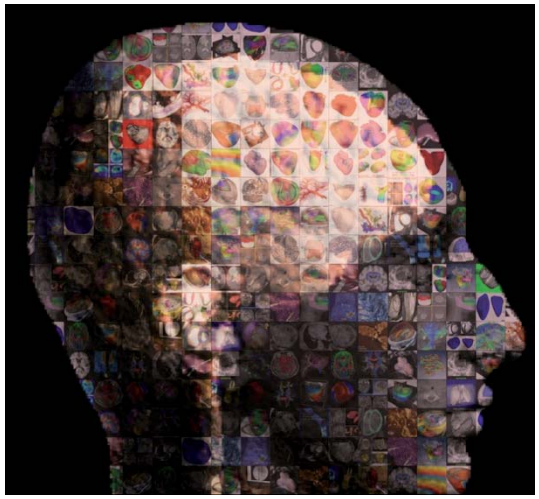
Chair of Informatics and Computational Sciences



The Future of the Personalized Digital Patient

Nicholas Ayache

24 June 2014

Collège de France

informatics mathematics

The Personalized Digital Patient
Images, Medicine and Informatics

COLLÈGE DE FRANCE 1530

Warning

« prediction is very difficult, especially when addressing the future »

Niels Bohr

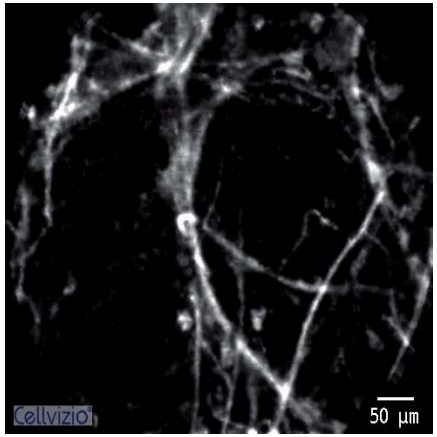
Woody Allen

1. More Images and Signals

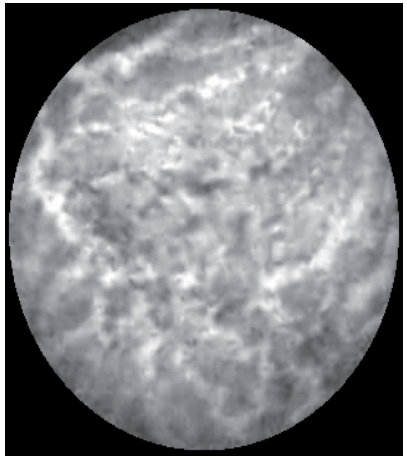
- Evidence based medicine
- Overflow of information
  - requires computer-assisted extraction of *clinically useful* information
- New modalities to be invented and to cover all scales *(nano-micro-meso-macro)*

Living Cells

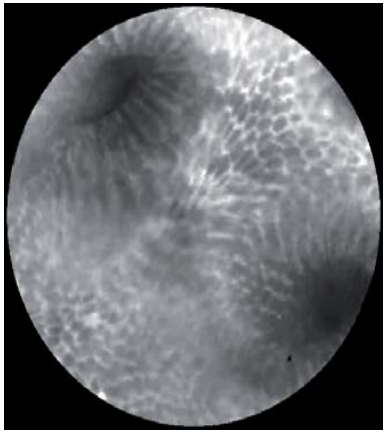
alveoli



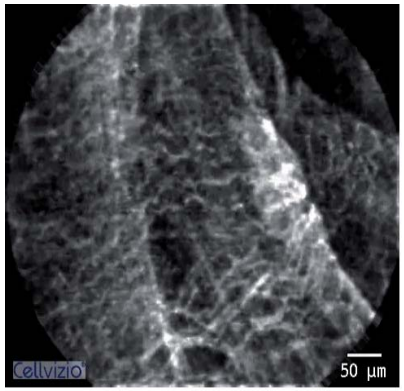
pancreas



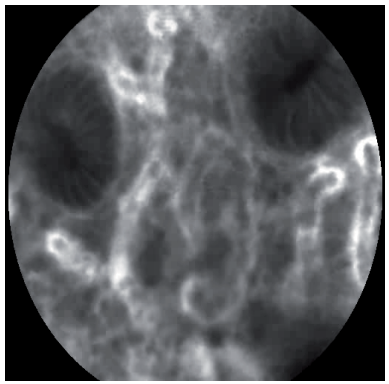
Stomach



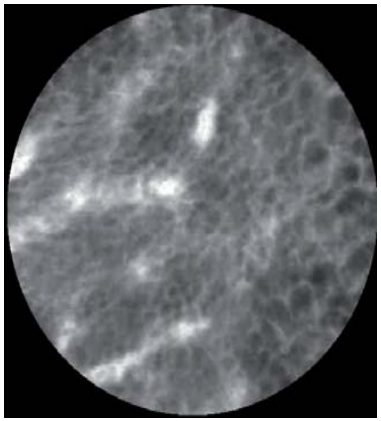
bronchi



small bowel



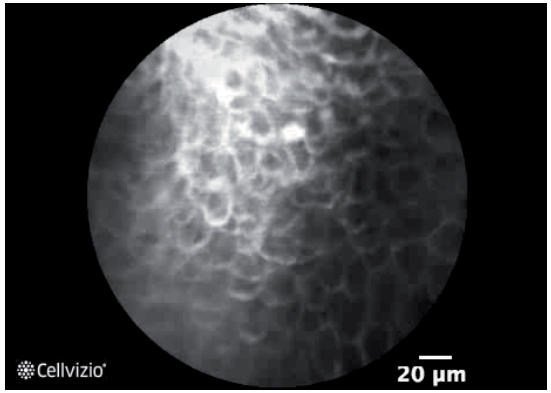
bladder



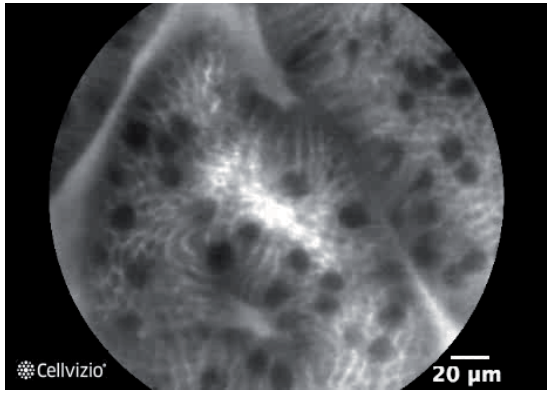
Cellvizio, Mauna Kea Technologies

Progression of Cancer

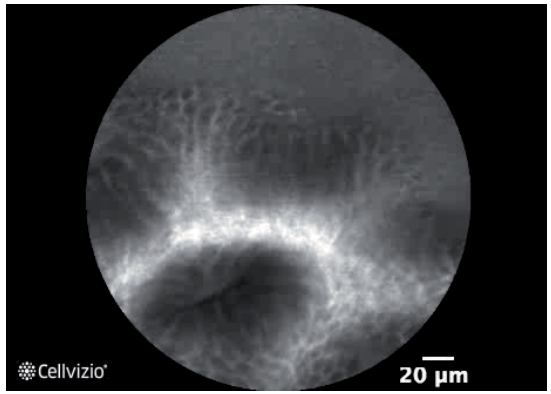
Barrett's esophagus



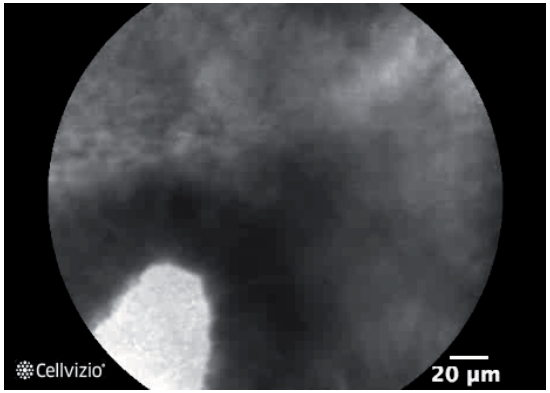
normal epithelium



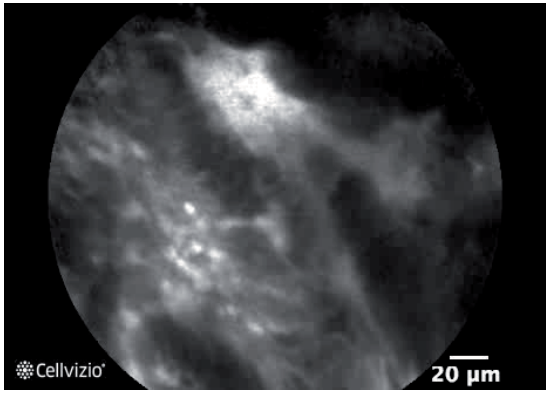
metaplasia



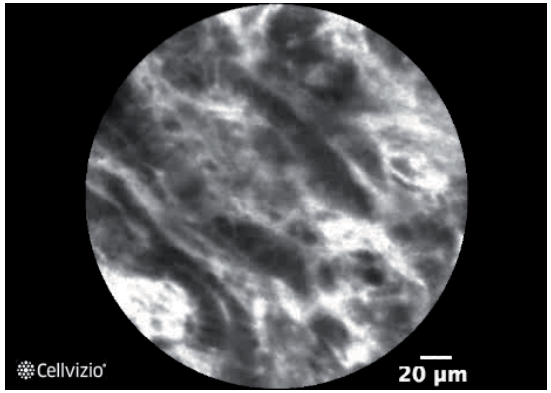
metaplasia



metaplasia



dysplasia



cancer

Cellvizio, Mauna Kea Technologies

More Images

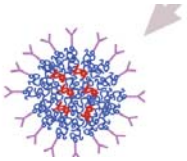
- Confocal Endomicroscopy
- Optical Coherence Tomography
- Elastography (MRI, US, etc.)
- MRI
  - High field (3-12T), spectroscopy, thermometry, diffusion, perfusion, etc.
- Mapping electric/magnetic fields
- Theranostic imaging
  - HIFU (High Intensity Focused Ultrasounds)
  - Nano-vectors (contrast + drug)

Supersonic Imagine

IHU Bordeaux

SiliconAngle

ECG, pression, oxygenation



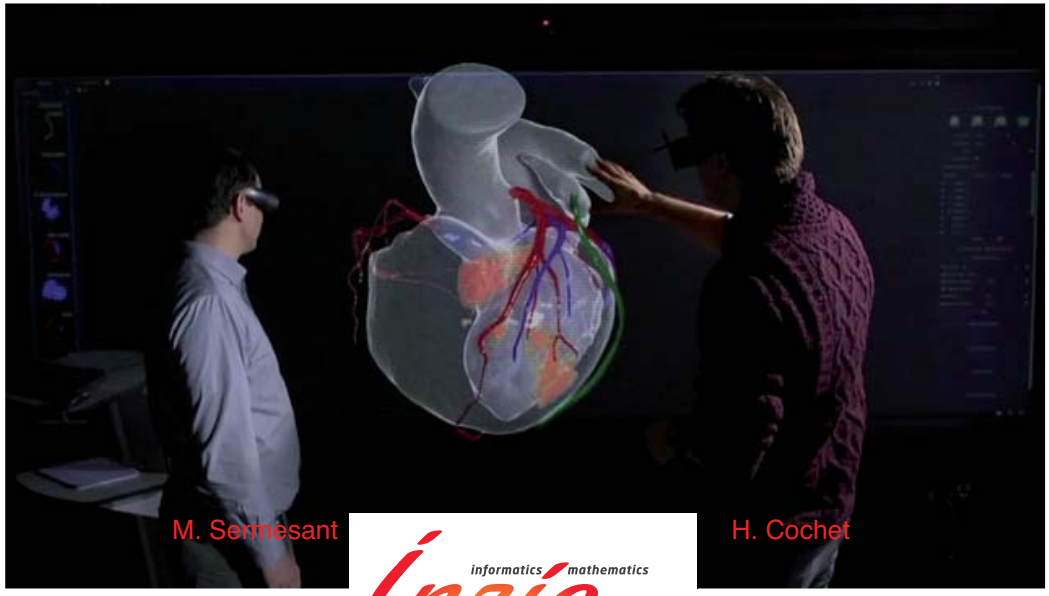
T. Baumert

2. Progress of Technology

- Power of computers
  - Moore's law: x2 (18 months)
    - x1000 (15 yrs),
    - x1.000.000 (30 yrs)…
  - **2014 :** Tihane 2 : 35 millions of billions of operations/sec
    - 3 million times faster than Deep Blue (1997)
  - ***2019 :*** exaflop : 1 billions of billions of operations/sec
  - ***2034* :** zetaflop : 1000 billions of billions of operations/sec

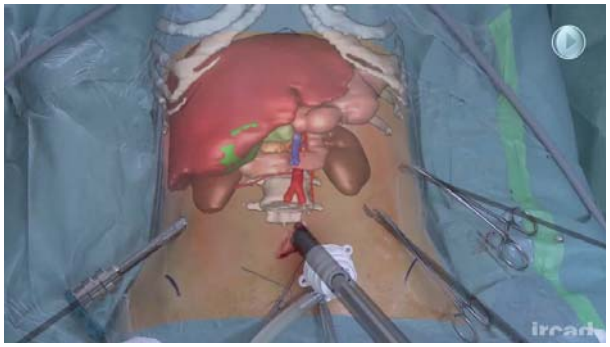
L. Alexandre, Le Monde 12 Feb 2014

Visualization

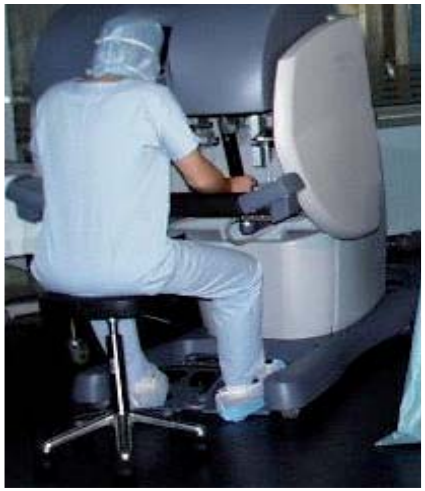


Robots

Surgical Robot



Augmented Reality

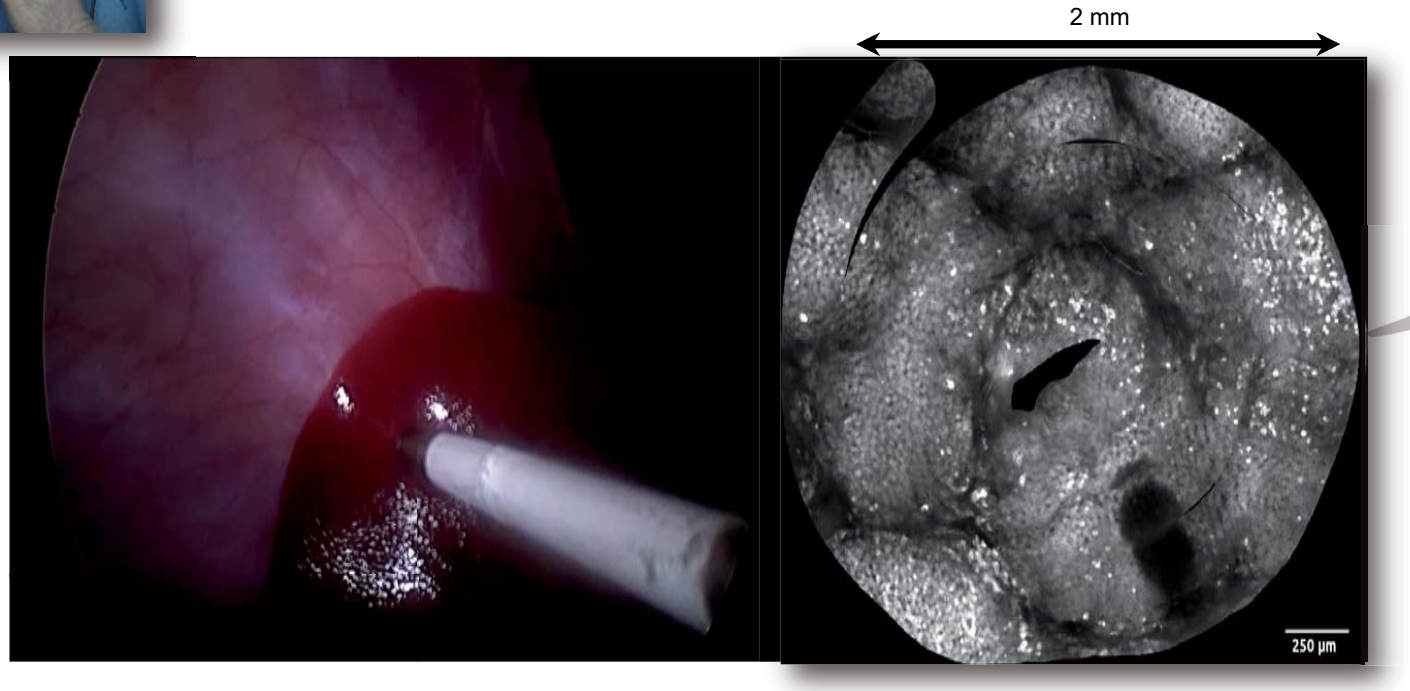


Da Vinci

Imaging Robot

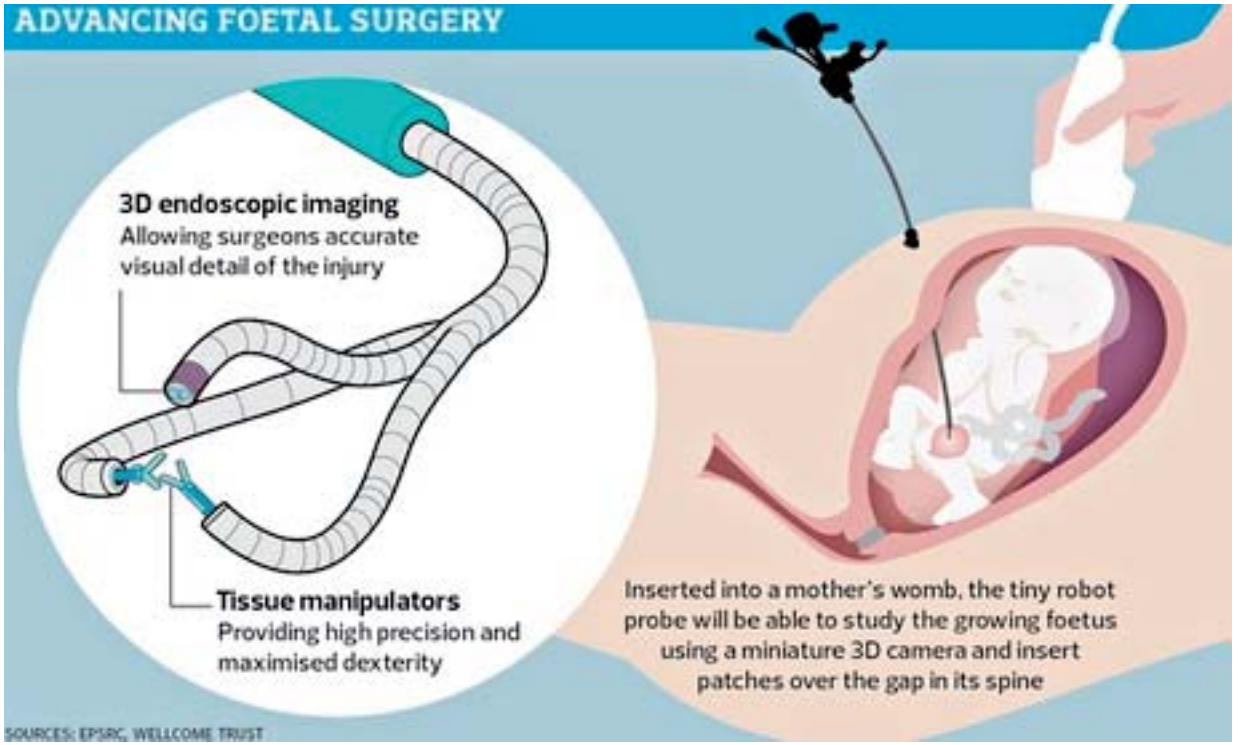
Zeego

Robotized Fibroscope



Perseus Project

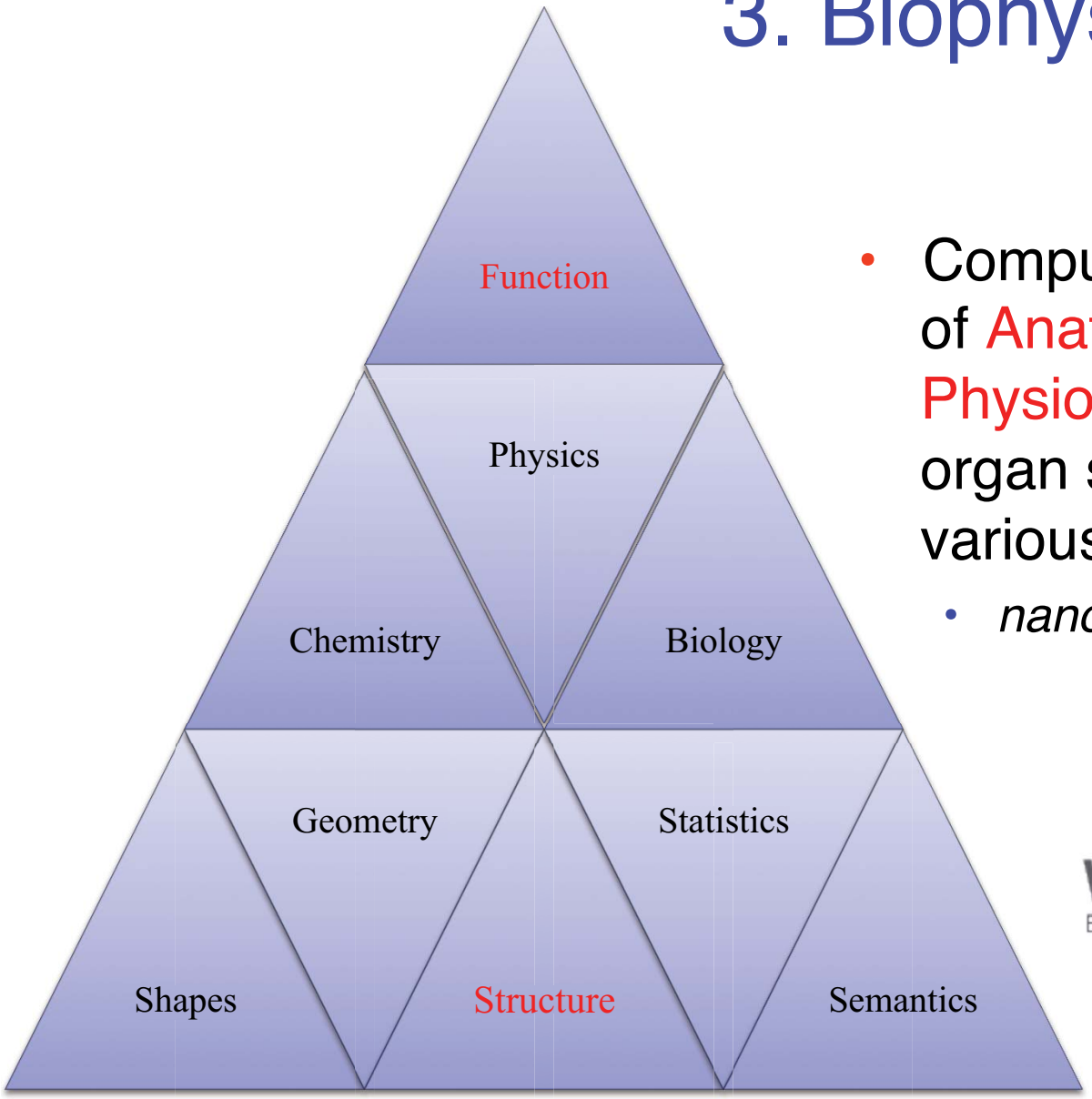
Robotized Fetal Surgery
guided by endoscopic imaging



The Observer 31 May 2014

PI : Sebastien Ourselin (UCL)

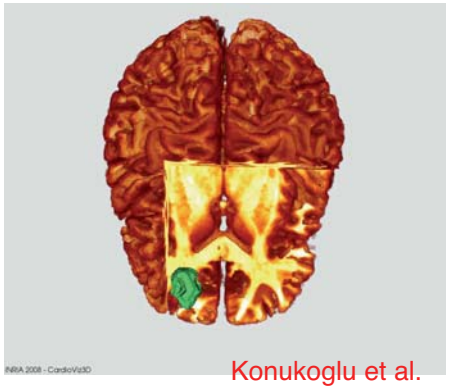
3. Biophysical Models



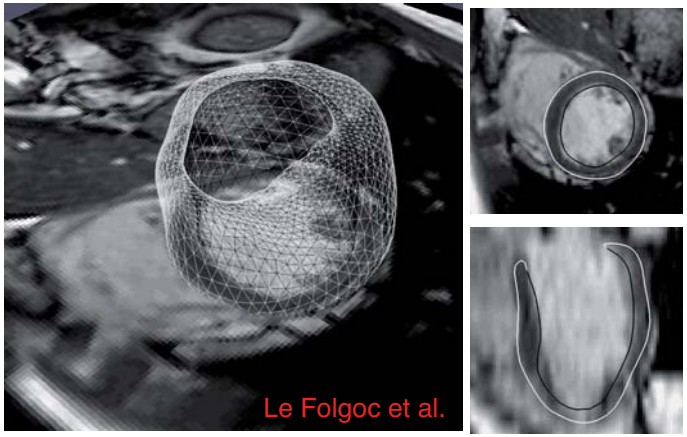
- Computational models of Anatomy and Physiology of the organ systems at various scales
  - *nano-micro-meso-macro*

VPH Institute
Building the Virtual Physiological Human
www.vph-institute.org

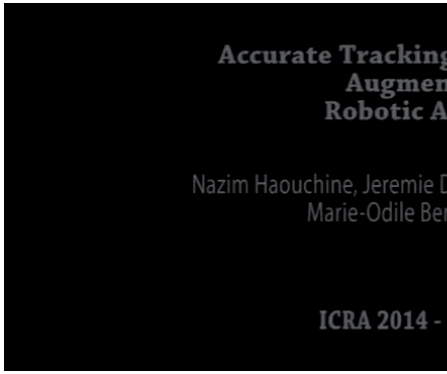
4. Personalization with Images and Signals



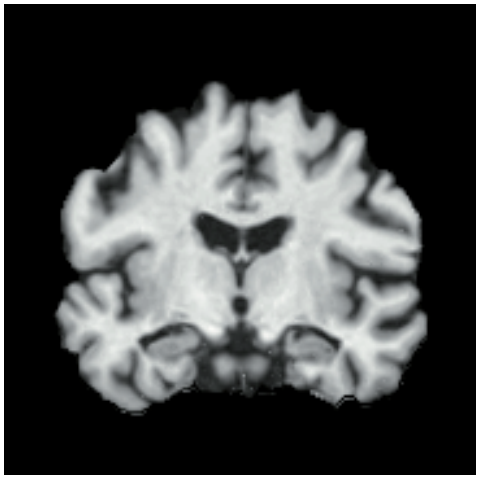
Konukoglu et al.



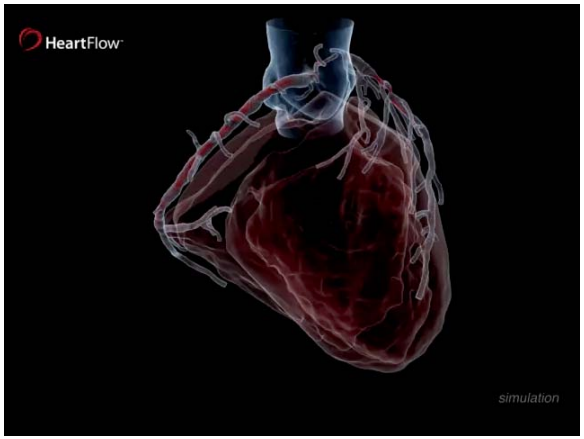
Le Folgoc et al.

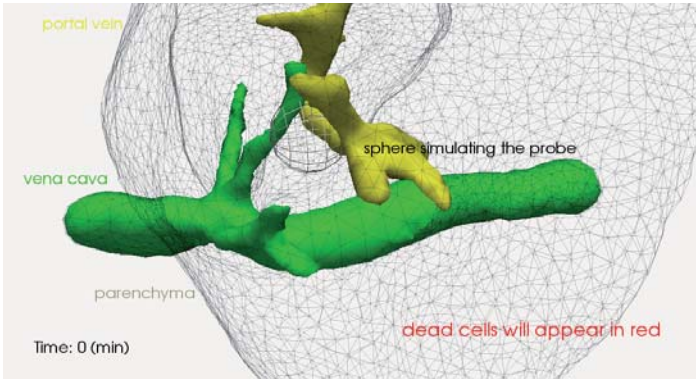


Cotin et al.



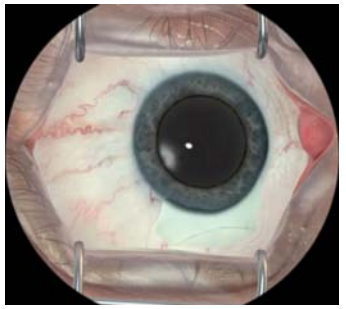
Lorenzi et al.





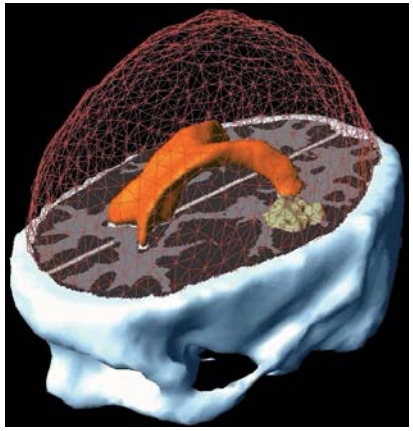
Audigier et al.

5. Biophysical Simulation

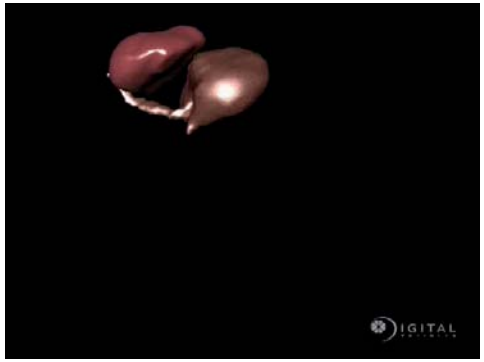


HelpMeSee

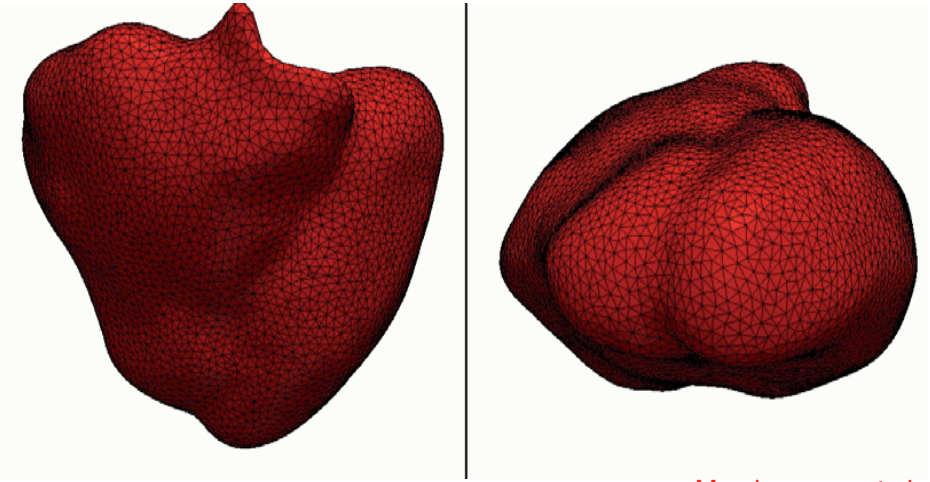
- A new pillar for research
  - understand, predict
  - plan, optimize



Clatz et al.



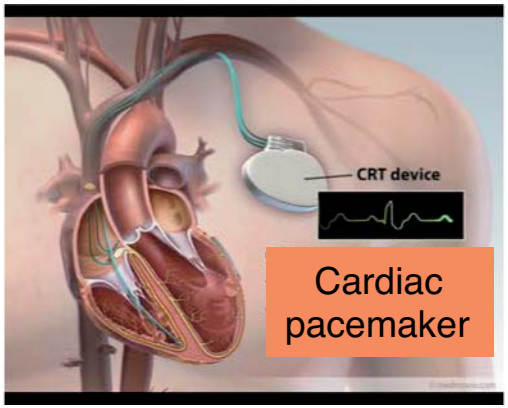
Forest et al.

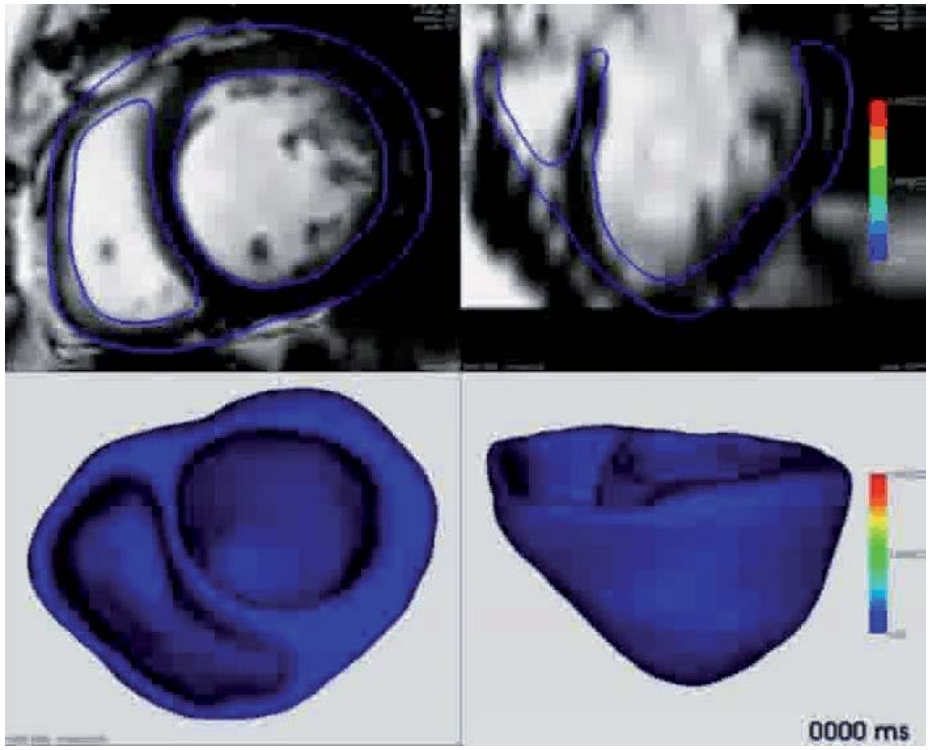


Marchesseau et al.

Talbot et al. 2014

Predicted Resynchronization



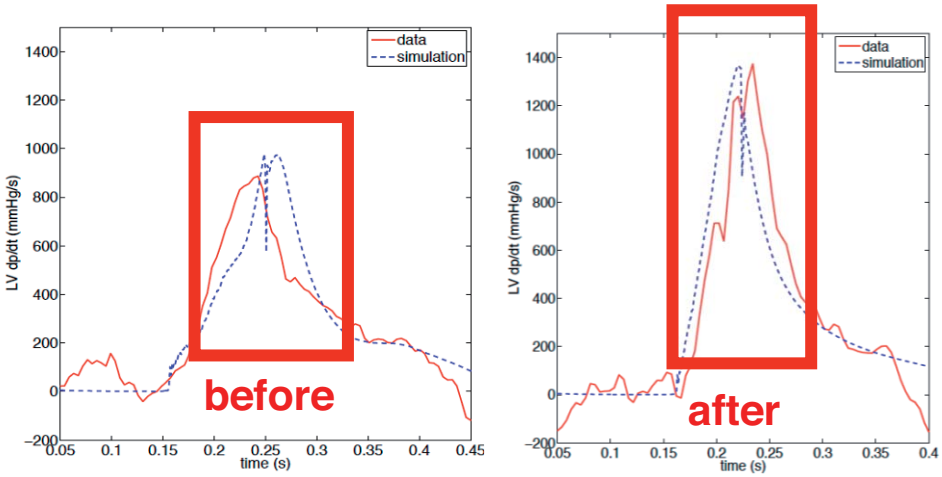


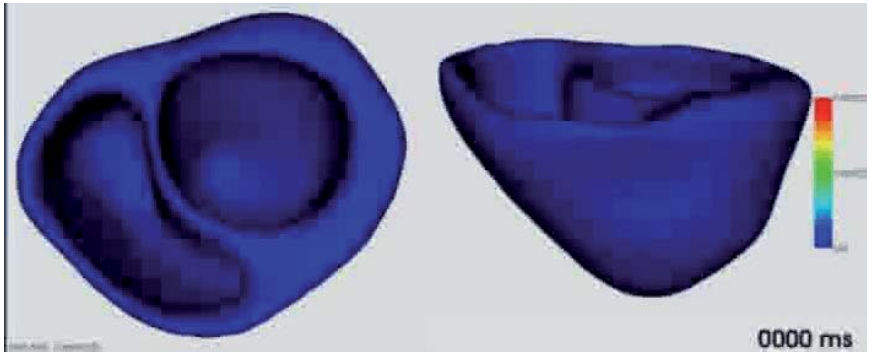
Left bundle branch block

dP/dt

measure simulation

dP/dt

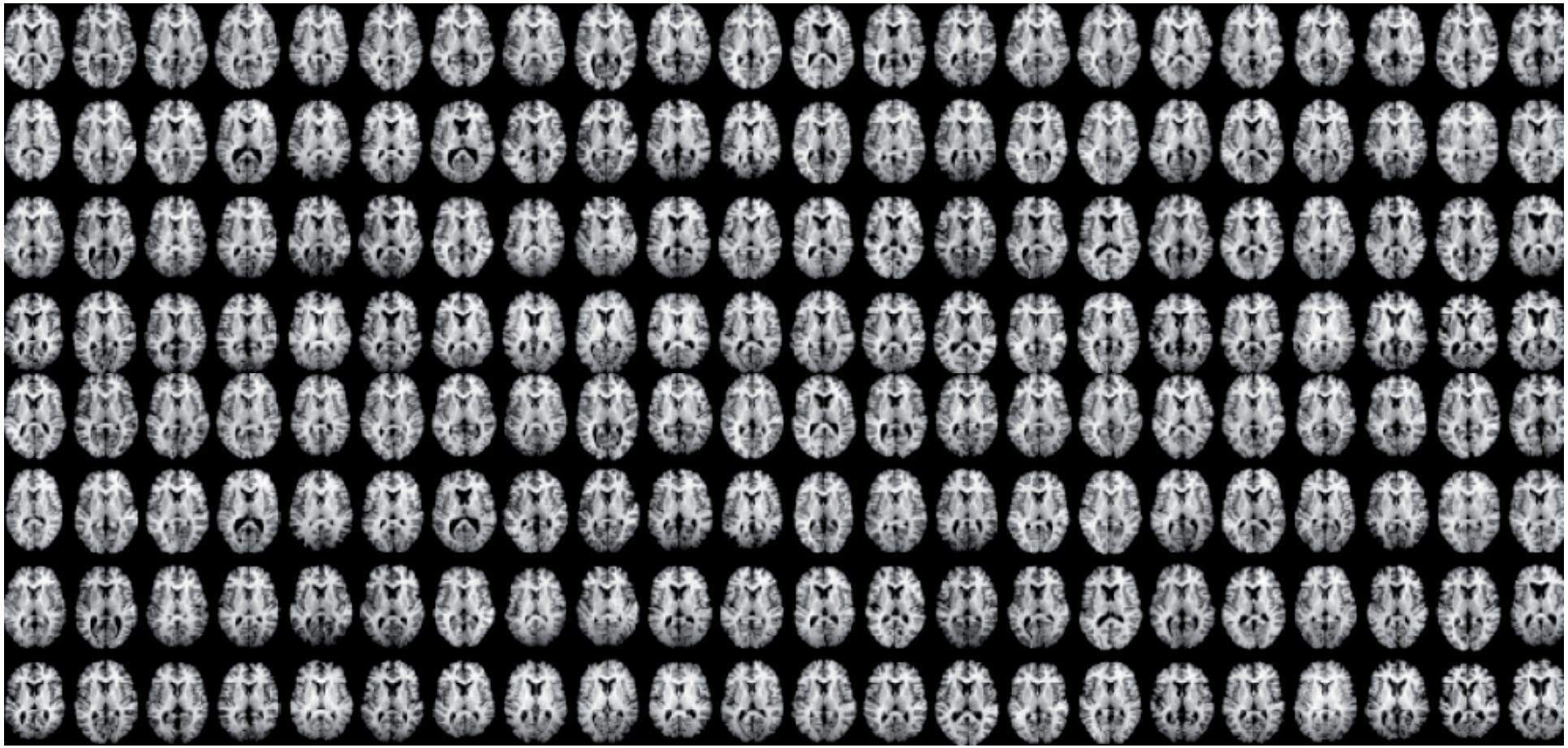




Simulated resynchronization

M. Sermesant, F. Billet, R Chabiniok, T Mansi, P Chinchapatnam, P Moireau, JM Peyrat, K Rhode, M Ginks, P Lambiase, S Arridge, H Delingette, M Sorine, A Rinaldi, D Chapelle, R Razavi, N Ayache, *Personalised Electromechanical Heart Model for Prediction of Acute Effects of CRT,* Medical Image Analysis 2012

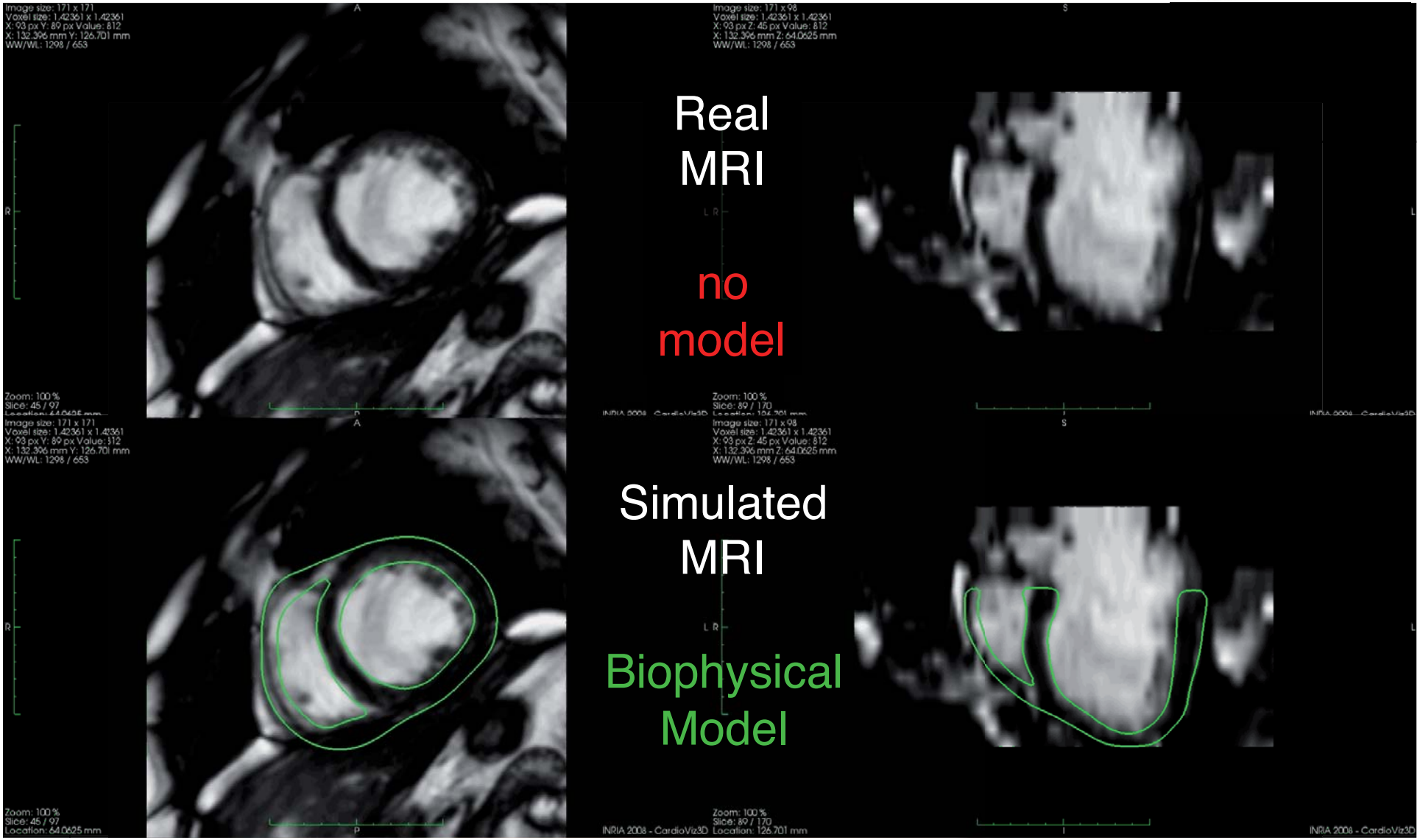
6. *Bigger Data*



6. Bigger Data

- Very large databases of images available on the web with attached expertise
  - *ADNI, OASIS, CATI, NIH, Creatis,…*
  - *Challenges MICCAI, etc.*
- Augmented by data simulated with biophysical models

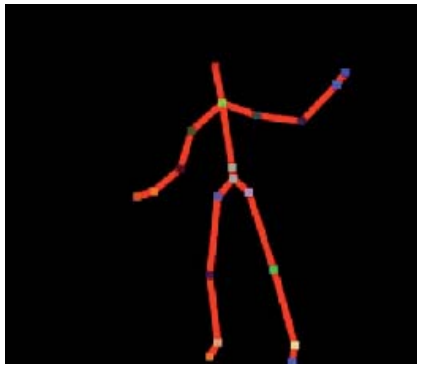
Simulate Cardiac MRI



Prakosa, Sermesant, Allain, Villain, Rinaldi, Rhode, Razavi, Delingette, Ayache, IEEE TBME 2013

7. More Machine Learning

- Training on very large databases
  - Real and synthetic (cf. Kinect)



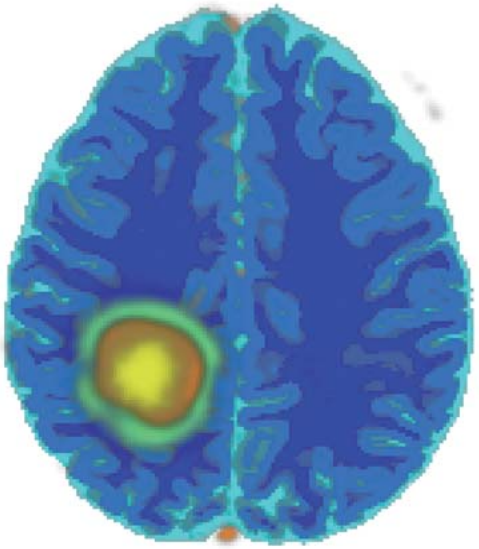
Microsoft Research Cambridge

Shotton et al., 2011

Simulate, Learn & Predict

erc MedYMA

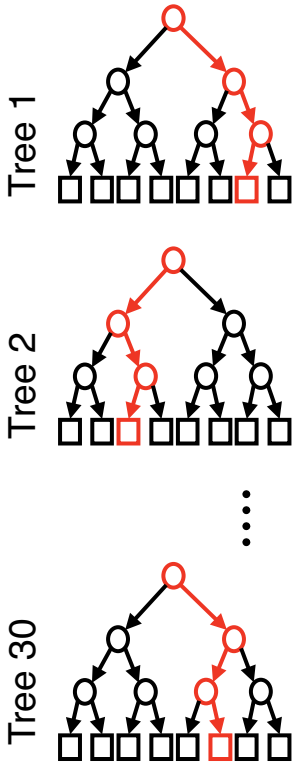
Simulated tumor growth



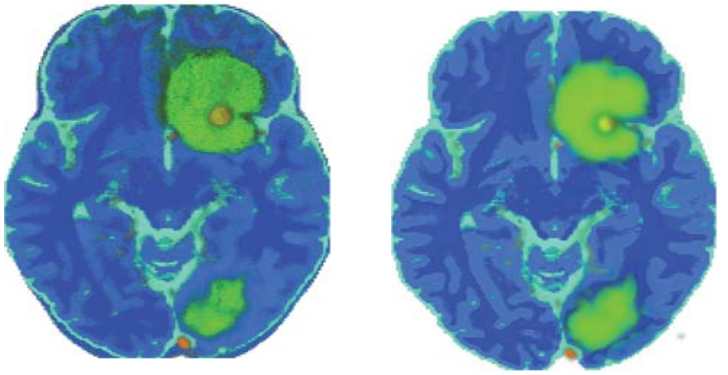
Univ Utah
Microsoft Research

Grey matter
White matter
LCR
necrosis
vessels
œdema

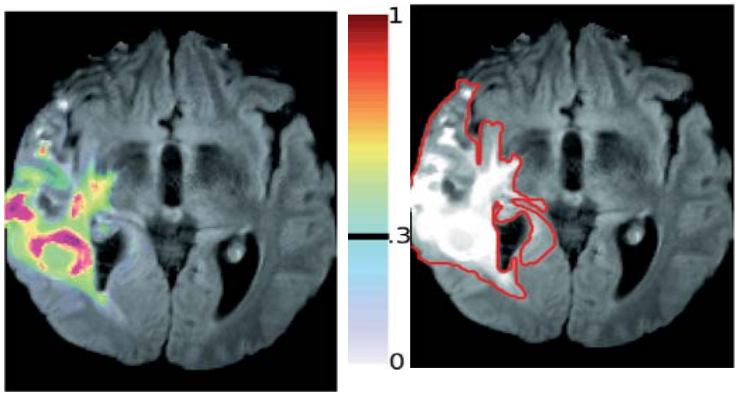
Statistical Learning



Tumoral cell density



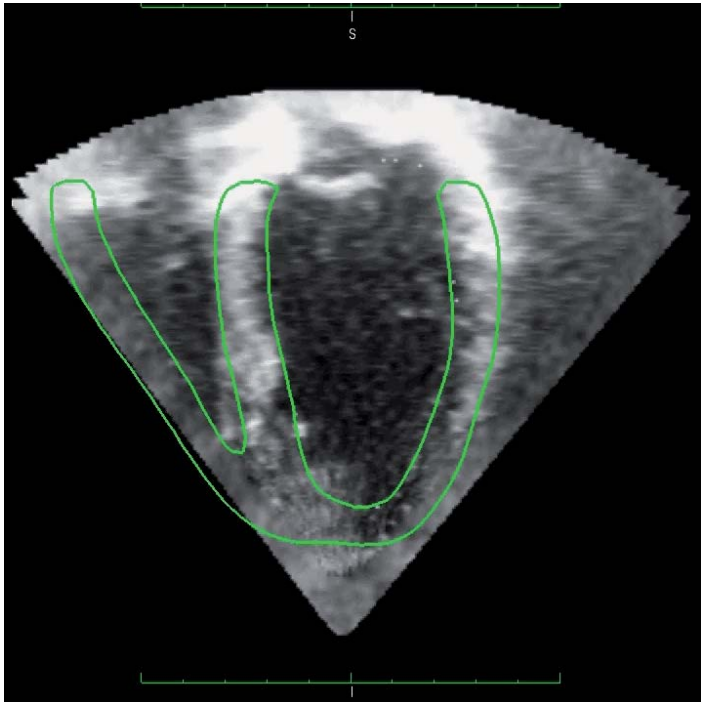
prediction ground truth



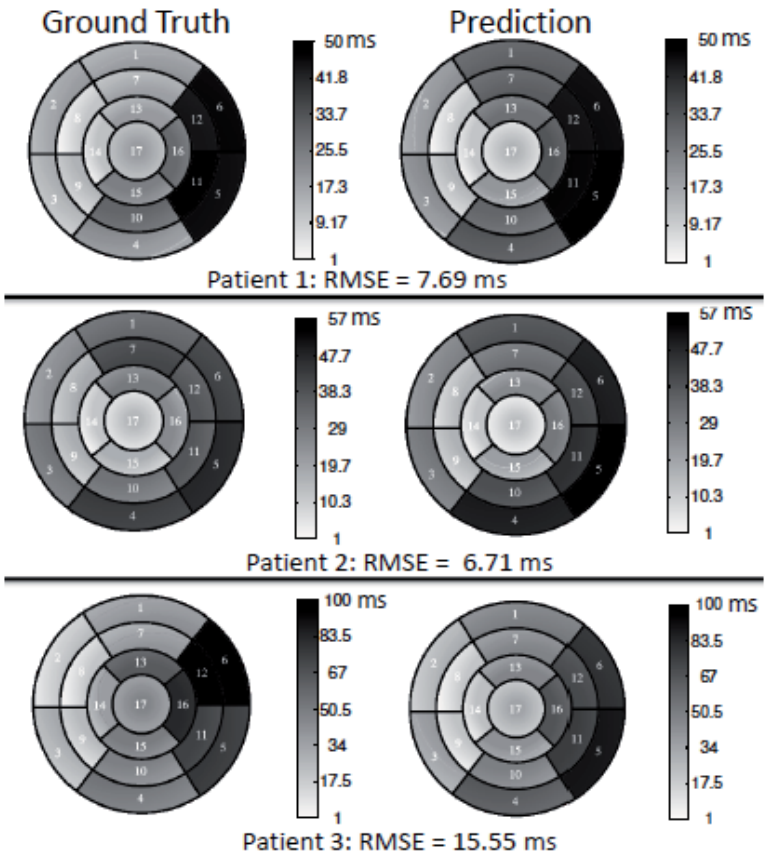
E Geremia, B H. Menze, M Prastawa, MA Weber, A Criminisi, and N Ayache. *Brain tumor cell density estimation from multi-modal MR images based on a synthetic tumor growth model.* In MICCAI Workshop on Medical Computer Vision, LNCS, 2012.

Simulate, Learn & Predict

- Predict depolarization time from observed motion in real and simulated images



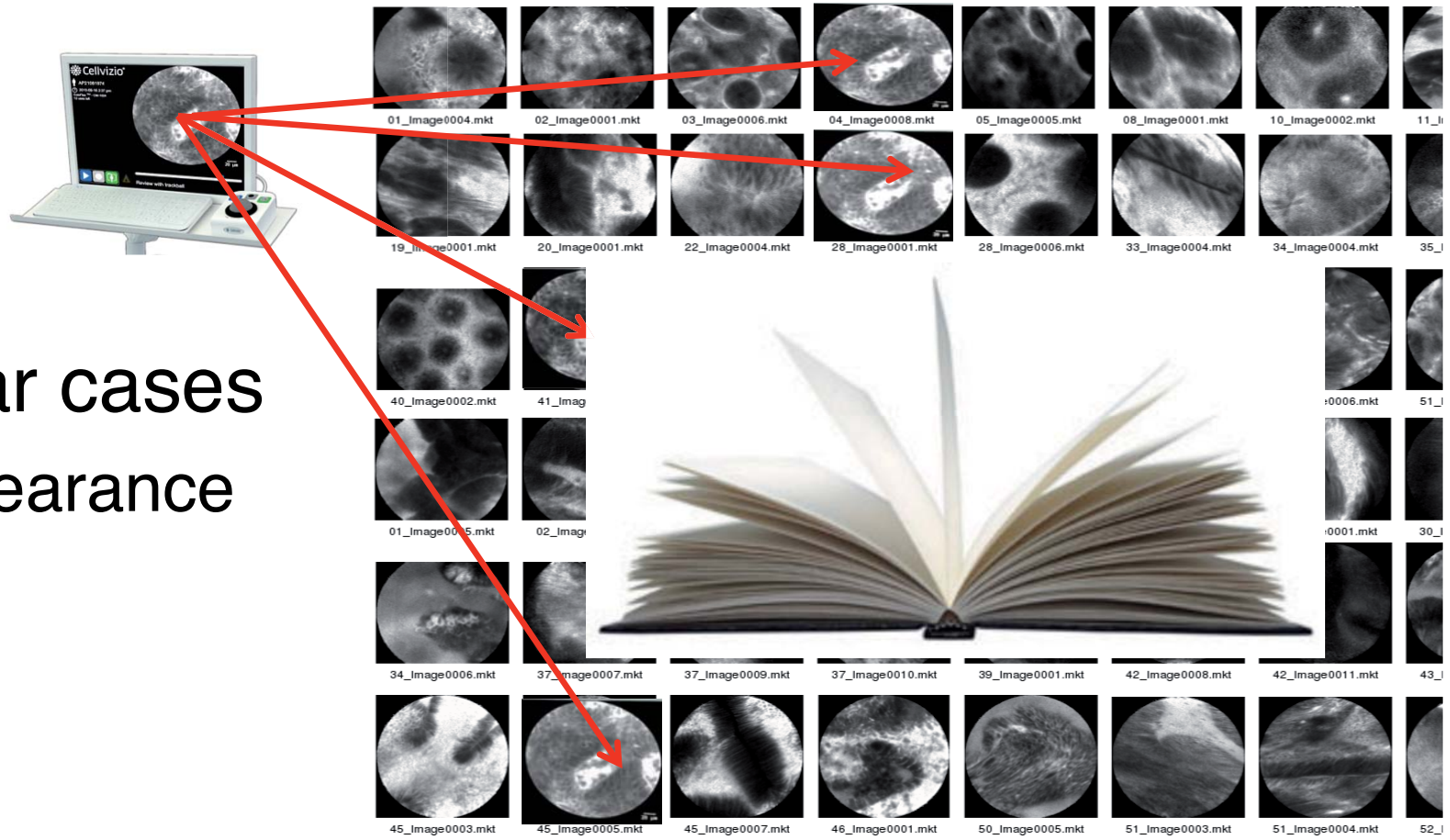
Depolarization time



A Prakosa, M Sermesant, P Allain, N Villain, C Rinaldi, K Rhode, R Razavi, H Delingette, N Ayache,
IEEE Tr Biomedical Engineering 2013

8. Smart Atlases

Images & expertise

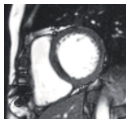


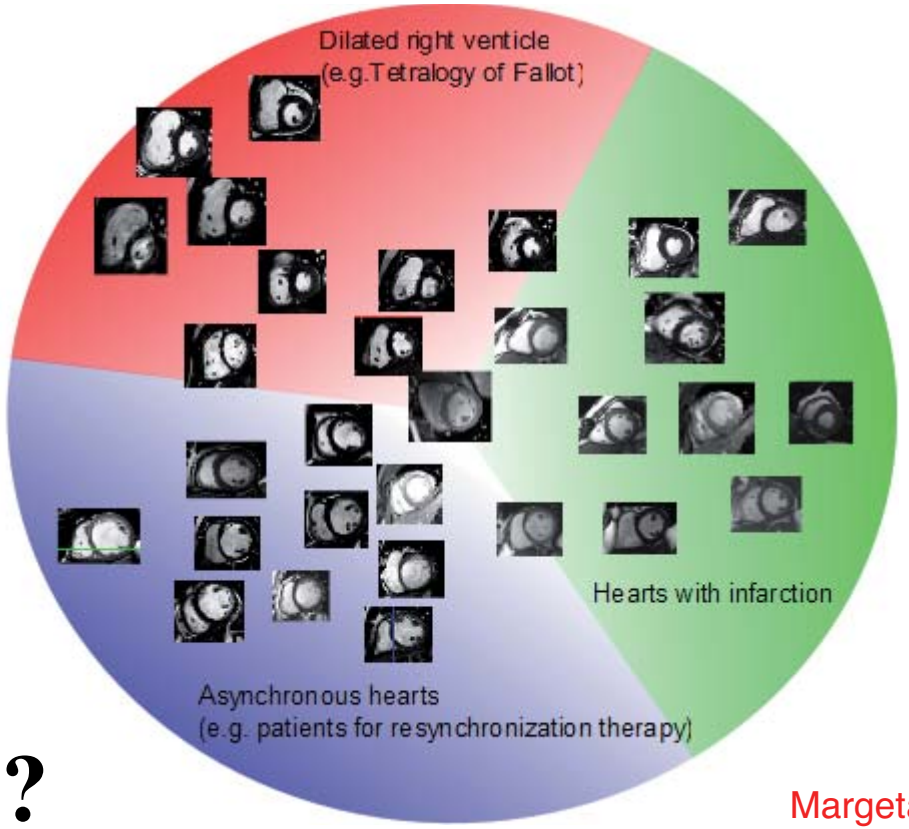
- Similar cases
  - appearance

M Kohandani, André et al., MICCAI 2014

Smart Atlases

- Similar cases
  - appearance
  - shape
  - motion
  - evolution

 ?



Margeta et al. MIU 2014
Le Folgoc et al. MICCAI 2014
Lombaert et al. MICCAI 2014

9. Closer links between scientific communities

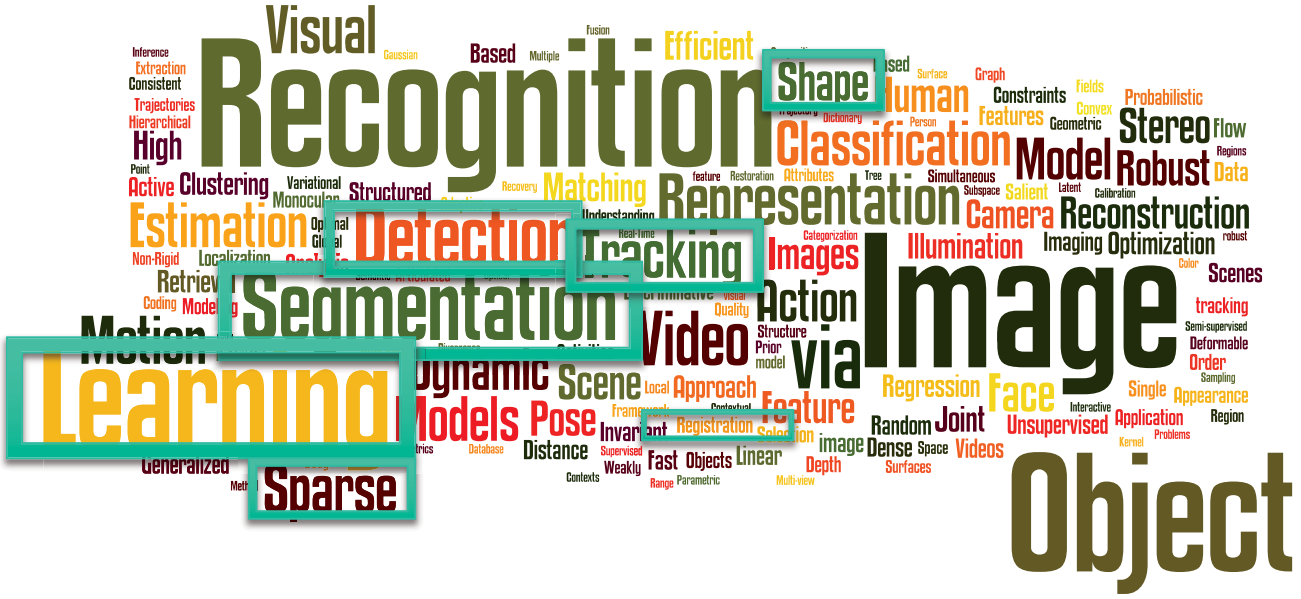
- informatics and computational sciences
- mathematics, physics, chemistry
- biology et medicine
- databases, security, certification, etc.

252 Titles

Medical Image Computing & Computer Assisted Intervention

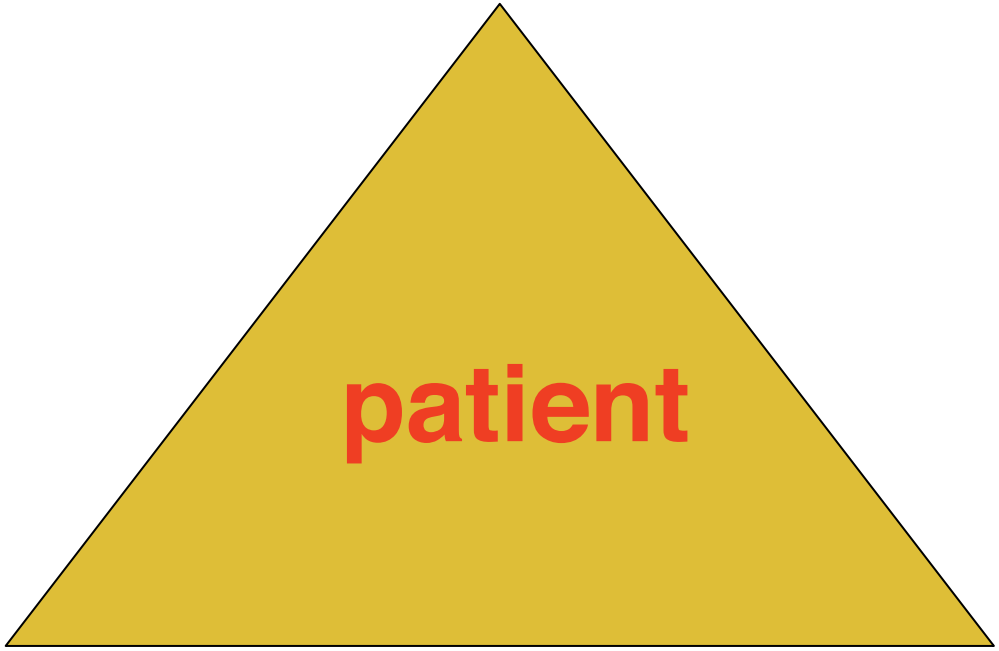
340 Titles

Computer Vision



10. Medical Image Computing & Computational Medicine

Academic pluridisciplinary research



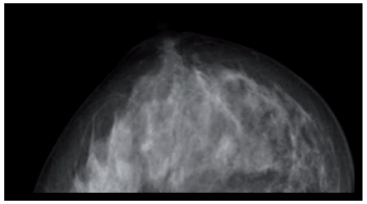
Clinical partners

Industrial partners


MICCAI
Medical Image Computing and
Computer Assisted Interventions
MICCAI 2012 NICE
A new
research field
supported by a
young research
community

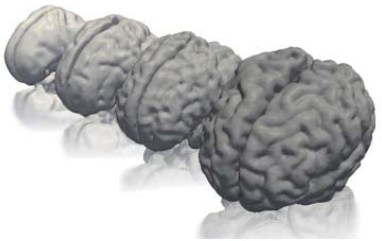
From Medical Images to Computational Medicine

Symposium



09h10 Biophysical Models for Cancer Imaging
Michael Brady, *University of Oxford, United Kingdom*

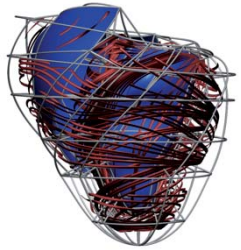
09h50 Learning Clinical information from Medical Images
Daniel Rueckert, *Imperial College London, United Kingdom*



10h30 Spatiotemporal Analysis of Brain Development and Disease Progression
Guido Gerig, *University of Utah, United States*

11h10 Break

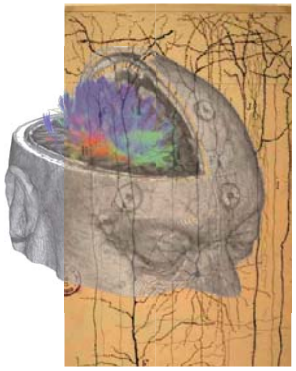
11h20 Decision Forests in Medical Image Analysis
Antonio Criminisi, *Microsoft Research, United Kingdom*



12h00 Computational Physiology: Connecting Molecular Systems Biology with Clinical Medicine
Peter Hunter, *University of Auckland, New Zealand*

14h00 Introduction

14h10 Toward a Statistical Neuroscience
Olivier Faugeras, *Inria, Université de Nice Sophia Antipolis*

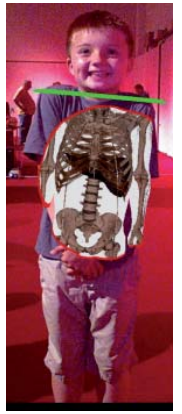


14h50 Model-Based Biomedical Image Analysis
James Duncan, *Yale University, United States*

15h30 Multi-Scale Image-Guided Interventions
David Hawkes, *University College London, United Kingdom*

16h10 Break

16h20 Augmented Reality in the Operating Room
Nassir Navab, *Tech. Univ. Munich, Germany & J. Hopkins Univ., United States*



17h00 Towards Image-Based Personalized Medicine
Dorin Comaniciu, *Siemens Corporate Technology, United States*

17h40 The Future of the Personalized Digital Patient
. Nicholas Ayache, *Collège de France*

18h00 Open discussion

Acknowledgements