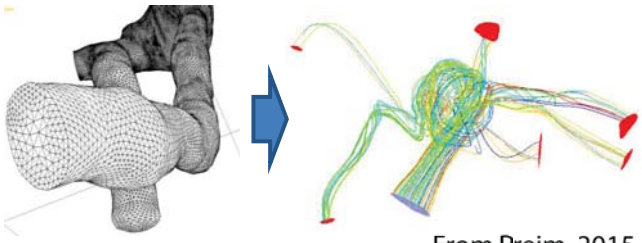


[SimVis 2008]

Challenges

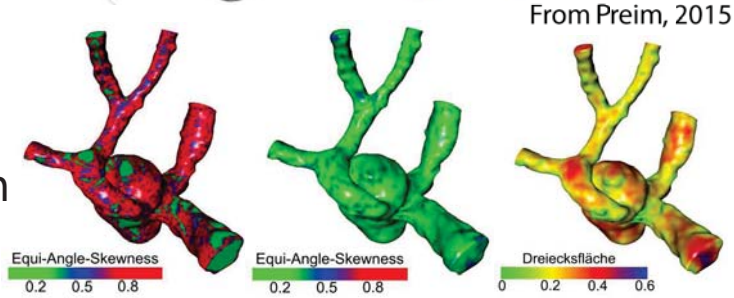
Interdisciplinary solution

- computational fluid dynamics, incl. gridding



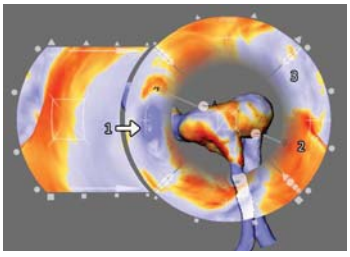
From Preim, 2015

- image processing, incl. surface reconstruction

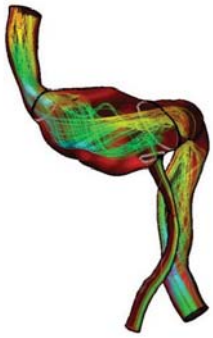


- mixed volume & flow visualization

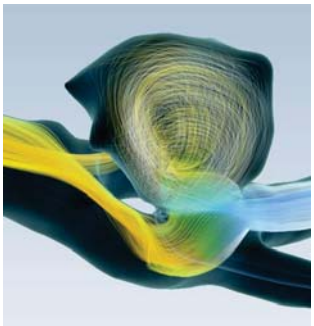
[CARS 2009]



[EuroVis 2009]



[VCBM 2010]



[EuroVis 2011]

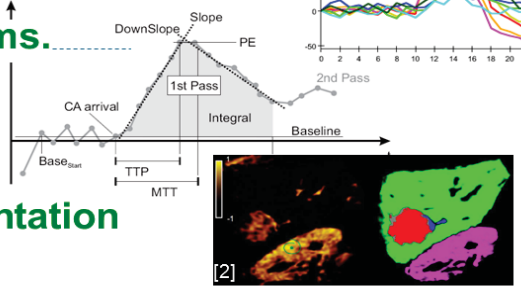
Example: Studying Tissue Perfusion

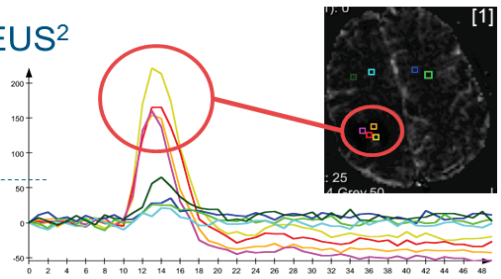
Data from perfusion imaging, *e.g.*, DCE-MRI[1] or CEUS[2]
[1] … dynamic contrast-enhanced magnetic resonance imaging; [2] … constrast-enhanced ultrasound

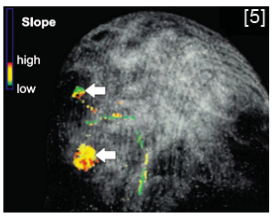
- **2D or 3D, time-dependent data**

Analysis via **time-intensity curves** (TICs)

- **either directly** (many curves)
- or via **derived perfusion params.**





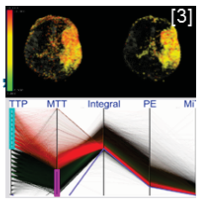


Results:

- **general / detailed overview of perfusion** (ROI-independent)
- **fast perfusion-based segmentation**

Application(s):

- **ischemic stroke** (tissue at risk analysis) [4, 5], **heart infarct** (CHD) [5]
- **brain tumors** (gliomas) [1, 3], **abdominal lesions**, e.g., liver lesions [2], **breast tumors** (via mammography) [4, 5]



Reference(s):

1. Glaßer, Oeltze, Preim, Bjørnerud, Hauser, Preim: **Visual analysis of longitudinal brain tumor perfusion**. Proc. SPIE Medical Imaging, 2013, DOI:10.1117/12.2007878
2. Angelelli, Nylund, Gilja, Hauser: **Interactive Visual Analysis of Contrast-enhanced Ultrasound Data based on Small Neighborhood Statistics**. Computers & Graphics 35(2):218–226, 2011
3. Oeltze, Preim, Hauser, Rørvik, Lundervold: **Visual Analysis of Cerebral Perfusion Data – Four Interactive Approaches and a Comparison**. Proc. 6th Int'l Symp. on Image & Signal Processing & Analysis (ISPA 2009), pp. 582–589
4. Muigg, Kehrer, Oeltze, Piringer, Doleisch, Preim, Hauser: **A Four-level Focus+Context Approach to IVA of Temporal Features in Large Scientific Data**. Computer Graphics Forum 27(3):775-782, 2008 *(35* cited)*
5. Oeltze, Doleisch, Hauser, Muigg, Preim: **Interactive Visual Analysis of Perfusion Data**. IEEE Transactions on Visualization and Computer Graphics 13(6):1392–1399, 2007 *(29* cited)*

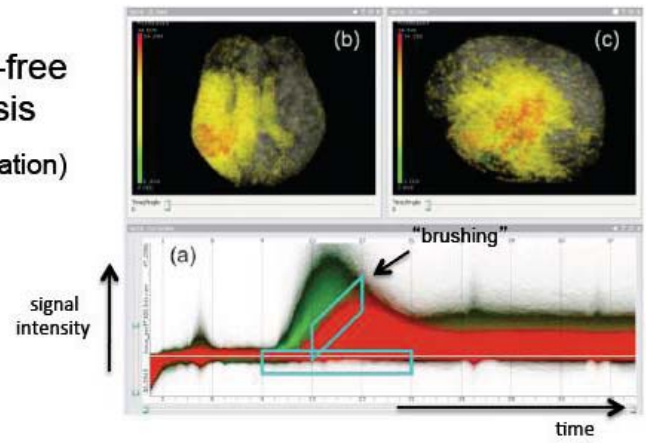
Cooperation:

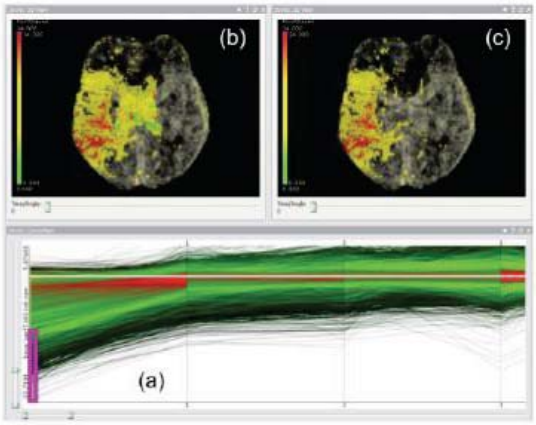
- **Univ. of Magdeburg**
- **VRVis**

Quantitative Perfusion Analysis

Model-free analysis

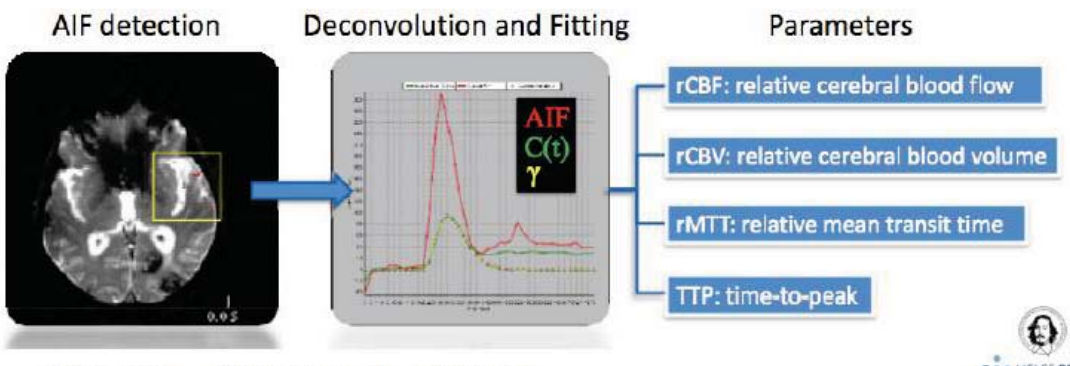
(visualization)





Model-based analysis

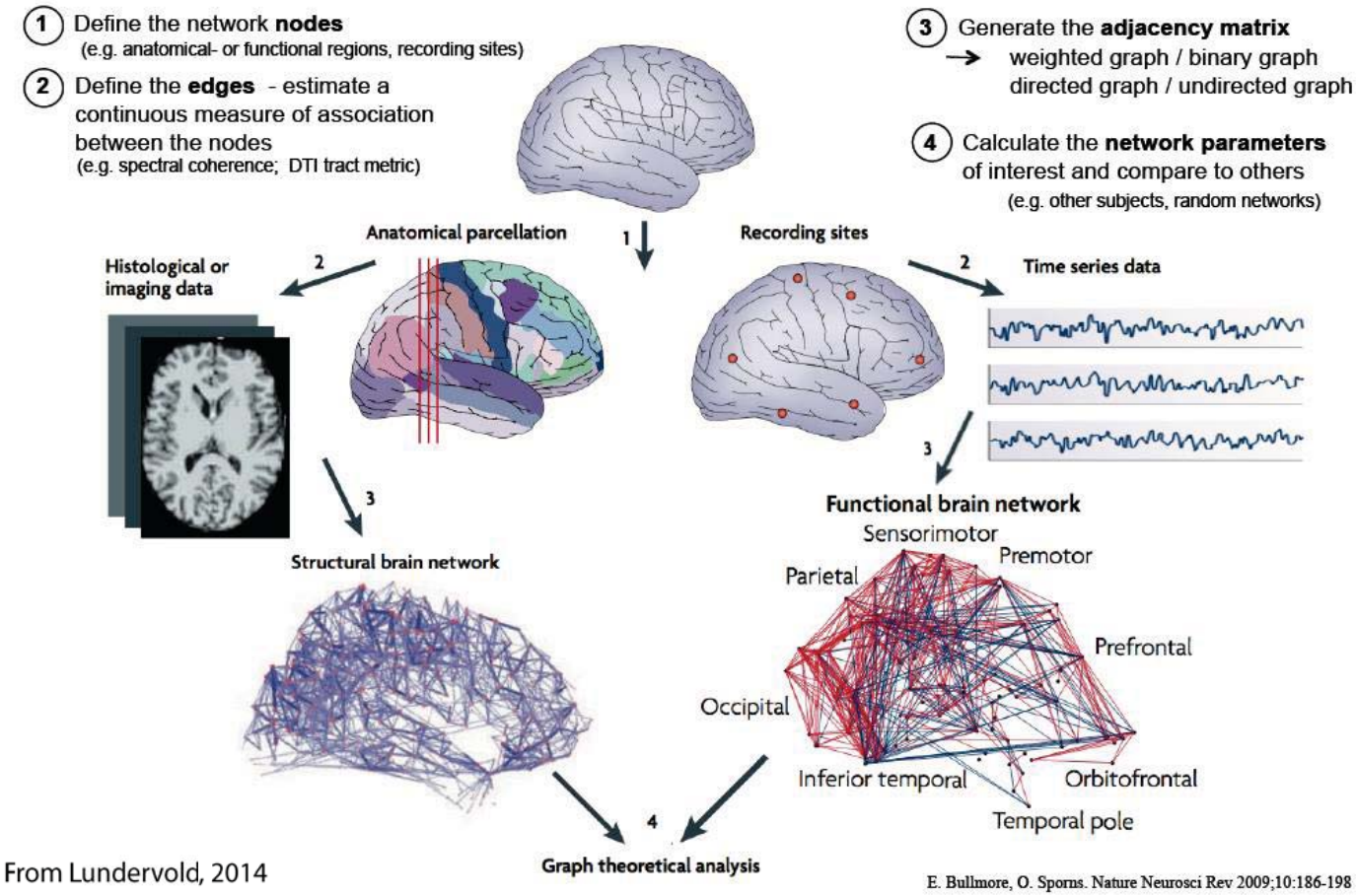
(parameter estimation)



From Lundervold, 2014

S. Oeltze[1], H. Hauser[2], J. Rørvik[3], A. Lundervold[4], B. Preim[1] ISPA 2009

Example: Functional Brain Studies

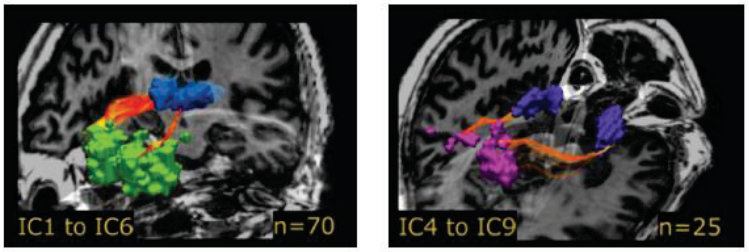


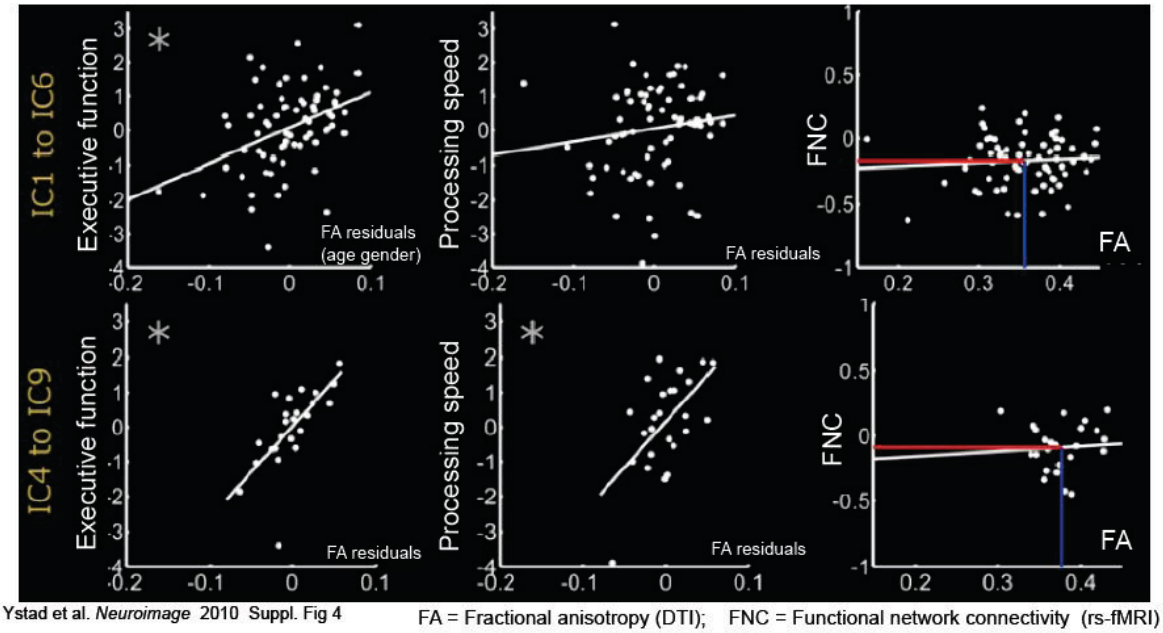
From Lundervold, 2014

E. Bullmore, O. Sporns. Nature Neurosci Rev 2009;10:186-198

Brain-behavior relationship

From Lundervold, 2014:
Cortico-strial connection and cognition



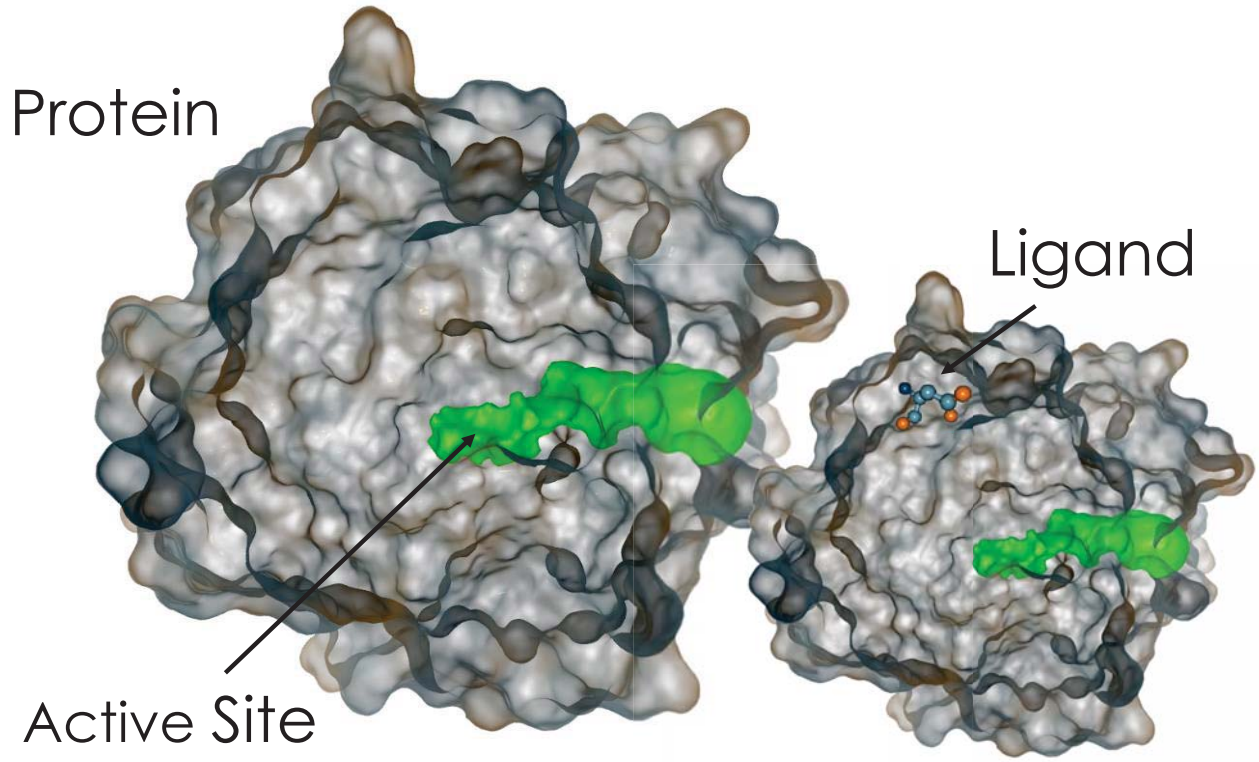


Ystad et al. *Neuroimage* 2010 Suppl. Fig 4

FA = Fractional anisotropy (DTI); FNC = Functional network connectivity (rs-fMRI)

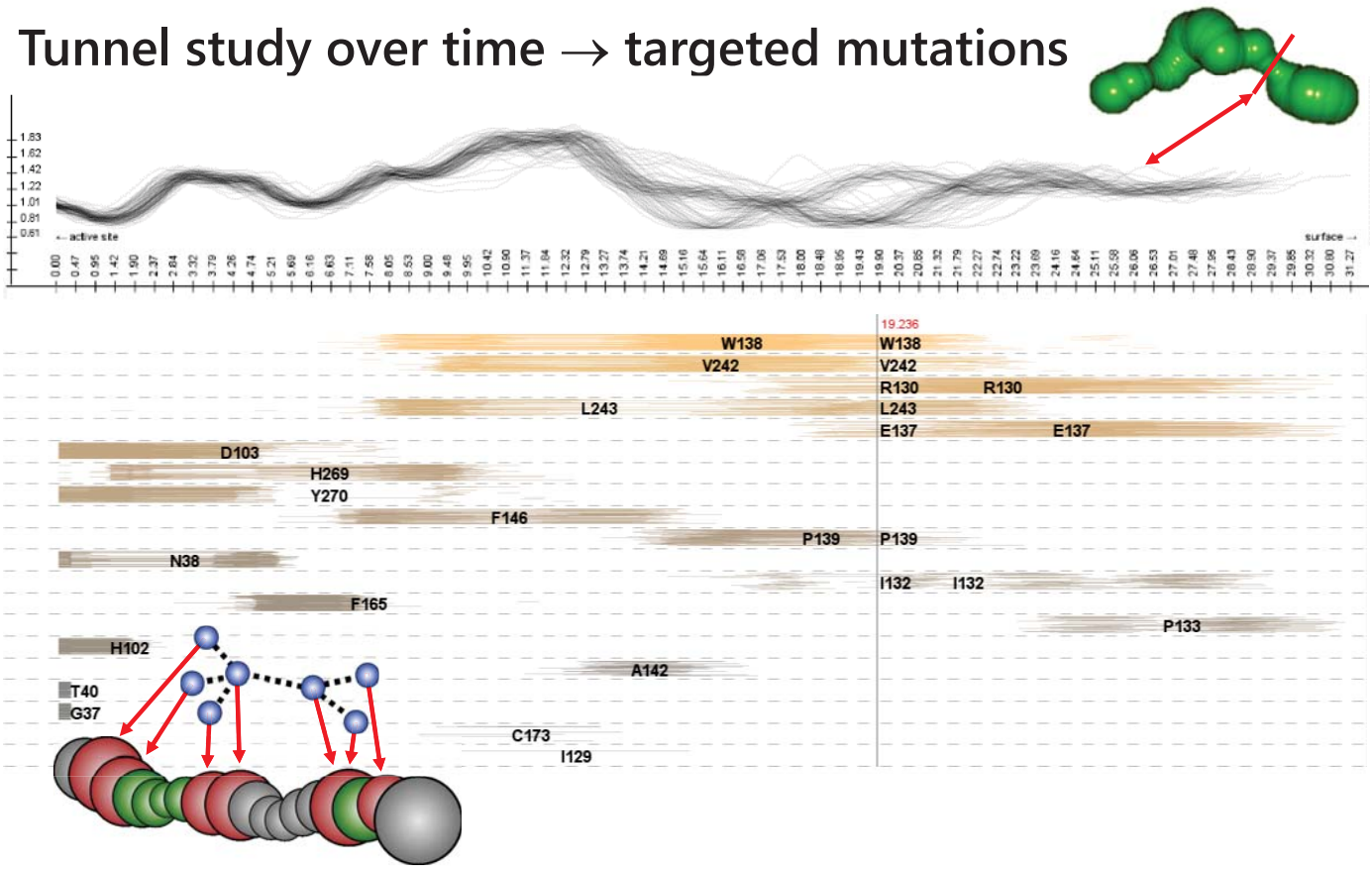
Example: Ligand Docking

Fri., first session! Jan Byška et al.



AnimoAminoMiner

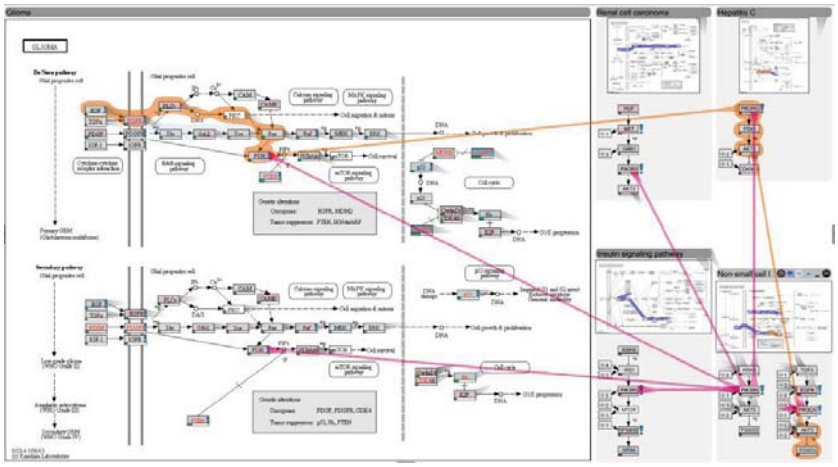
Tunnel study over time → targeted mutations



Further examples

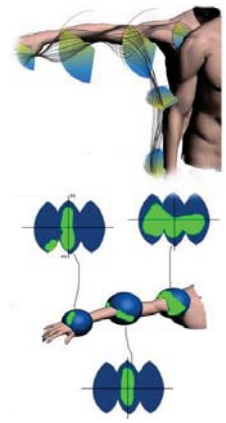
Pathways

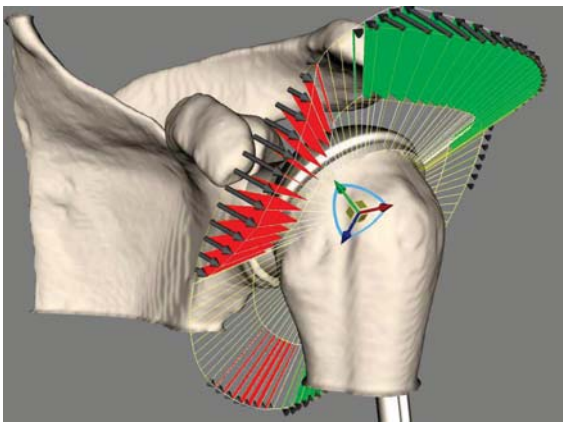
– Lex et al., 2013–



Kinematics

– Krekel et al., 2006–





Large Field of Research Opportunities

Cellular physiology	Nerve, muscle, membrane	Metabolism	Heart physiology	Blood circulation
Micro circulation	Body fluids and kidneys	Blodd cells and immunity	Respiration	Gastro-intestinal
Brain	Endocrinology & reproduction	Sport physiology	Aviationn, space, deep-sea phys.	Kinematics

Challenges

Multi-scale visualization

- both in space and time
- truly many scales

Long time sequences

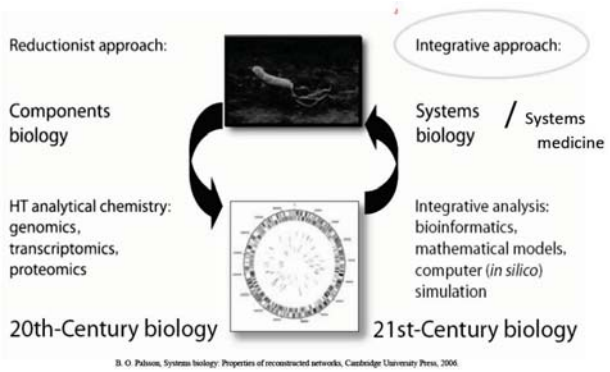
- for ex., MD (molecular dynamics)

Model-based visualization

- integration of data and models
- bridging missing information

Systematic approach

- complementing reductionism

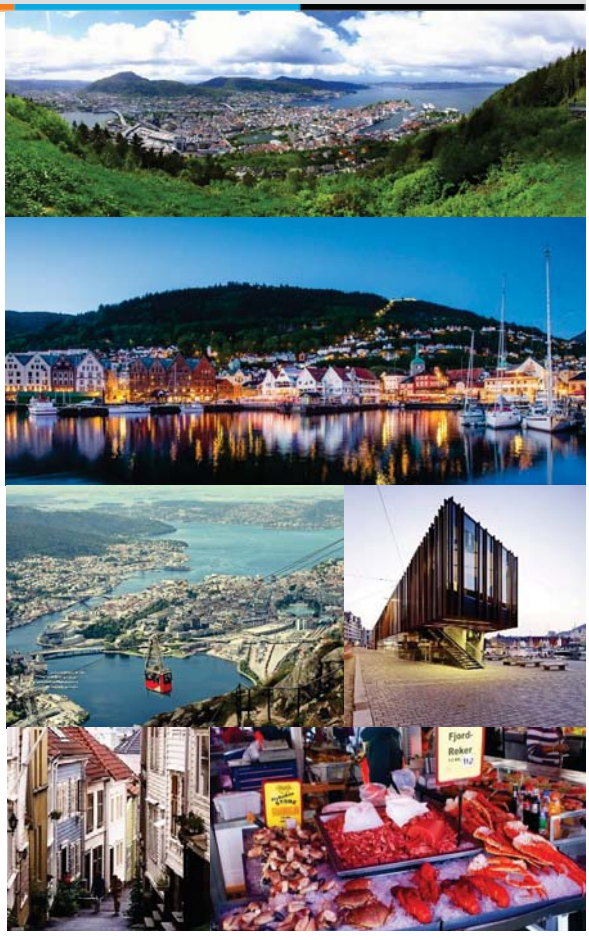


from Lundervold, 2014

VCBM 2016, together with MedViz

VCBM = Eurographics Workshop on Visual Computing for Biology and Medicine

- 2016 in Bergen, Norway
- collocated with MedViz 2016, a >100 participants interdiscipl. meeting of medicine & techn.
- important dates:
  - June, 2016: full paper deadline
  - Sept. 7–9, 2016: workshop



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Arvid Lundervold (computational medicine),
Kim Nylund et al. (CEUS),
Steffen Oeltze-Jafra (perfusion),
Bernhard Preim (MedViz),
et al.