Technologies for Digital Life - Radisson Blu Royal Hotel, Bryggen, Bergen, 21.10 2016, 14:00-14:15

https://www.ntnu.no/dln/technologies-for-digital-life

In vivo imaging and image analysis

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Technologies for Digital Life

CENTRE FOR DIGITAL LIFE NORWAY

- The Centre for Digital Life Norway (DLN) aims to drive the development of a new branch of Norwegian biotechnological research and innovation, by mixing life scientists, mathematicians, statisticians, computer scientists and engineers.

- This will be a key ingredient to scale up the success of generating **predictive models** of biological systems – by using many different types of technologies and methodologies.

- How can we best integrate different technologies and methodologies in **transdisciplinary** research projects?

- Are we equipped for this type of research?

How does "In vivo imaging & image analysis" fit in ?

Predictive models of biological systems

- Development and use of algorithms, data structures, visualization and communication tools with the goal of **computer modelling** of biological systems.
  Includes stochastic and deterministic **computer simulations** and **machine learning** from biological measurements: -omics, images …

- When deployed commercially, predictive modelling is often referred to as **predictive analytics** (extracting information from data and using it to predict trends and system behavior patterns)

Wikipedia

Transdisciplinary research = team science

- In a transdisciplinary research endeavor, scientists **contribute their unique expertise** but **work outside their own discipline**.

- Strive to **understand the complexities of the whole project**, rather than one part of it.

- Allows investigators to **transcend their own disciplines** to inform one another's work, capture complexity, and **create new intellectual spaces**.

http://www.obesity-cancer.wustl.edu/en/About/What-Is-Transdisciplinary-Research

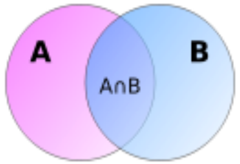
Mathematics is the body of knowledge centered on concepts such as ***quantity, structure, space,*** *and* ***change,*** *and the academic discipline which studies them …*

… being instrumental in ***predictive models*** *of biological systems and* ***"Digital Life"***

FOUNDATIONS

$P \Rightarrow Q$

Mathematical logic

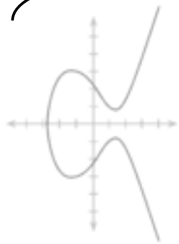


Set theory

$$\begin{tikzcd} X \arrow[r, "f"] \arrow[dr, "g \circ f"'] & Y \arrow[d, "g"] \\ & Z \end{tikzcd}$$

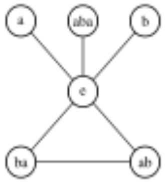
Category theory

STRUCTURE



Number theory

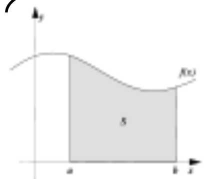
Abstract algebra



Group theory

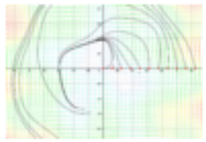
Order theory

CHANGE

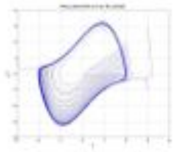


Calculus

Vector calculus



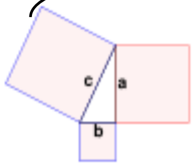
ODEs/PDEs/SDEs



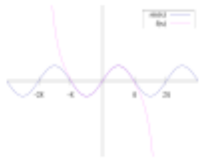
Dynamical systems

Chaos theory

SPACE

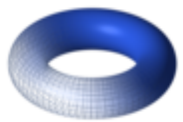


Geometry



Trigonometry

Differential geometry



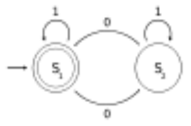
Topology

Fractal geometry

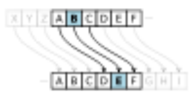
DISCRETE MATHEMATICS

$$\begin{matrix} (1,2,3) & (1,3,2) \\ (2,1,3) & (2,3,1) \\ (3,1,2) & (3,2,1) \end{matrix}$$

Combinatorics



Theory of computation



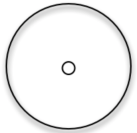
Cryptography

Graph theory

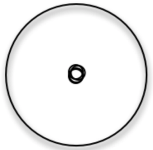
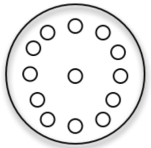
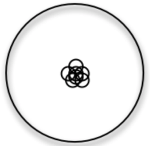
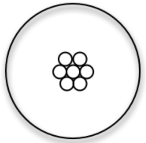
What is the difference?

- **Transdisciplinary**
- **Multidisciplinary**
- **Interdisciplinary**
- **Crossdisciplinary**

research



Intradisciplinary

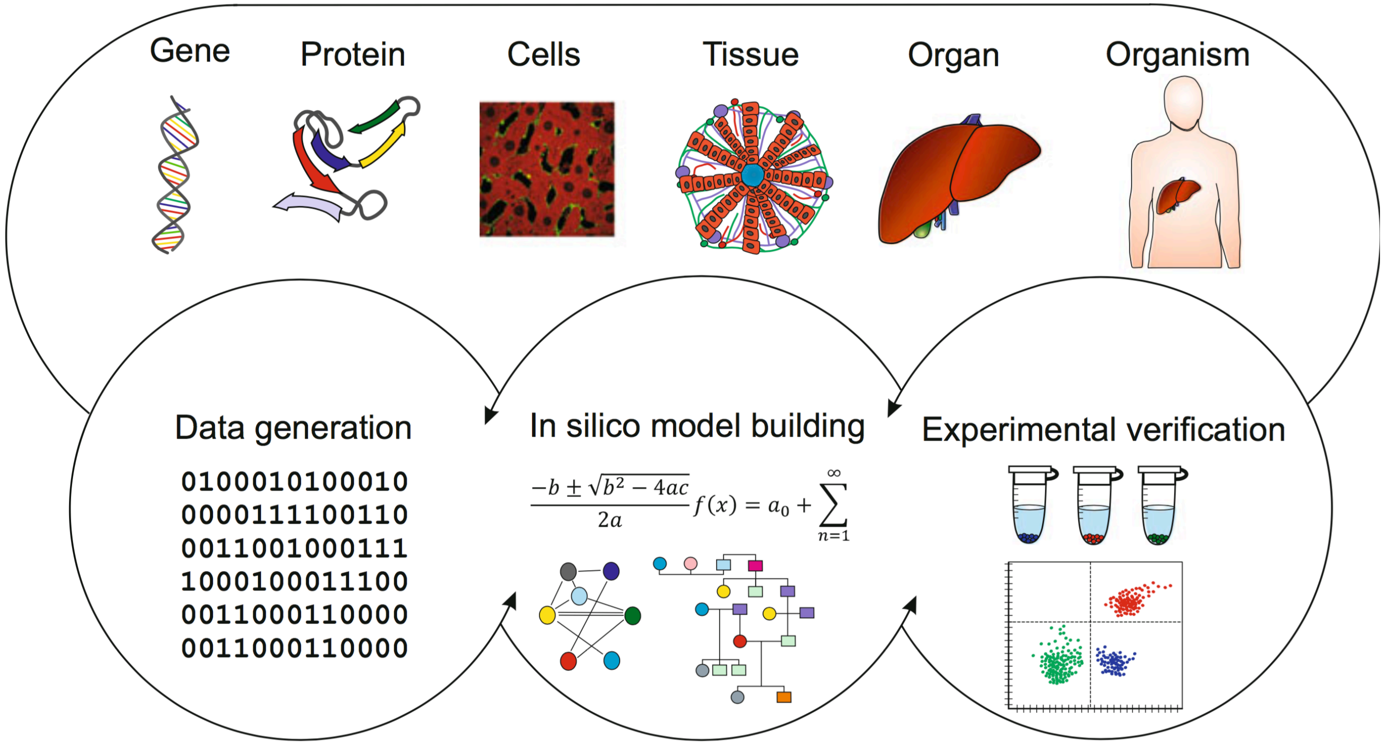





Transdisciplinary Research	Multidisciplinary Research	Interdisciplinary Research	Crossdisciplinary Research
Collaboration in which exchanging information, altering discipline-specific approaches, sharing resources and integrating disciplines achieves a common scientific goal *e.g. pharmacokinetic modeling from DCE-MRI measurements for assessment of tumor physiology*	Researchers from a variety of disciplines work together at some point during a project, but have separate questions, separate conclusions, and disseminate in different journals. *e.g. image co-registration and segmentation*	Researchers interact with the goal of transferring knowledge from one discipline to another. Allows researchers to inform each other's work and compare individual findings. *e.g. multimodal validation of automated image segmentation*	Researchers are viewing one discipline from the perspective of another. *e.g. Digital Life in transition to transdisciplinary research ?*

http://www.obesity-cancer.wustl.edu/en/About/What-Is-Transdisciplinary-Research

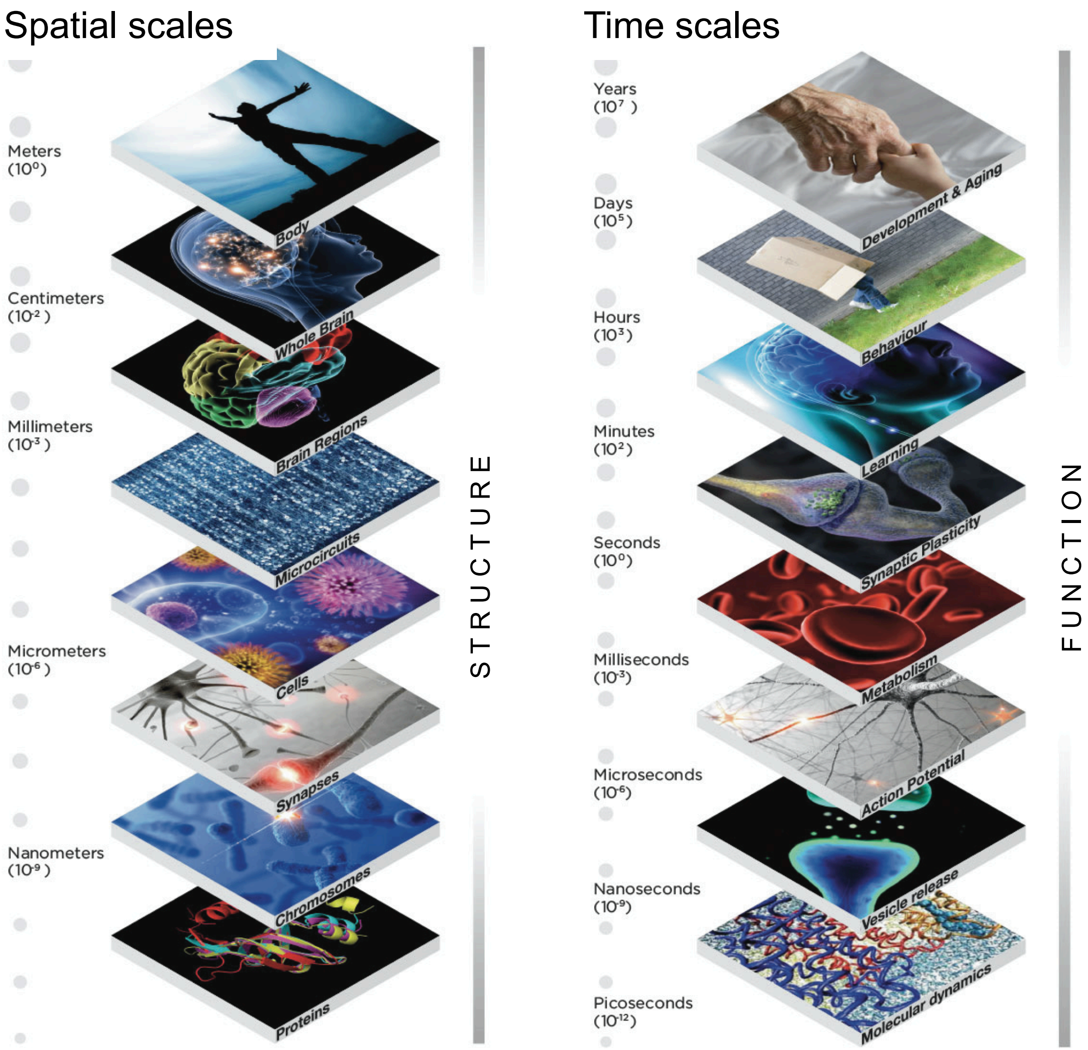
http://www.arj.no/2012/03/12/disciplinarities-2

Systems biology & medicine and computational imaging



Ulf Schmitz, Olaf Wolkenhauer (eds) Systems Medicine, Springer, 2016

MULTISCALE



https://www.humanbrainproject.eu

TRENDS

Computational Medicine

It will soon be common for clinical research studies to:

- Collect genetic, transcriptional, proteomic, imaging and clinical data from every patient in large, carefully selected cohorts sharing a specific disease diagnosis.

Johns Hopkins University

- The challenge of the coming decade will be
  - how best to use these *multi-scale* biomedical data
  - to gain a *quantitative understanding* of disease mechanisms
  - across *hierarchical levels* of biological organization
  - to identify *biological markers* which correlate with different disease states
  - and inter-individual differences in *disease risk*
- Discover more effective *therapeutics targeted to the individual*

http://www.icm.jhu.edu

Unit of Computational Medicine - **Karolinska Institutet**

CompMed
Unit of Computational Medicine

Uniquely integrated multidisciplinary team of more than 30 scientists from

- **pure and applied mathematics**
- **immunology**
- **physics**
- **midwifery**
- **complexity theory**
- **cell and molecular biology**
- **computer science**
- **pharmacology**
- **engineering**
- **medicine**

- develop and apply integrative *computational-experimental approaches*
- provide fundamental insights of *life beyond physics*
- enable prediction, prevention and treatment of *diseases*

http://www.compmed.se

TRENDS

Data analytics - Machine learning

Deep learning is a growing trend in general data analysis and has been termed one of the 10 breakthrough technologies of 2013 [1]. Deep learning is an improvement of artificial neural networks, consisting of more layers that permit higher levels of abstraction and improved predictions from data [2]. To date, it is emerging as the leading machine-learning tool in the general imaging and computer vision domains.

IEEE TRANSACTIONS ON

MEDICAL IMAGING

A PUBLICATION OF
THE IEEE ENGINEERING IN MEDICINE AND BIOLOGY SOCIETY
THE IEEE NUCLEAR AND PLASMA SCIENCES SOCIETY
THE IEEE SIGNAL PROCESSING SOCIETY
THE IEEE ULTRASONICS, FERROELECTRICS, AND FREQUENCY CONTROL SOCIETY

MAY 2016 VOLUME 35 NUMBER 5

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SPECIAL ISSUE ON DEEP LEARNING IN MEDICAL IMAGING

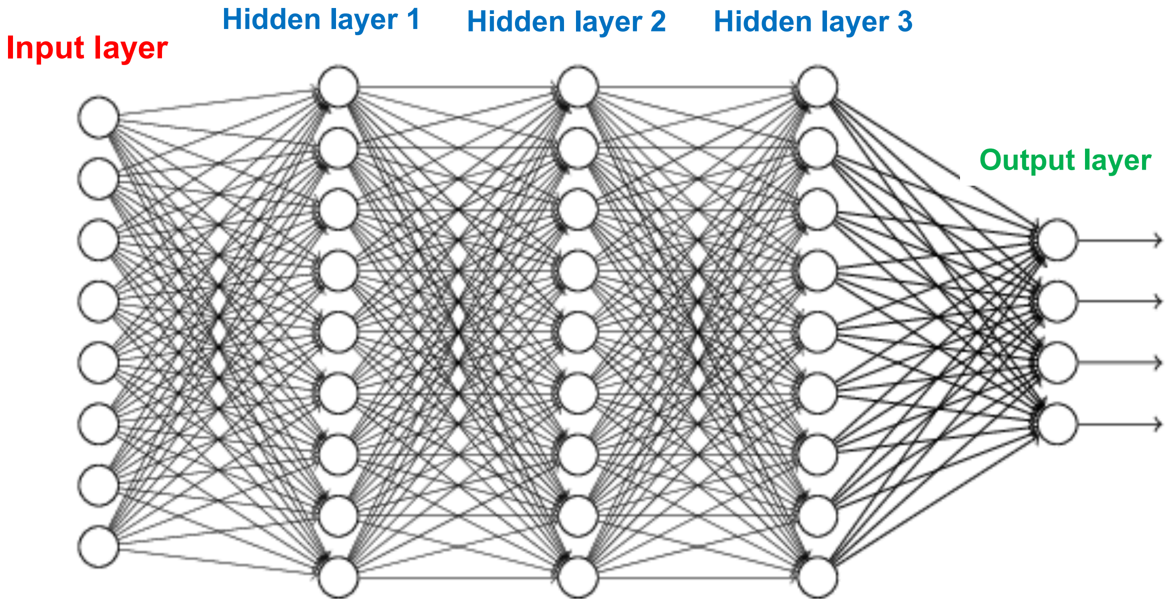
GUEST EDITORIAL

SPECIAL ISSUE PAPERS

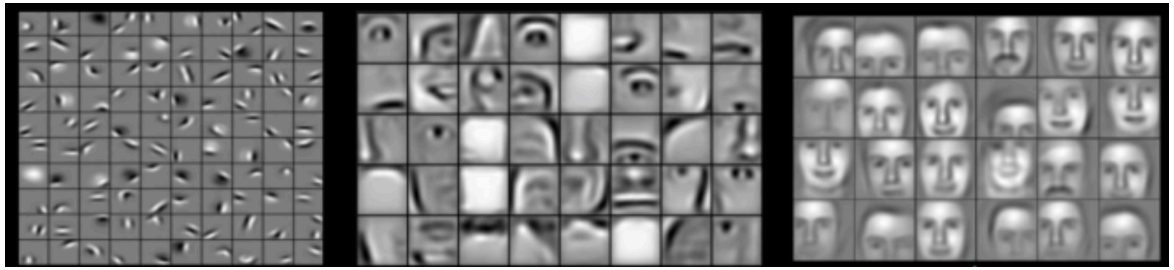
(Contents Continued on Back Cover)

Neural networks - deep learning

TRENDS



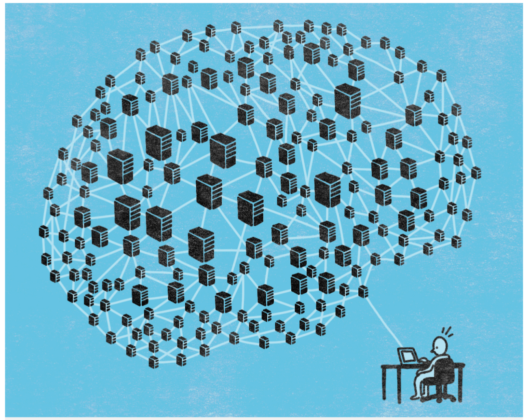
layers of features

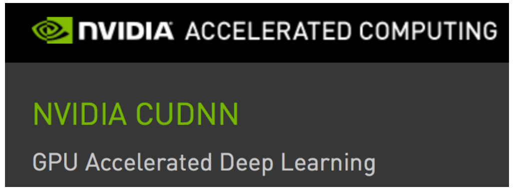


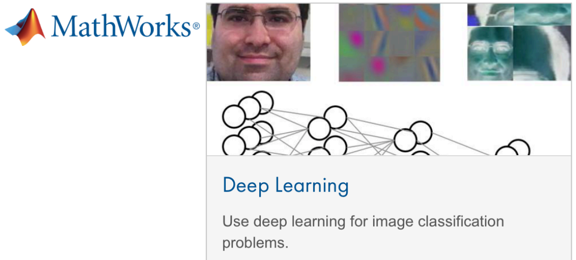
Deep learning is a branch of machine **learning** based on a set of algorithms that attempt to model high-level abstractions in data by using multiple processing layers, with complex structures or otherwise, composed of multiple non-linear transformations

Wikipedia

Microsoft releases CNTK, its open source deep learning toolkit, on GitHub







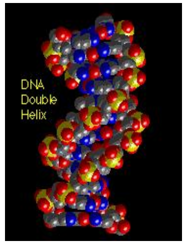
Imaging infrastructure (in Bergen)

INFRASTRUCTURE

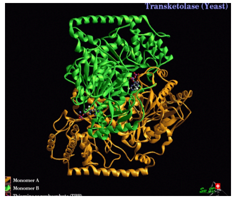
- Superresolution microscopy (STED)
- MRI experts (acquisition + analysis)

- New visualization center from 2017

DNA

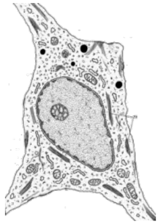


Protein



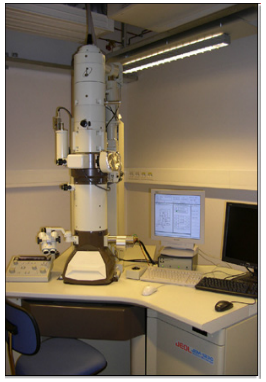
Organelle

Cell



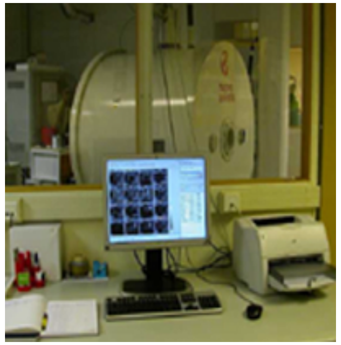
Microscopy

EM



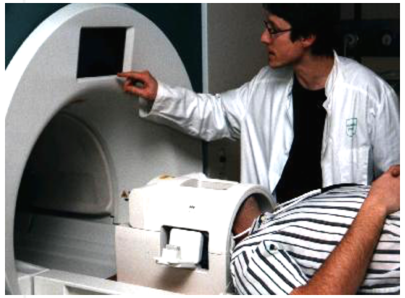
Confocal

Animal MRI



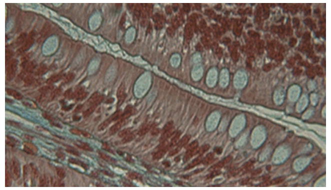
7 Tesla Bruker Pharmascan

Clinical MRI



1 GE + 2 x Siemens 3 Tesla

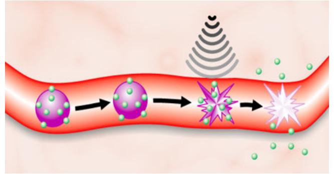
Tissue



$$\frac{\partial M_x(t)}{\partial t} = \gamma(\mathbf{M}(t) \times \mathbf{B}(t))_x - \frac{M_x(t)}{T_2}$$
$$\frac{\partial M_y(t)}{\partial t} = \gamma(\mathbf{M}(t) \times \mathbf{B}(t))_y - \frac{M_y(t)}{T_2}$$
$$\frac{\partial M_z(t)}{\partial t} = \gamma(\mathbf{M}(t) \times \mathbf{B}(t))_z - \frac{M_z(t) - M_0}{T_1}$$

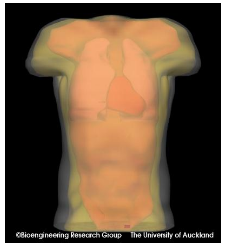
Clinical US

Organ

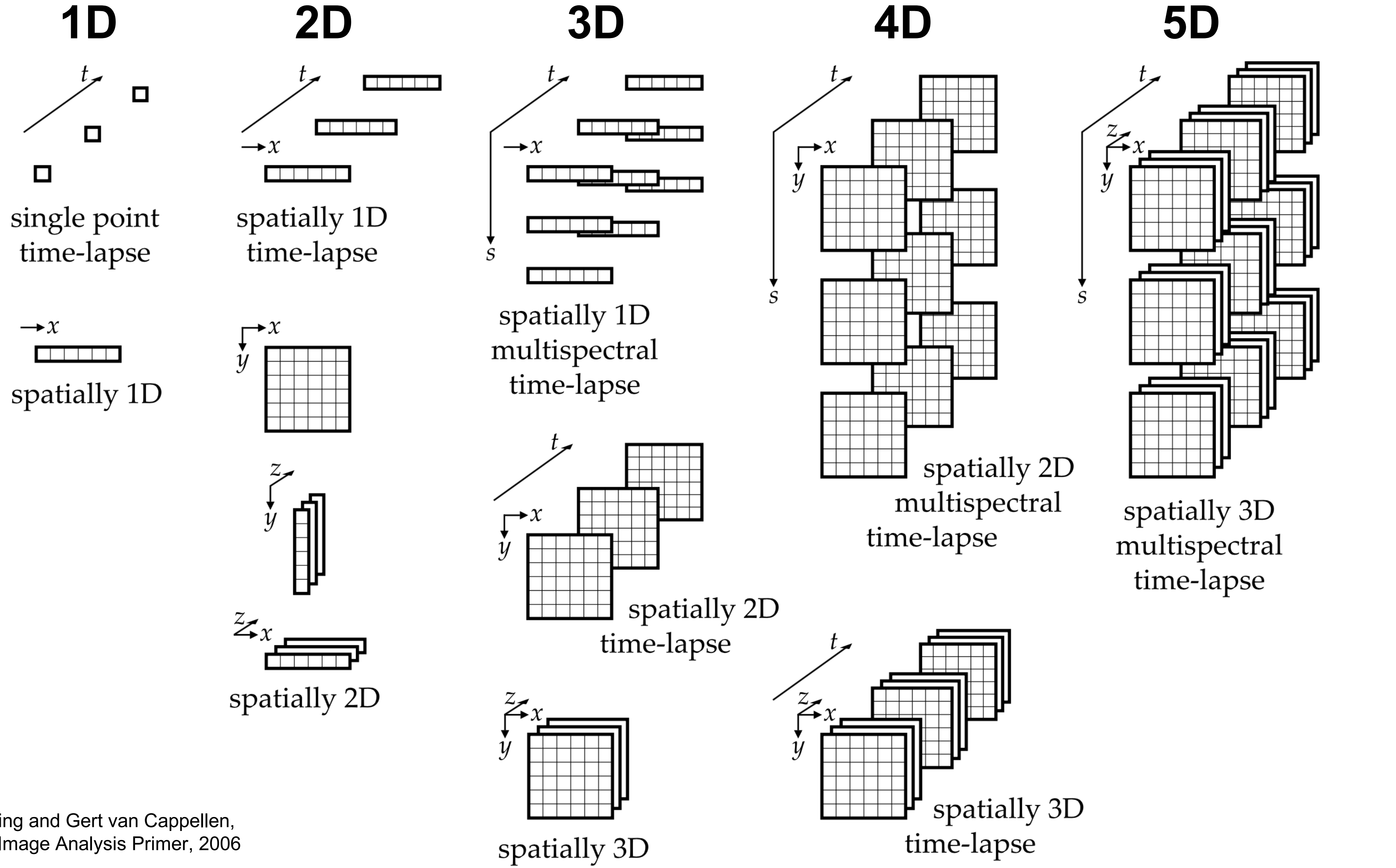


Clinical PET/CT

Organism



Images as matrices



From: Erik Meijering and Gert van Cappellen,
Biological Image Analysis Primer, 2006

http://www.imagescience.org/meijering/publications/download/biap2006.pdf

“Image formation” vs. “Image processing”

Image Formation

object in → image out

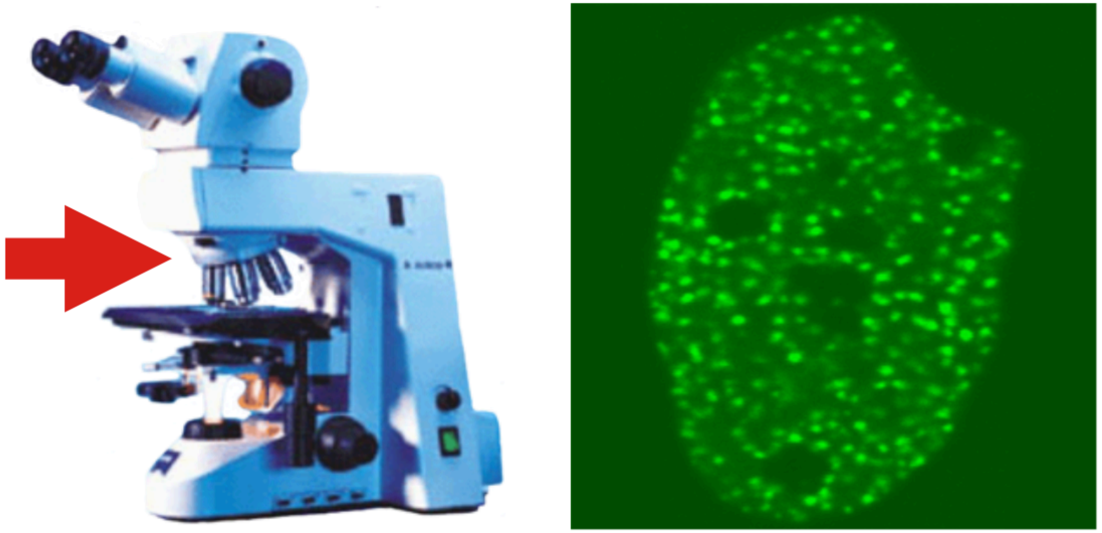
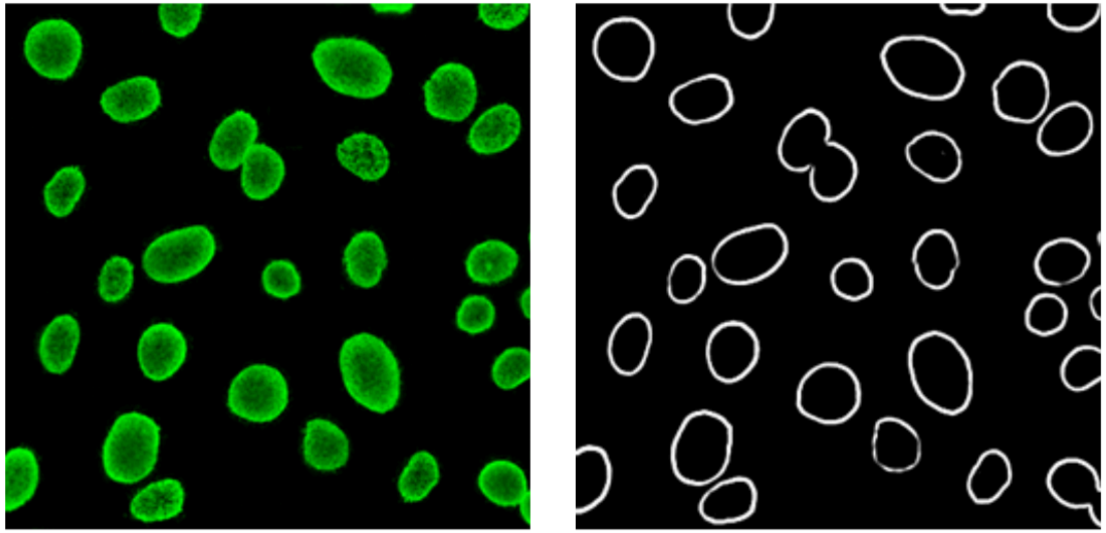


Image Processing

image in → image out



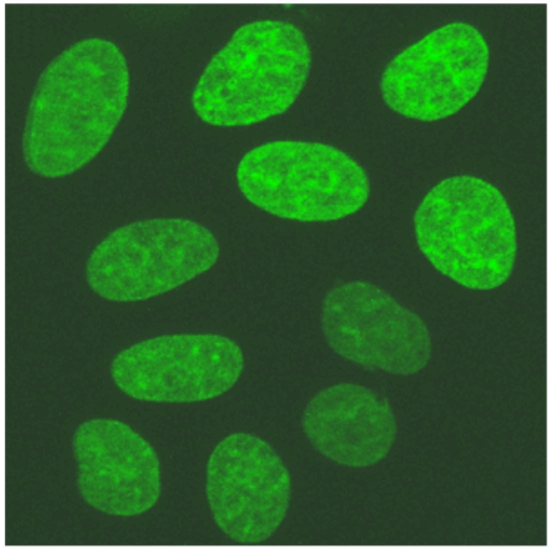
From: Erik Meijering and Gert van Cappellen,
Biological Image Analysis Primer, 2006

http://www.imagescience.org/meijering/publications/download/biap2006.pdf

“Image analysis” vs. “Computer graphics”

Image Analysis

image in ⟶ features out

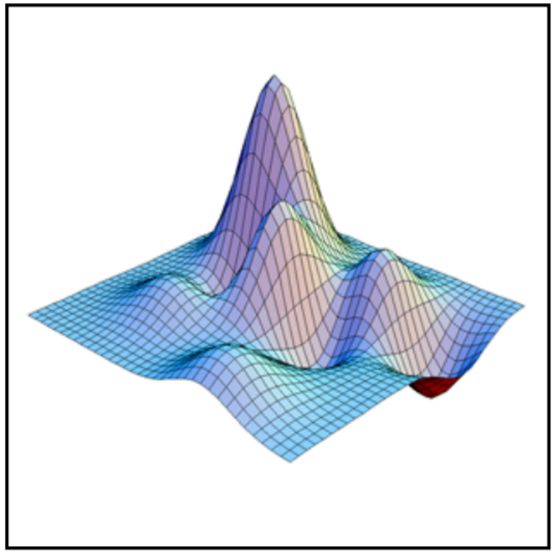


Obj	Area	Perim
1	324.2	98.5
2	406.7	140.3
3	487.1	159.2
4	226.3	67.8
5	531.8	187.6
6	649.5	203.1
7	582.6	196.4
8	498.0	162.9
9	543.2	195.1

Computer Graphics

numbers in ⟶ image out

X	Y	I
-3.54	-2.32	0.50
-2.78	-1.90	0.12
-1.15	0.42	3.09
0.45	1.65	5.89
1.83	2.18	7.72
2.98	3.33	2.07
4.21	3.96	-4.58
5.62	4.54	-11.45
7.16	5.02	-3.63



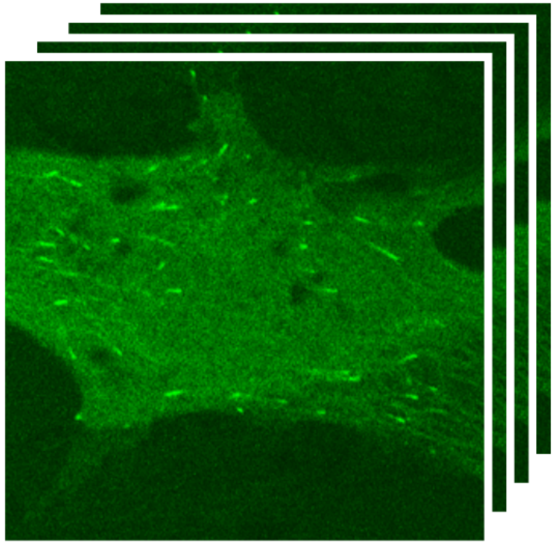
From: Erik Meijering and Gert van Cappellen,
Biological Image Analysis Primer, 2006

http://www.imagescience.org/meijering/publications/download/biap2006.pdf

“Computer vision” vs. “Visualization”

Computer Vision

image in ➞ interpretation out

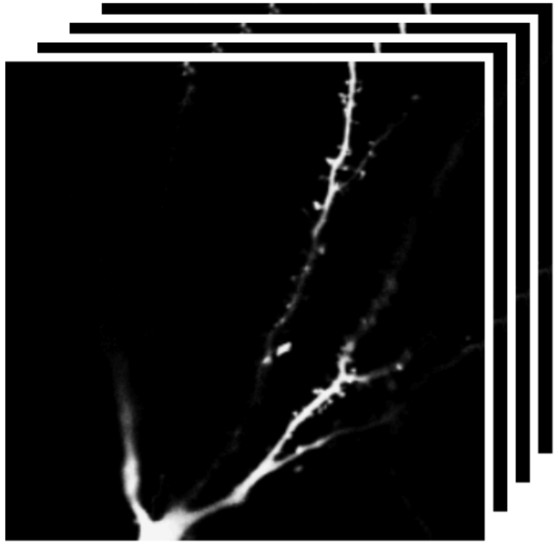


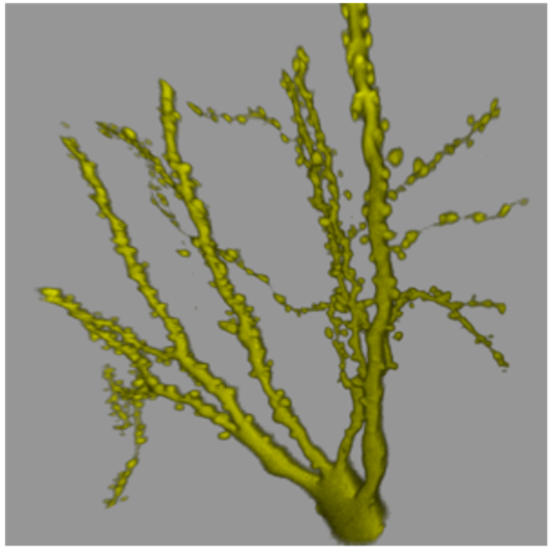
The series shows microtubule growth in a live neuron. The average speed of the distal ends is comparable in the cell body, dendrites, axons, and growth cones.

(Image understanding)

Visualization

image in ➞ representation out





From: Erik Meijering and Gert van Cappellen, Biological Image Analysis Primer, 2006

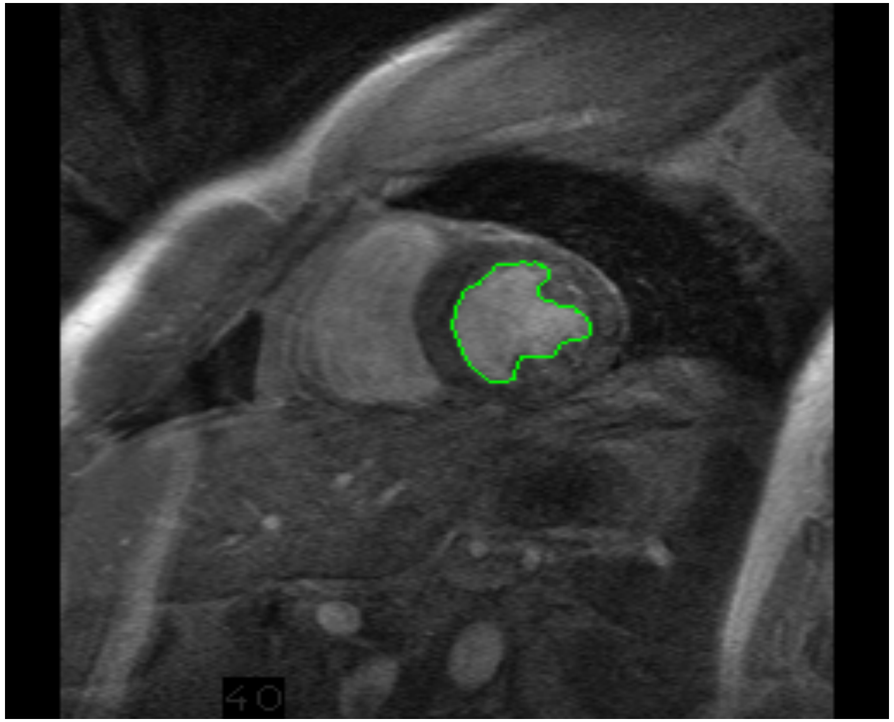
http://www.imagescience.org/meijering/publications/download/biap2006.pdf

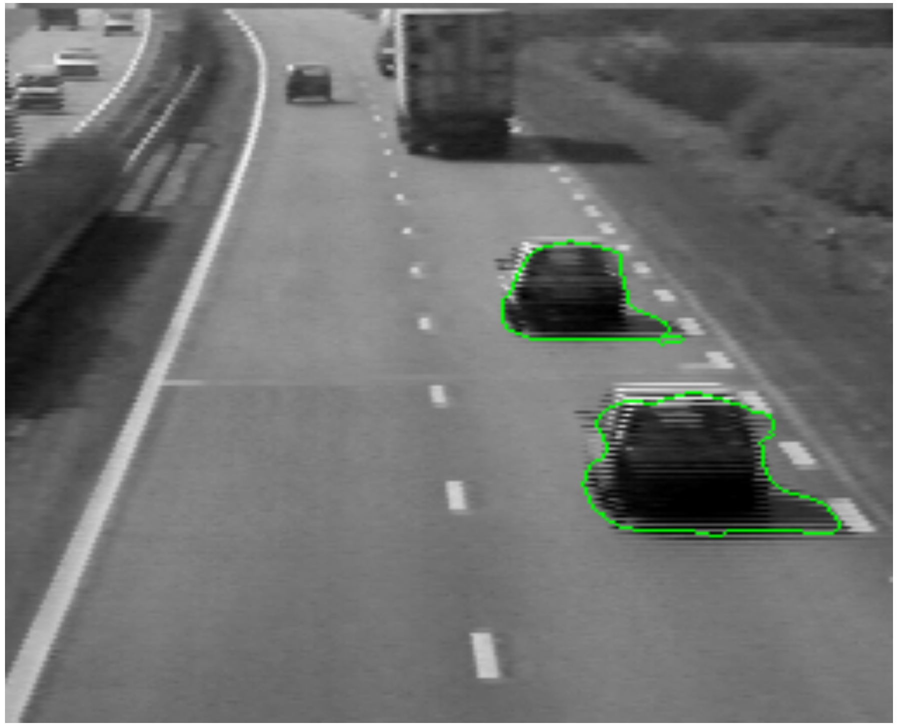
Modeling and image analysis can be **generic** in nature

("active contours")

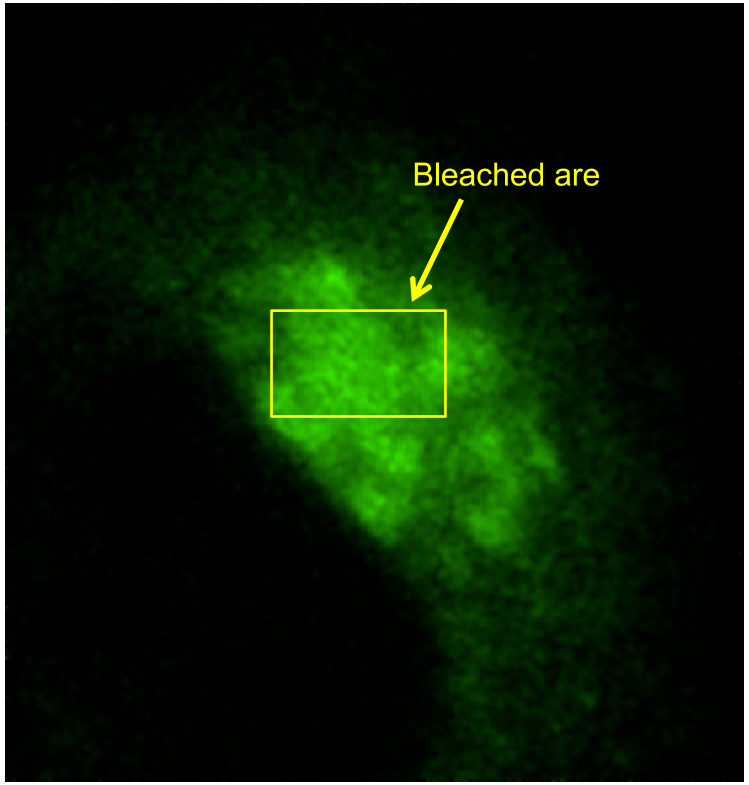
Medical MR imaging

Surveillance engineering



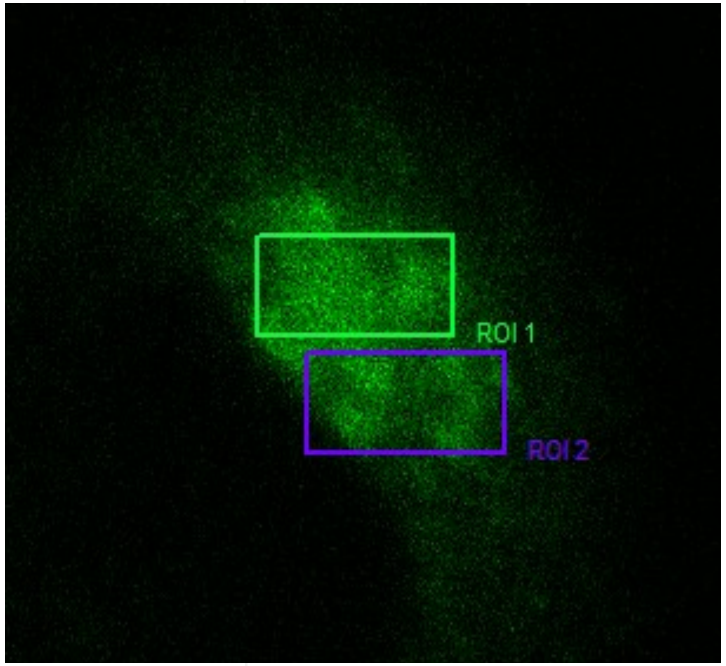


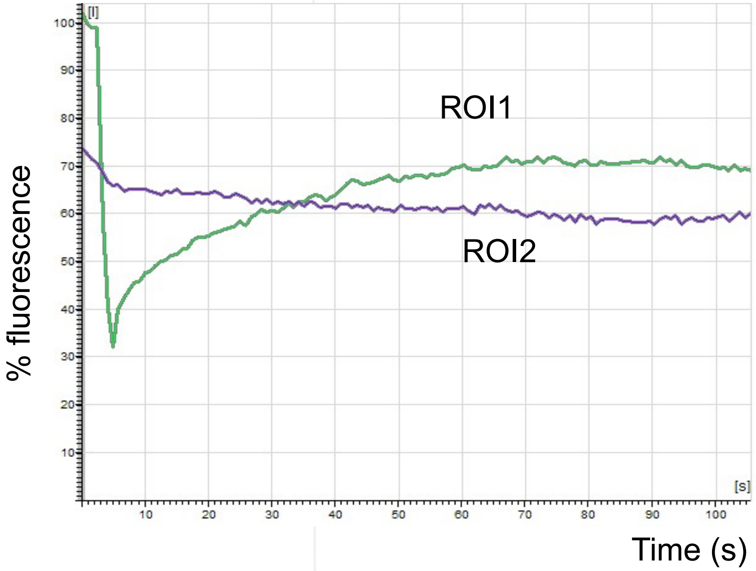
Live cell imaging: **FRAP** – Fluorescence Recovery After Photobleaching



Photobleaching of GFP in the Golgi area (ROI1) with a high intensity laser.

The recovery of fluorescence in the bleached area is followed.





Measure the dynamics of a molecule over time (diffusional mobility) and chemical changes of molecular species

Image-based modelling:

2-compartment model

O - organelle-associated protein

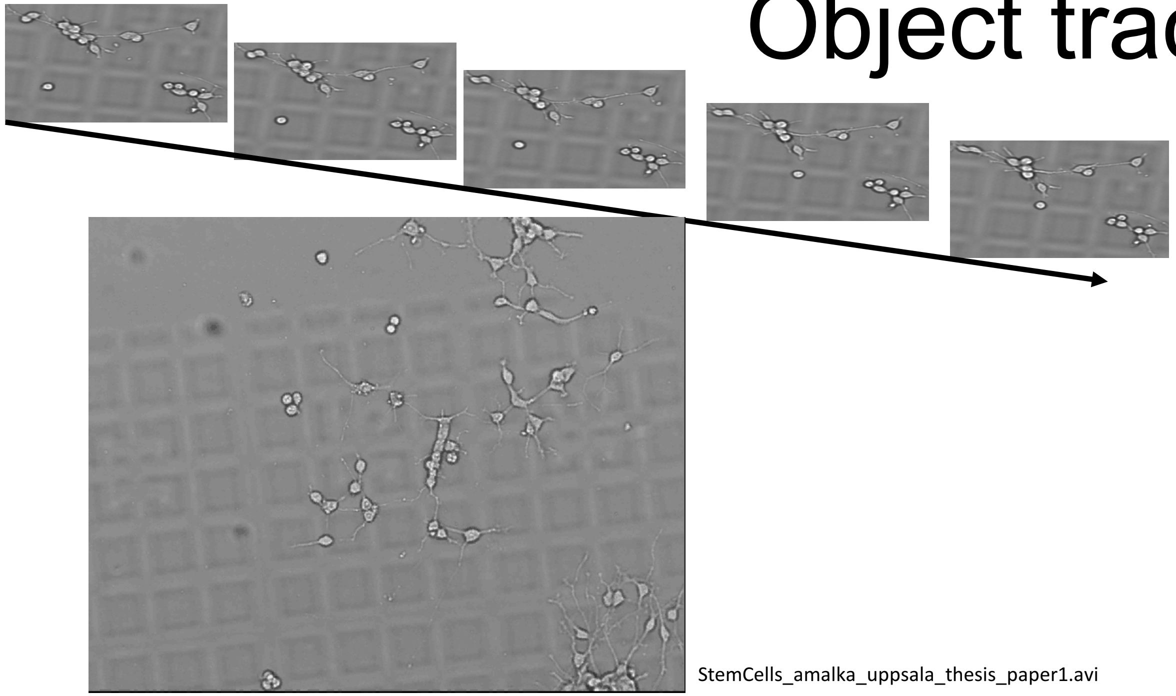
C - cytoplasmic protein

$$\left.\begin{aligned} \frac{dO}{dt} &= k_{in}\,C - k_{out}\,O \\ \frac{dC}{dt} &= k_{out}\,O - k_{in}\,C \end{aligned}\right\}$$

k_x – reate constants

MIC
Molecular Imaging Center

Object tracking

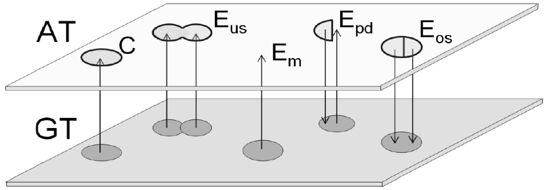


Time

StemCells_amalka_uppsala_thesis_paper1.avi

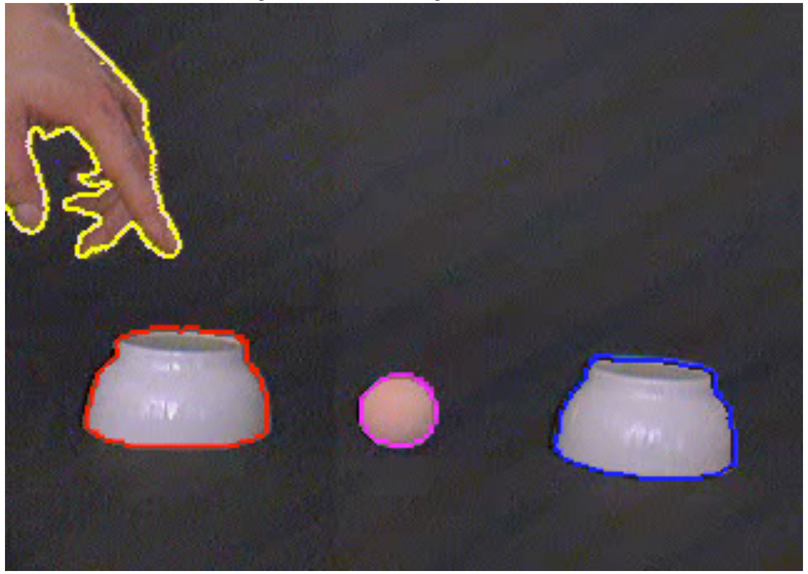
Performance evaluation

Automatically segmented and tracked



Ground truth

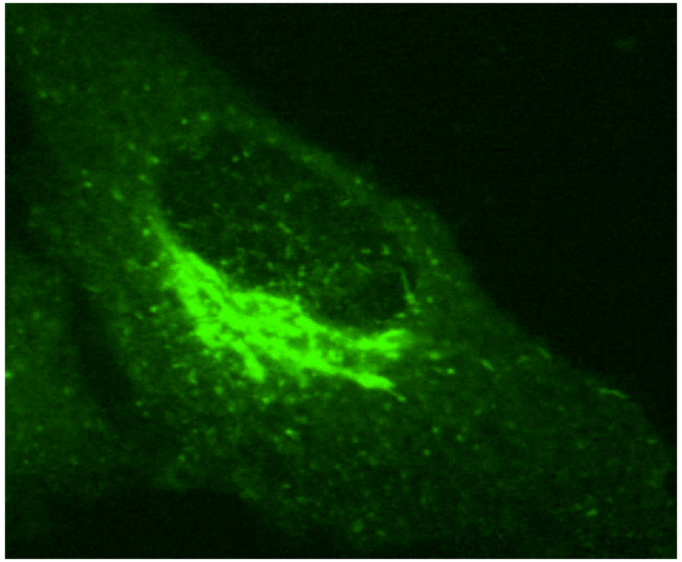
”Easy” - ”Toy problem ”



occlusion is handeled

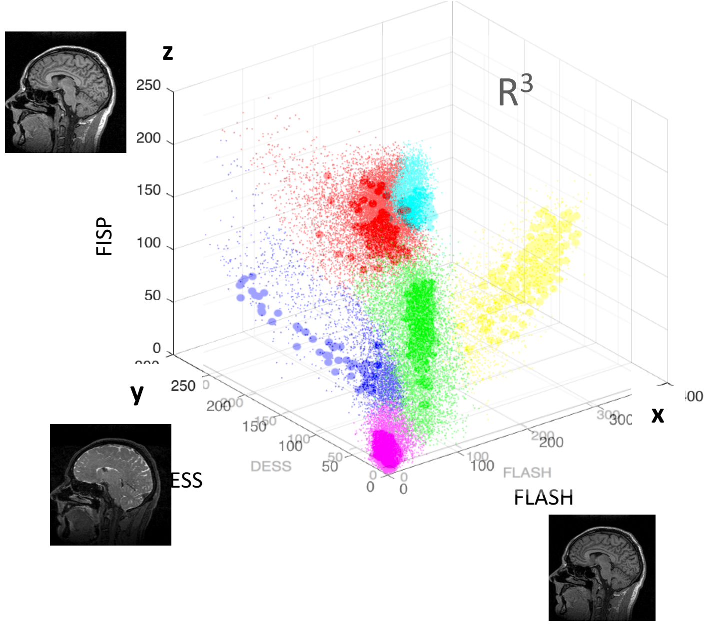
” Intracellular transport vesicles ”

Difficult:

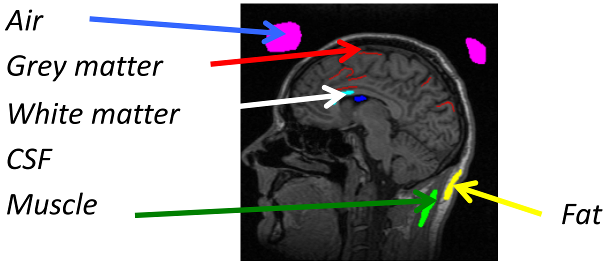


Automated brain tissue classification - kNN

k=7 Nearest Neighbor classification
to six different tissue types of the human head



⇦ Classification of new voxels based on a training set (mask) made by an expert (**supervised learning**):



TRENDS

Reproducible research – Open Science – Open source

Computational (bio)medicine

& Software development

GitHub

From Wikipedia, the free encyclopedia

GitHub is a web-based Git repository hosting service. It offers all of the distributed revision control and source code management (SCM) functionality of Git as well as adding its own features. Unlike Git, which is strictly a command-line tool, GitHub provides a Web-based graphical interface and desktop as well as mobile integration. It also provides access control and several collaboration features such as bug tracking, feature requests, task management, and wikis for every project.[3]

GitHub offers both plans for private repositories and free accounts,[4] which are usually used to host open-source software projects.[5] As of April 2016, GitHub reports having more than 14 million users and more than 35 million repositories,[6] making it the largest host of source code in the world.[7]

" Build software better, together "

README.md

Example

MITK

The Medical Imaging Interaction Toolkit (MITK) is a free open-source software system for development of interactive medical image processing software. MITK combines the Insight Toolkit (ITK) and the Visualization Toolkit (VTK) with an application framework.

The links below provide high-level and reference documentation targeting different usage scenarios:

- Get a high-level overview about MITK with pointers to further documentation
- End-users looking for help with MITK applications should read the MITK User Manual
- Developers contributing to or using MITK, please see the MITK Developer Manual as well as the MITK API Reference

See the MITK homepage for details.

Supported Platforms

MITK is a cross-platform C++ toolkit and officially supports:

- Windows
- MacOS X
- Linux

For details, please read the Supported Platforms page.

License

Copyright (c) German Cancer Research Center.

MITK is available as free open-source software under a BSD-style license.

Download

The future of (bio)medicine …

➡ - **mindset**
- **skillset**
- **toolset**

- **open science**
- **reproducible research**

- **SYSTEMS BIOLOGY, SYSTEMS MEDICINE** and **IN VIVO IMAGING**
- **TRANSDISCIPLINARITY** and **COMPUTATIONAL APPROACHES** addressing the multi-scale nature of organs and tissues in health and disease

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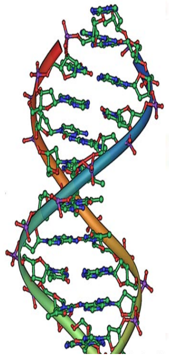
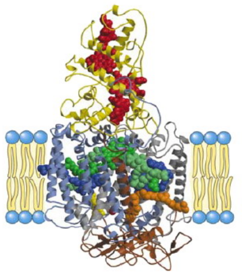
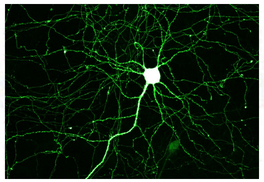
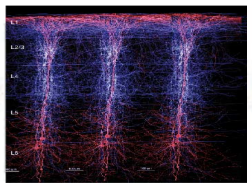
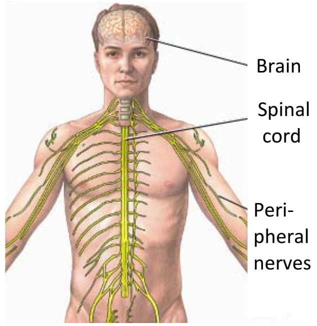
SPACE:

Atom	Protein	Cell	Tissue	Organ	Organ system & organism
10^{-12} m	10^{-9} m	10^{-6} m	10^{-3} m	10^{0} m Anatomy	Physiology
					
Gene networks	Pathway models	Stochastic models	Ordinary Differential Equations	Continuum models (Partial Differential Equations)	Systems models

TIME:

10^{-6} s	10^{-3} s	10^{0} s	10^{3} s	10^{6} s	10^{9} s
molecular events (ion channel gating)	diffusion cell signalling	motility	mitosis	protein turnover	human lifetime

From: C. Dollery and R. Kitney, Systems biology: A vision for engineering and medicine, Tech. report, The Academy of Medical Sciences and The Royal Academy of Engineering, London, UK, Feb. 2007.