



# Medical Visualization: Visualizing the Invisible

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UiB Dept. of Informatics

19-08-2018



# Introduction

- Licensed Radiographer
- Studied Computer Science in Delft, the Netherlands
  - Specialized in Computer Graphics & Visualization
- PhD in Medical Visualization
- Associate Professor in the Visualization group



# The VisGroup at the University of Bergen



Researching and teaching new solutions for the efficient and effective visualization of large and complex datasets

from

- **measurements** (e.g., from medical imaging modalities or from seismic/sonar sensors),
- **computational simulation** (e.g., based on computational fluid dynamics), or from
- **analytic modeling** (e.g., in the form of difference or differential equations)

for the purpose of

- data exploration, analysis, and presentation.



# Introduction - What is Visualization?



"Computer-based visualization systems provide **visual representations of datasets** designed to help **people** carry out tasks more effectively"

The purpose of computing is insight, not numbers

[R. Hamming, 1962]

The purpose of visualization is insight, not pictures

[B. Shneiderman, 1999]

# Why represent all the data?

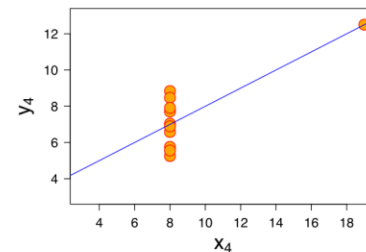
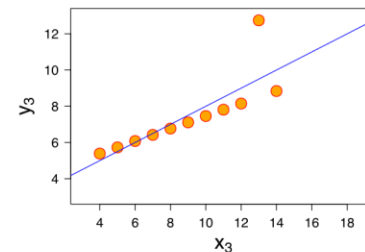
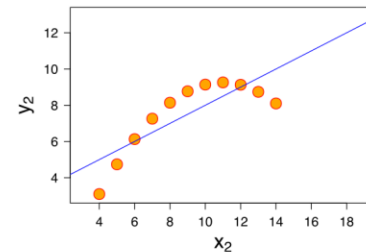
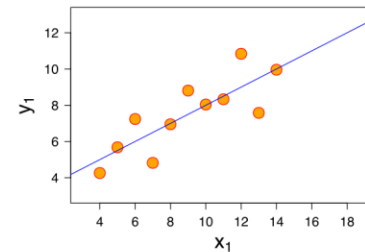
## Summaries lose information, details matter

- Confirm expected and find unexpected patterns

## Anscombe's quartet, 4 datasets:

### Identical statistics

x mean	9
x variance	10
y mean	8
y variance	4
x/y correlation	1

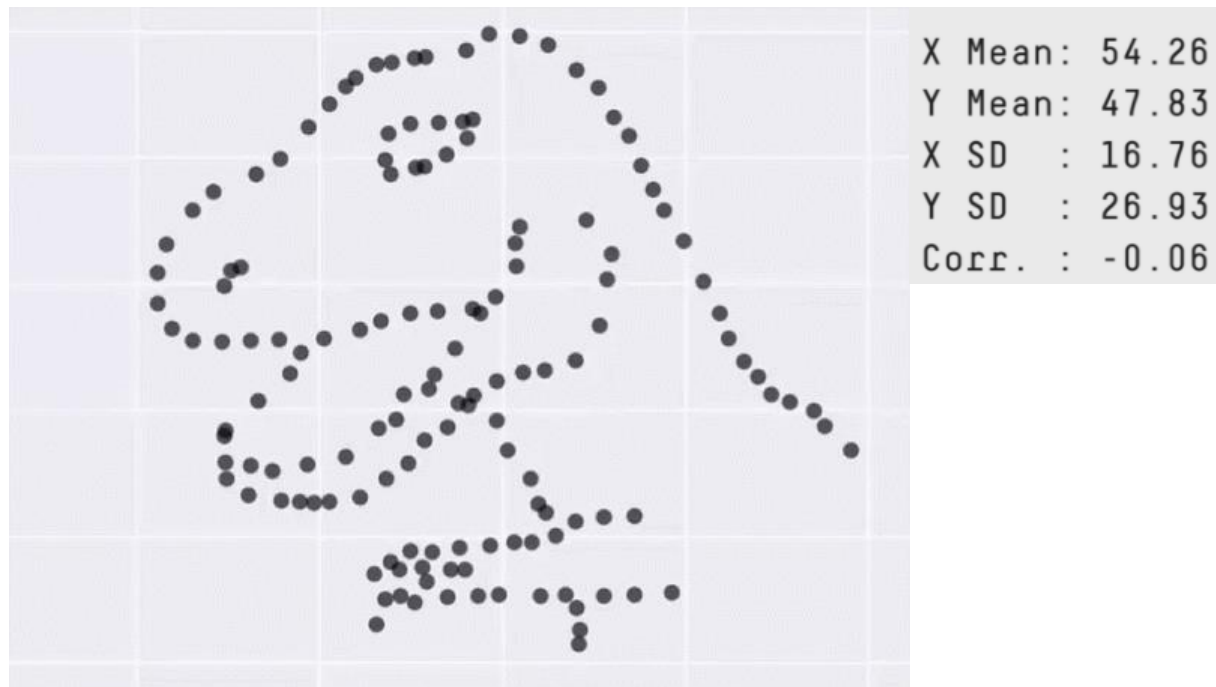


[https://en.wikipedia.org/wiki/Anscombe%27s\\_quartet](https://en.wikipedia.org/wiki/Anscombe%27s_quartet)

# Same Stats, Different Graphs

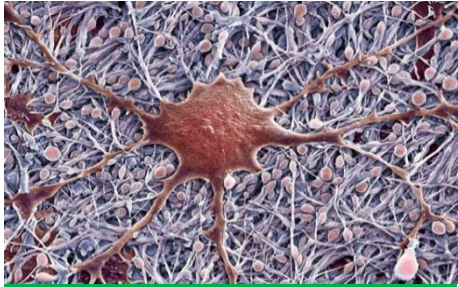


## The Datasaurus Dozen:



<https://www.autodeskresearch.com/publications/samestats>

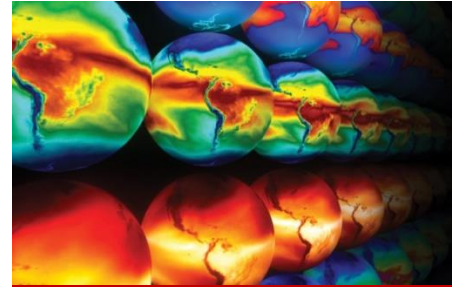
# Visualization



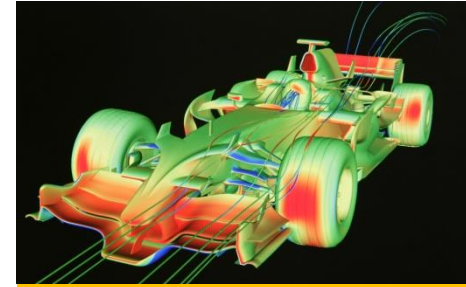
**BIOLOGY**



**MEDICINE**

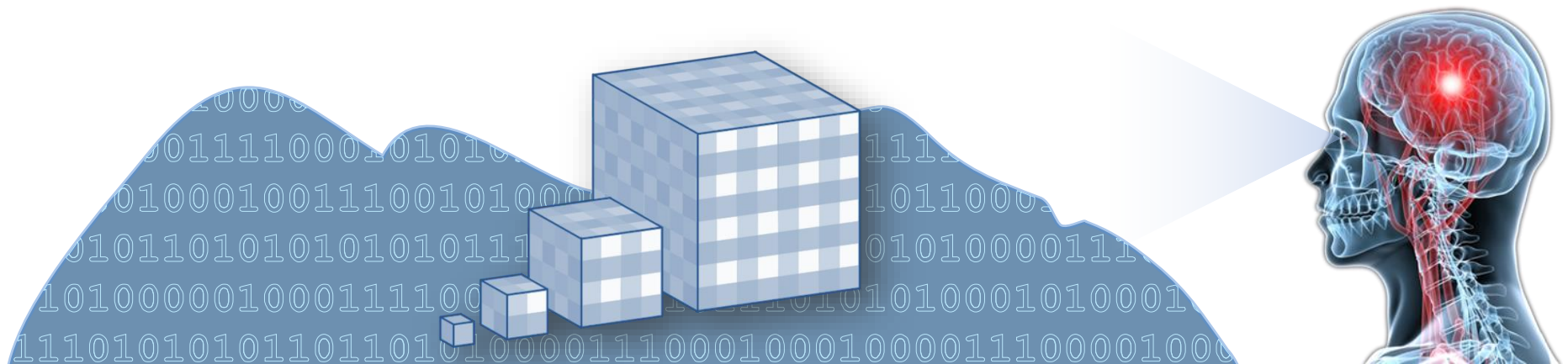


**EARTH  
SCIENCES**



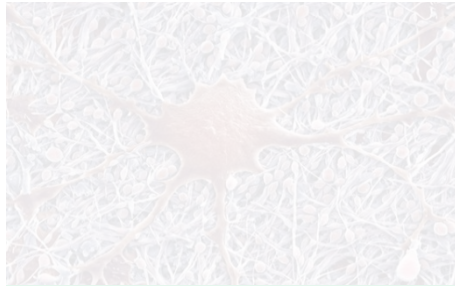
**ENGINEERING**

**Visualization –**  
from data/models/simulations to insight





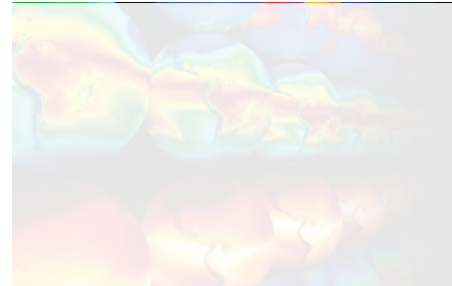
# Medical Visualization



BIOLOGY



MEDICINE

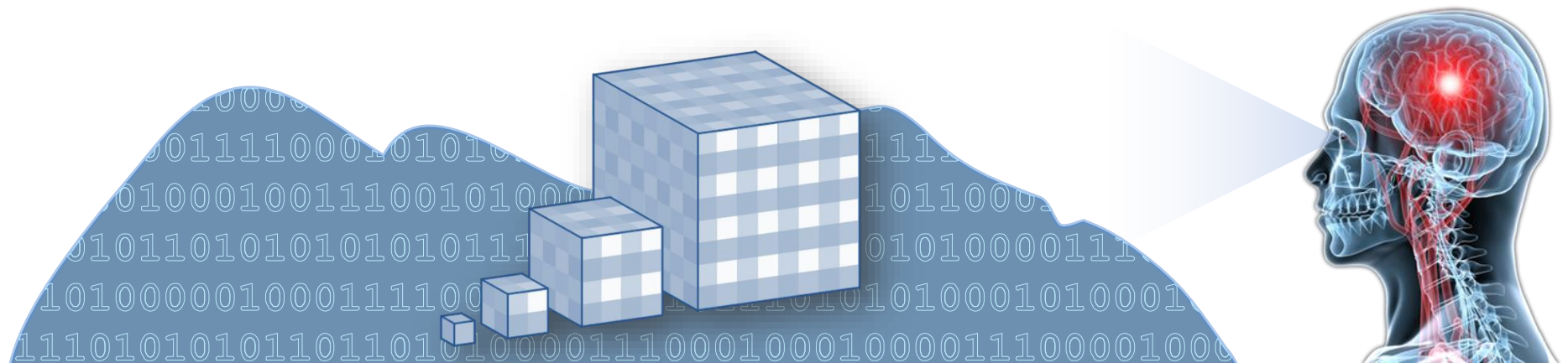


EARTH  
SCIENCES



ENGINEERING

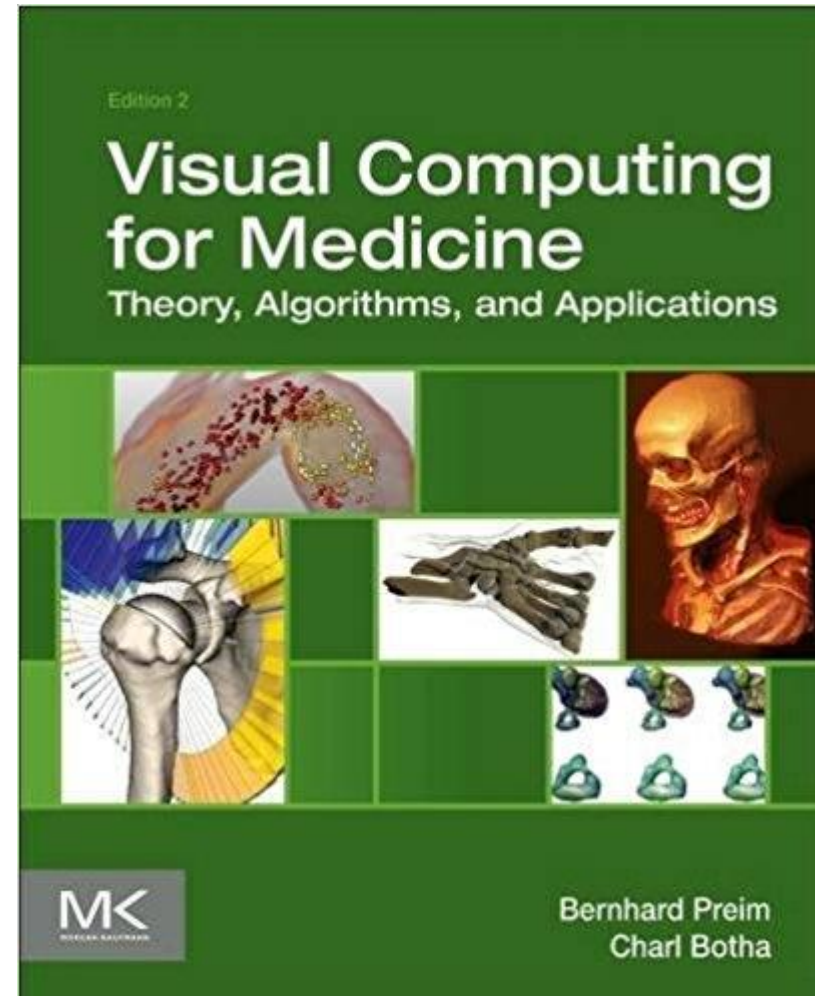
**Visualization –**  
from data/models/simulations to insight



- **Medical paradigm:**
  - Predictive
  - Preventive
  - Personalized
  - Participatory
- **Shift from reactive to proactive**
- **To make this possible: richer data acquisition**

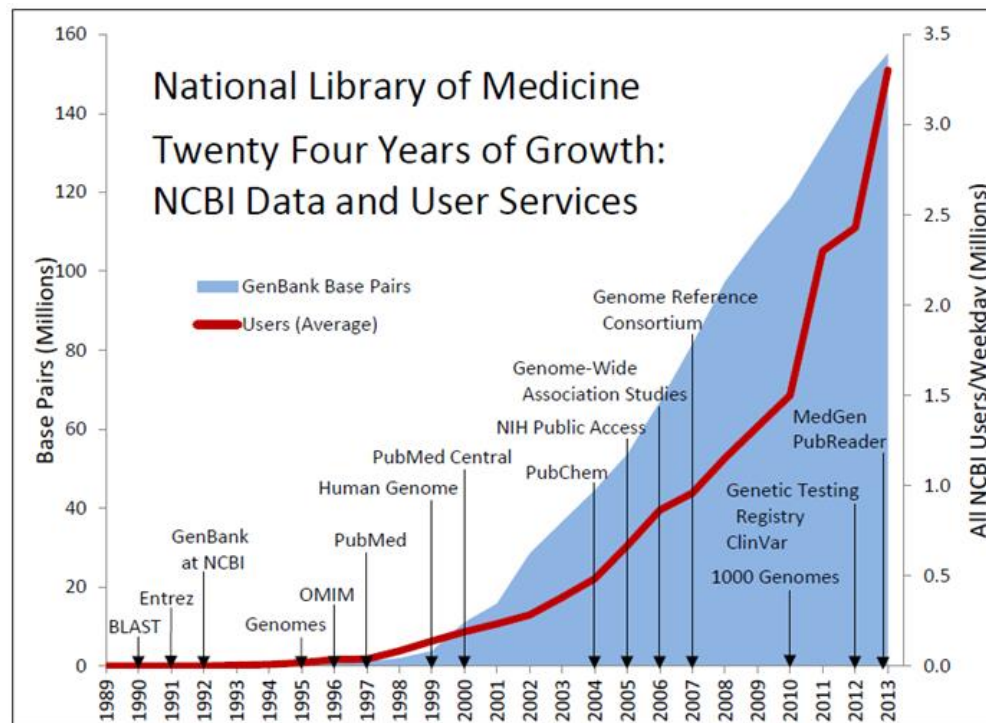
# Medical Visualization - Goals

- Education
- Diagnosis
- Treatment planning
- Treatment guidance
- Doctor-patient communication



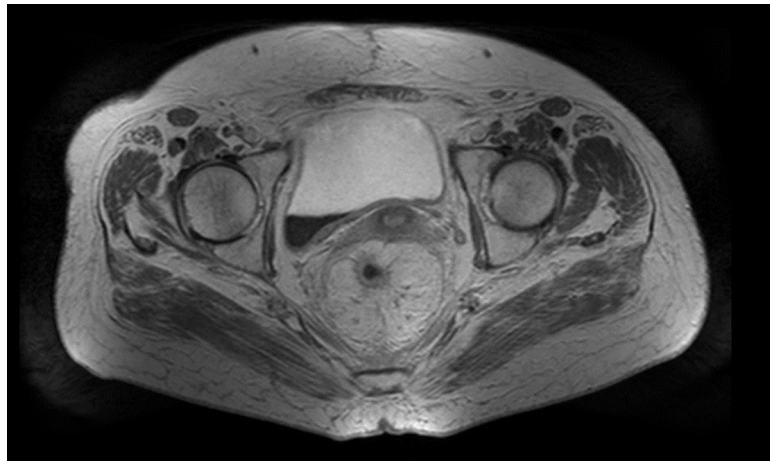
# Biomedical data explosion

- Exponentially growing data generation
- Increased complexity of analysis
- Higher demands on visualization for decision making



<https://www.nlm.nih.gov/about/2015CJ.html>

- **'Traditional medical visualization':**
  - Direct visualization of medical imaging data
  - For diagnostic/treatment planning purposes



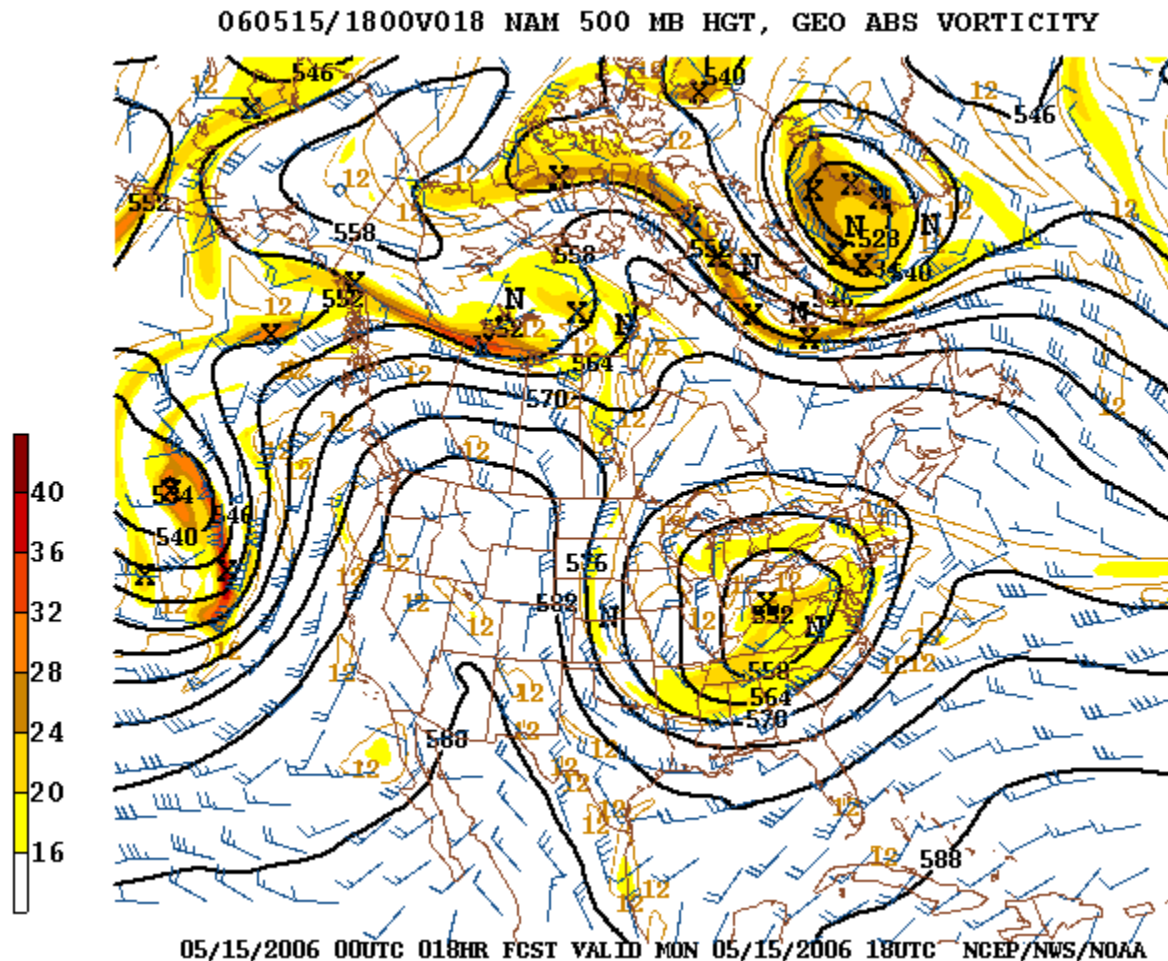
- **P4: Prediction and prevention:**
  - More advanced techniques needed
  - Beyond what is available directly from medical imaging

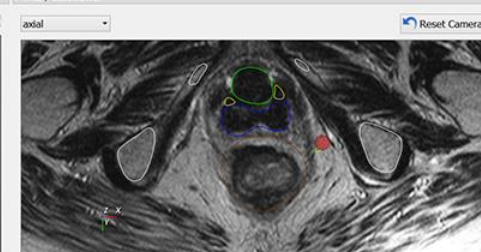
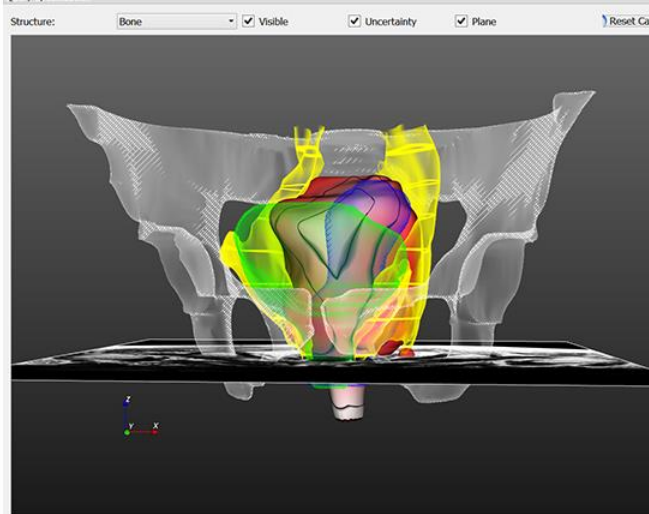
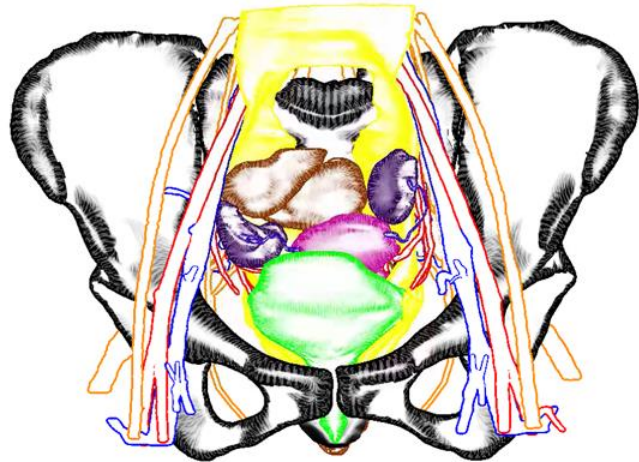


# Model-based visualization

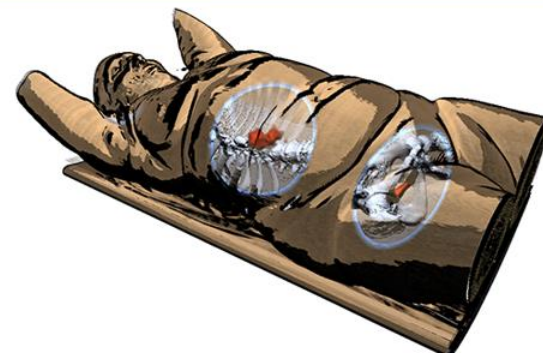
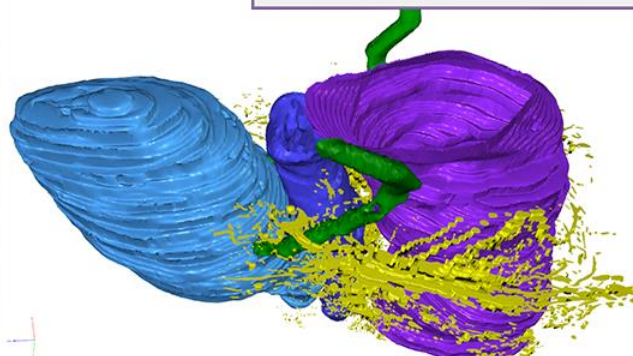
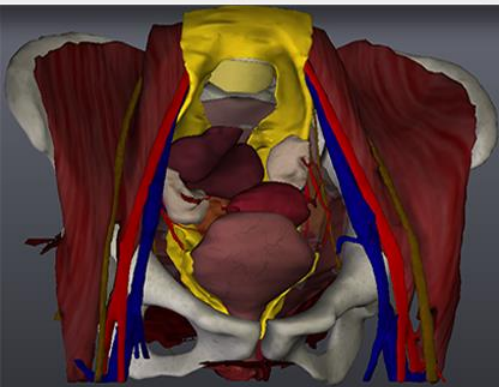
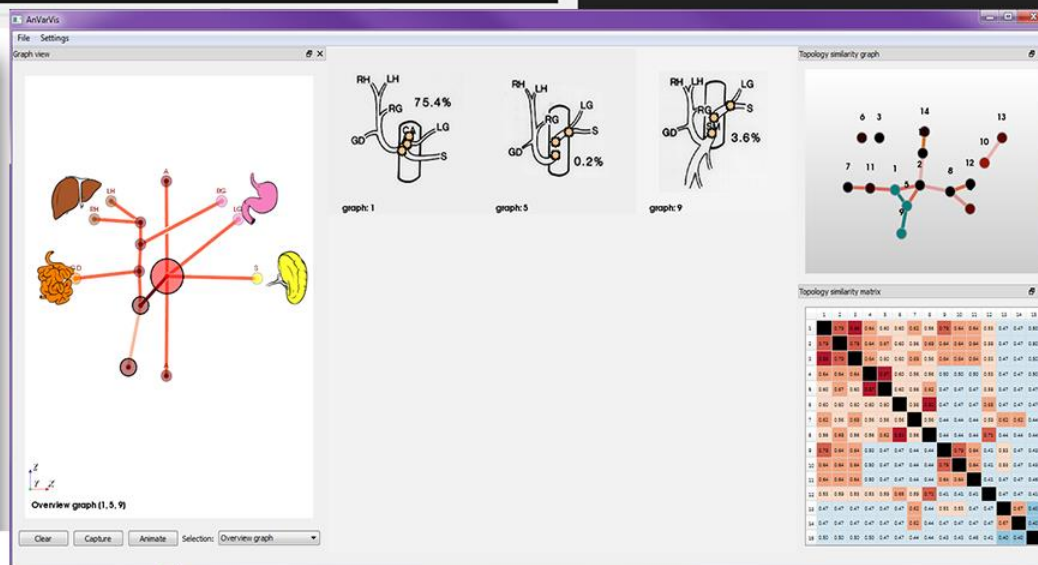
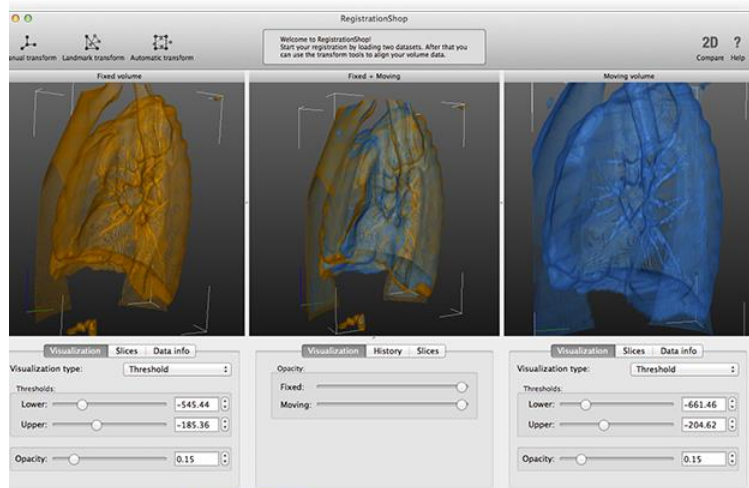
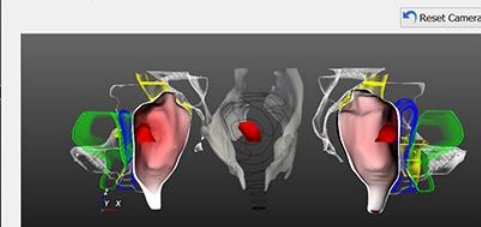


- When measurements are not enough, models or simulations can add knowledge

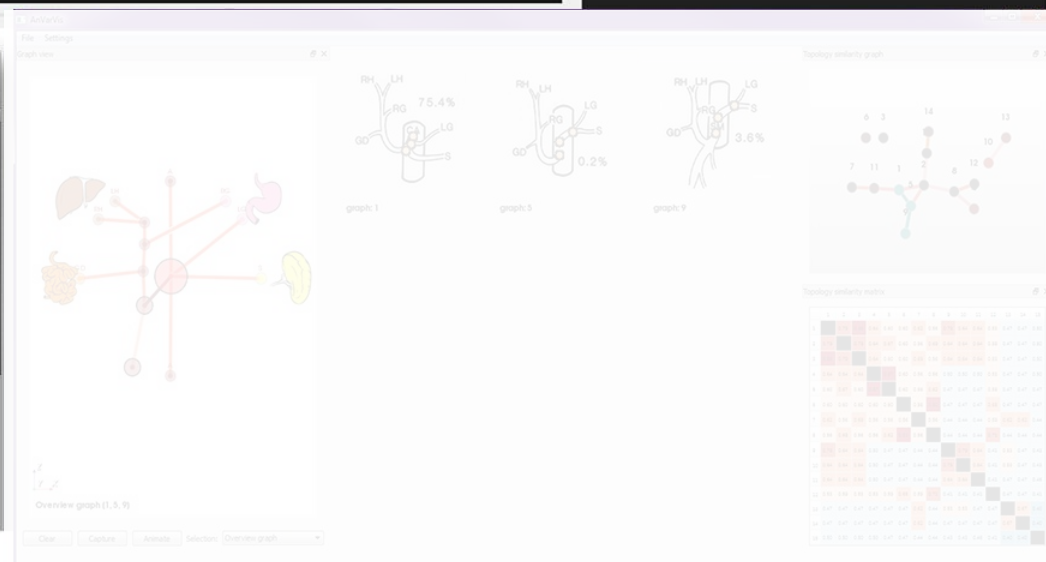
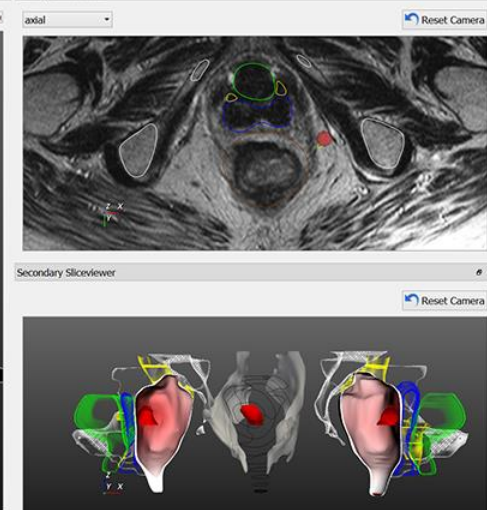




Secondary Sliceviewer









- Dept. Anatomy & Embryology
  - Prof. Dr. M.C. de Ruiter
  - Drs. D. Jansma
  - Dr. Annelot Kraima
- Dept. Surgery, LUMC
  - Prof. Dr. C.J.H. van de Velde
- Dept. Surgery, Eindhoven
  - Prof. Dr. H. Rutten

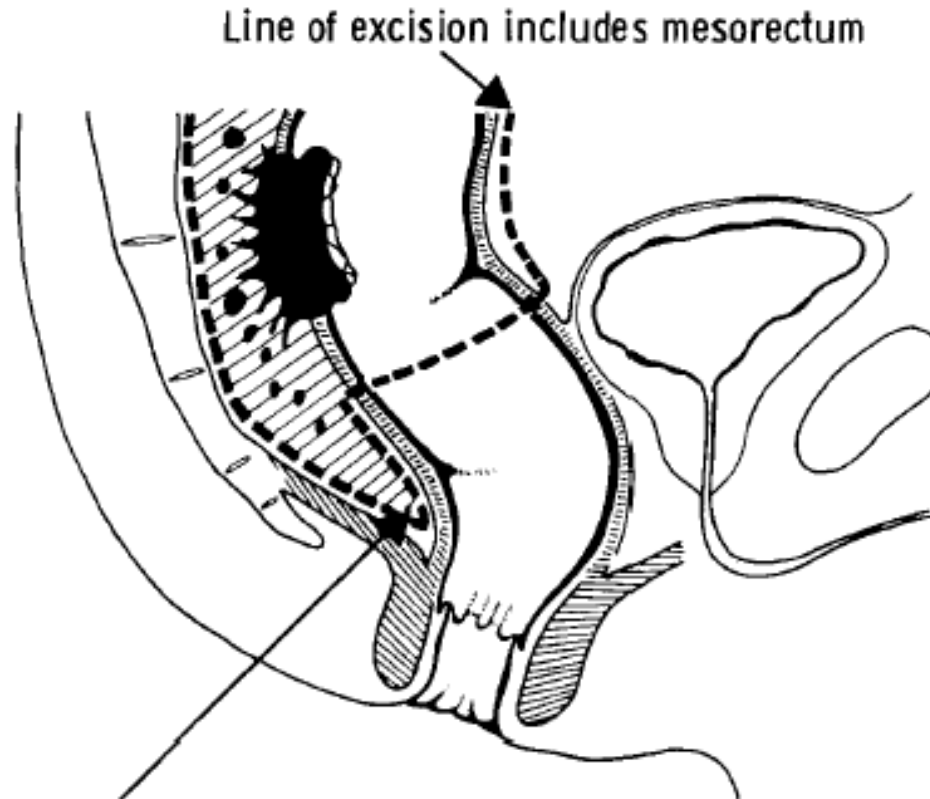


**Delft University of Technology**

- Computer Graphics & Visualization
  - Prof. Dr. Elmar Eisemann
  - Dr. Anna Vilanova
  - (Dr. C.P. Botha)
  - **Dr. Noeska Smit**

# Rectal cancer

- 4.000 patients every year
- 5 years survival ~ 50%
- Golden standard: Total Mesorectal Excision (TME)





# Background: TME Surgery Complications

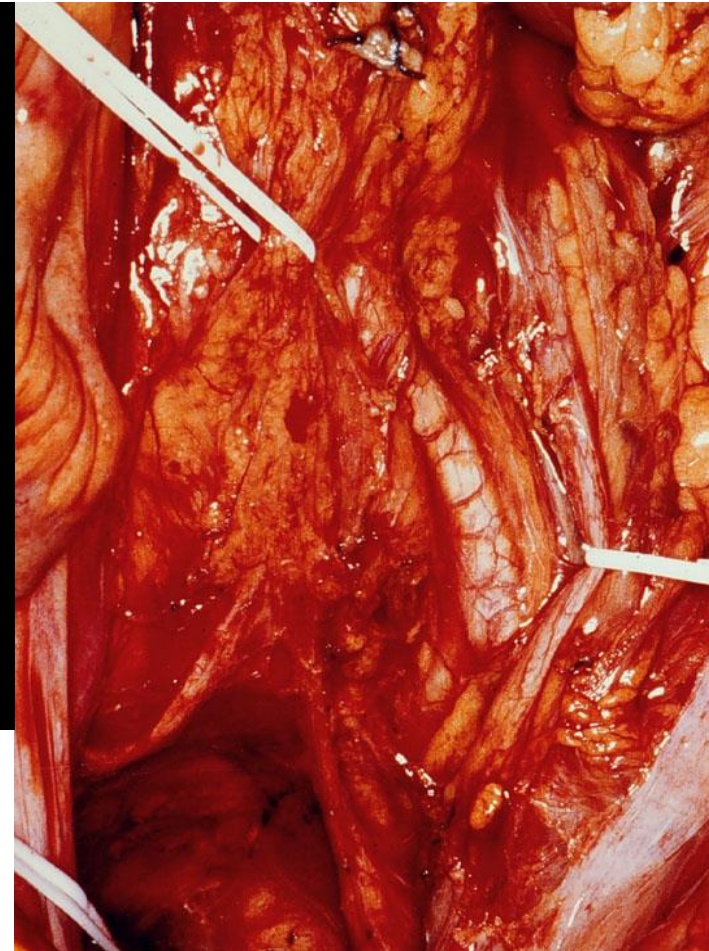
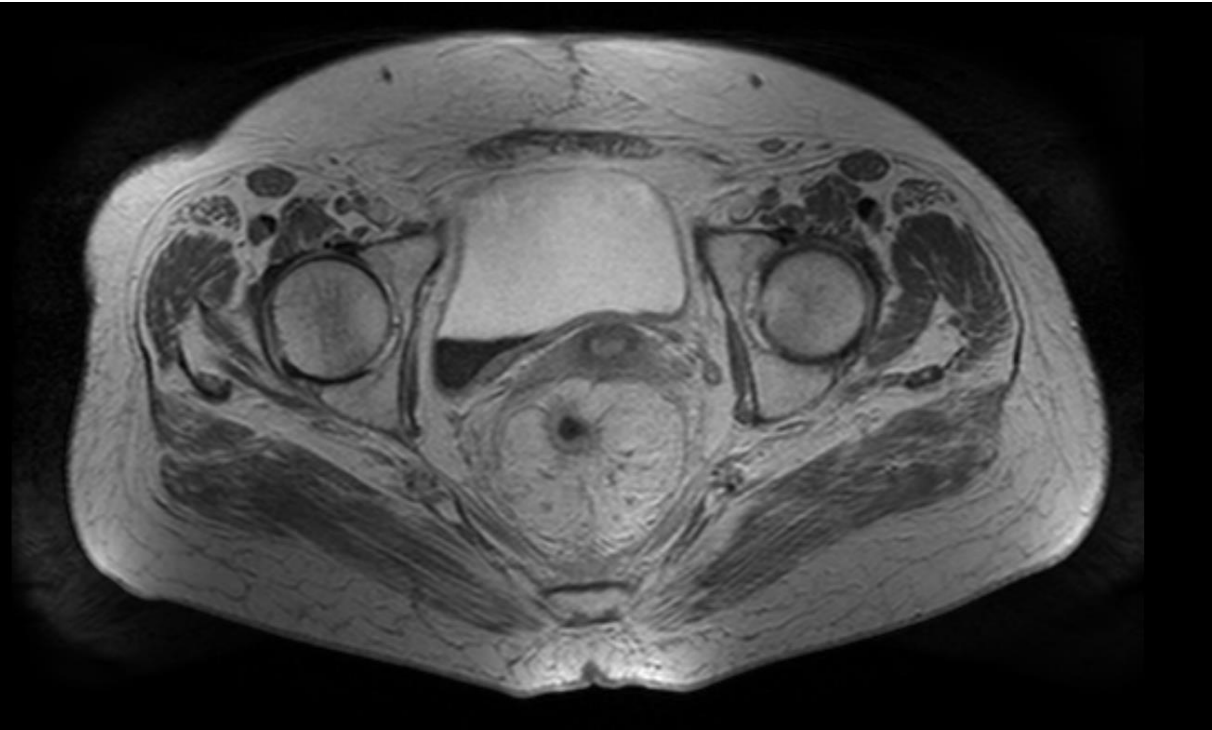


- Urinary incontinence in 34%
- Fecal incontinence in 39%
- Sexual dysfunction in 56 – 79%

## Autonomic nerve damage

(Wallner et al., *J Clin Oncol*, 2008; Lange et al., *Eur J Ca*, 2009)

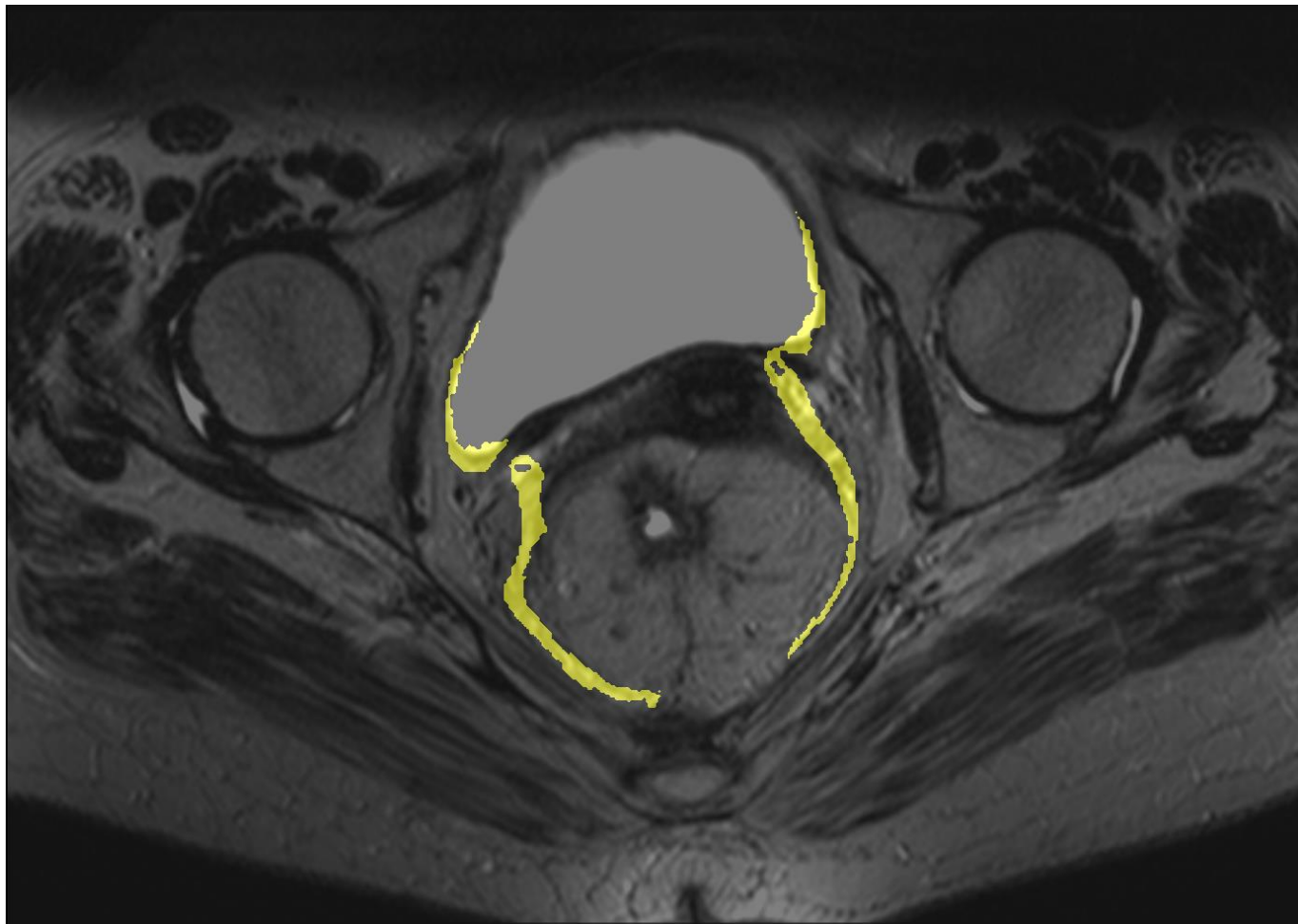
# Invisible Nerves



# Goal: Modeling Anatomical Knowledge

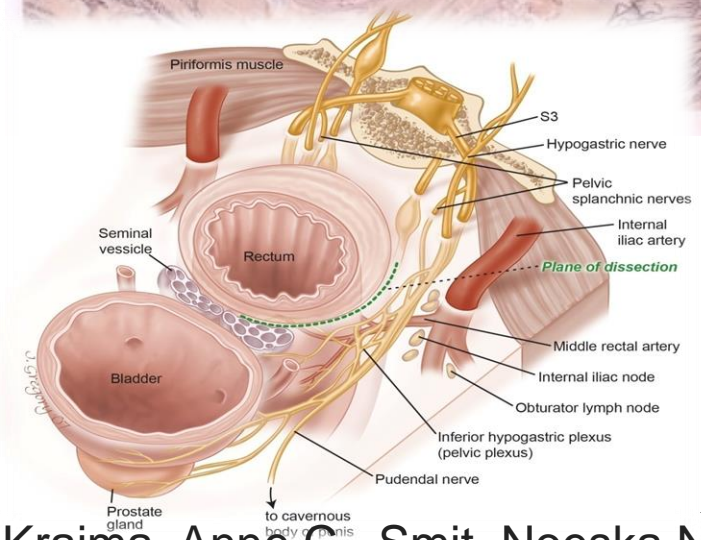
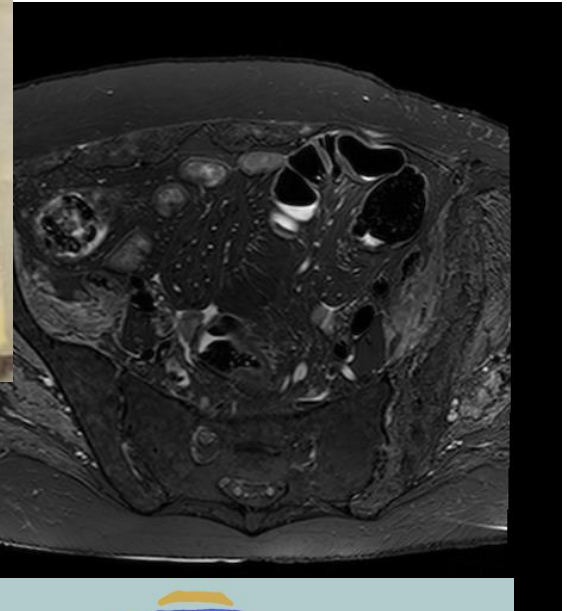
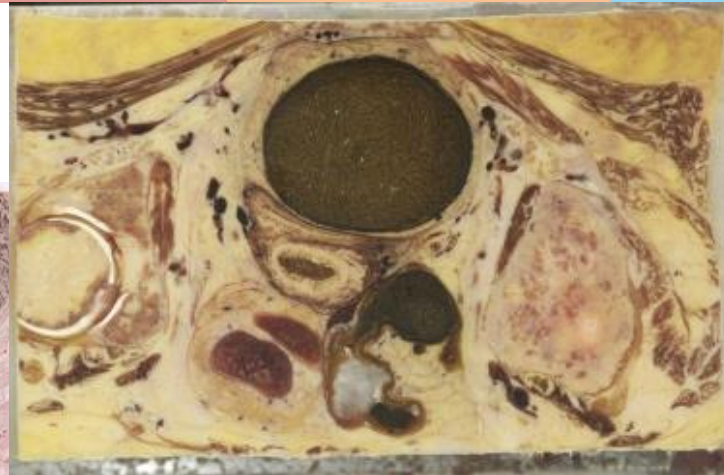
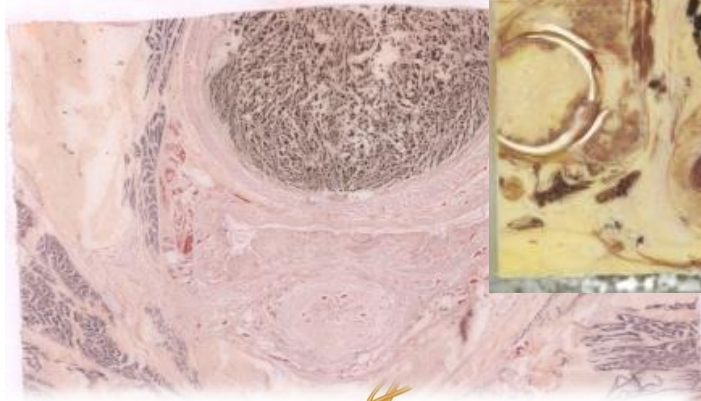


- Modeling knowledge of where 'invisible' nerves occur to enrich medical imaging data for surgical planning





# Virtual model of human anatomy



VOLUME 27 NUMBER 31 NOVEMBER 1 2009  
JOURNAL OF CLINICAL ONCOLOGY ORIGINAL REPORT

## Preoperative Multimodality Therapy Improves Disease-Free Survival in Patients With Carcinoma of the Rectum: NSABP R-03

Mart S. Bab, Linda H. Colangelo, Michael J. O'Connell, Craig Taylor, Mehrez Douch, Cameron I. Allgier, Minnie S. Kalishman, John Bern, David Cantel, S. Chinn, Nicholas J. Jewell, and Norman Wolpert

See accompanying editorial on page 5115

**ABSTRACT**

**Purpose**  
Although chemoradiotherapy plus resection is considered standard treatment for operable rectal carcinoma, the optimal time to administer this therapy is not clear. The NSABP R-03 (National Surgical Adjuvant Breast and Bowel Project R-03) trial compared neoadjuvant versus adjuvant chemoradiotherapy in the treatment of locally advanced rectal carcinoma.

**Patients and Methods**  
Patients with clinical T3 or T4 or node-positive rectal cancer were randomly assigned to preoperative or postoperative chemoradiotherapy. Chemotherapy consisted of fluorouracil and leucovorin with 45 Gy in 25 fractions with a 5.40-Gy boost within the original margins of treatment. In the preoperative group, surgery was performed within 8 weeks after completion of radiotherapy. In the postoperative group, chemotherapy began after recovery from surgery but no later than 8 weeks after surgery. The primary and points were disease-free survival (DFS) and overall survival (OS).

**Results**  
From August 1993 to June 1999, 267 patients were randomly assigned to NSABP R-03. The intended sample size was 500 patients. Excluding 11 ineligible and two eligible patients without follow-up data, the analysis used data on 121 patients randomly assigned to preoperative and 131 to postoperative chemoradiotherapy. Surviving patients were observed for a median of 8.4 years. The 5-year DFS for preoperative patients was 68.1% v 52.6% for postoperative patients ( $P = .011$ ). The 5-year OS for preoperative patients was 74.5% v 65.6% for postoperative patients ( $P = .005$ ). A complete pathologic response was achieved in 15% of preoperative patients. No preoperative patient with a complete pathologic response has had a recurrence.

**Conclusion**  
Preoperative chemoradiotherapy, compared with postoperative chemoradiotherapy, significantly improved DFS and showed a trend toward improved OS.

J Clin Oncol 27:5128-5136. © 2009 by American Society of Clinical Oncology

**INTRODUCTION**

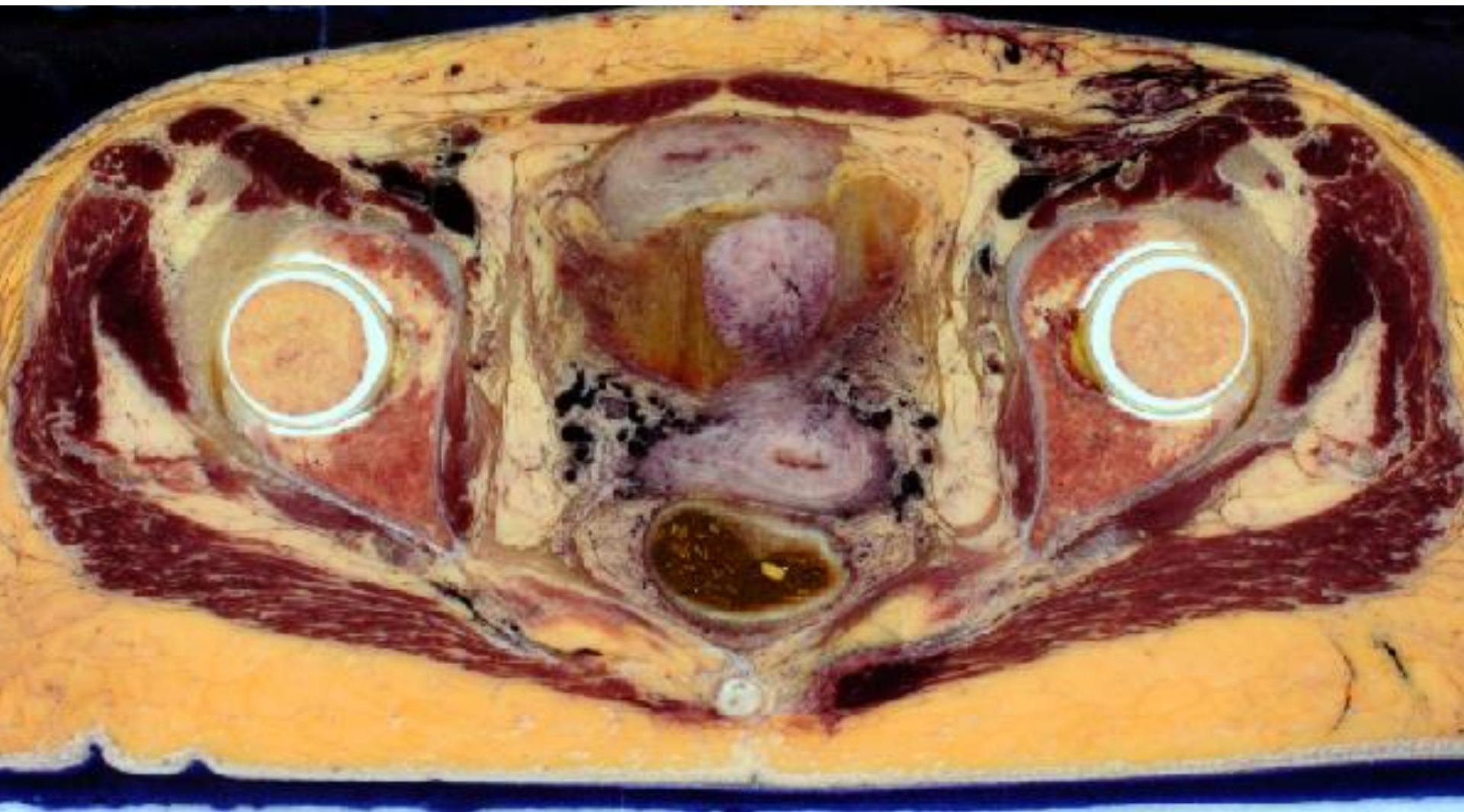
Radiotherapy and surgical resection are standard components of therapy for patients with stage B3/C1 carcinoma of the rectum.<sup>1-4</sup> Numerous randomized trials have investigated the impact of dose modifications and preoperative/postoperative administration in an effort to improve safety without compromising effectiveness, reduce the incidence of local recurrence, and significantly prolong survival.<sup>5-11</sup>

The Dutch Colorectal Cancer Group administered 25 Gy during 5 days followed by immediate total mesorectal resection and significantly reduced locoregional tumor recurrence at 2 years from 8.2% to 2.4% (relative risk ratio 0.29).<sup>12</sup> The addition of radiotherapy did not prolong survival compared with surgery alone. The European Organization for Research and Treatment of Cancer (EORTC) evaluated the value of preoperative chemoradiotherapy or postoperative radiotherapy alone and postoperative chemotherapy versus preoperative radiotherapy and surgery alone. The addition of fluorouracil and leucovorin to the preoperative administration of 45 Gy during 5 weeks reduced locoregional recurrence from 17.1% to 8.5% (the 5-year overall survival [OS] did not improve with the addition of chemotherapy).<sup>13</sup> A similar study conducted by the



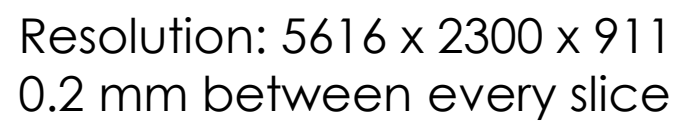
Kraima, Anne C., Smit, Noeska N. et al. "Toward a highly-detailed 3D pelvic model: approaching an ultra-specific level for surgical simulation and anatomical education." *Clinical Anatomy* 26.3 (2013): 333-338.

# Cryosection (Visible Korean Human female)



Resolution: 5616 x 2300 x 911  
0.2 mm between every slice



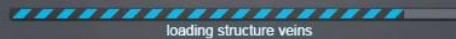


# 3D Virtual Atlas of the Pelvis



Smit, N. N. "The Virtual Surgical Pelvis: Anatomy Visualization for Education and Surgical Planning." (2016)

## The Online Anatomical Human



Smit, Noeska, et al. "The online anatomical human: web-based anatomy education." *Proceedings of the 37th Annual Conference of the European Association for Computer Graphics: Education Papers*. Eurographics Association, 2016.

# MOOC deployment



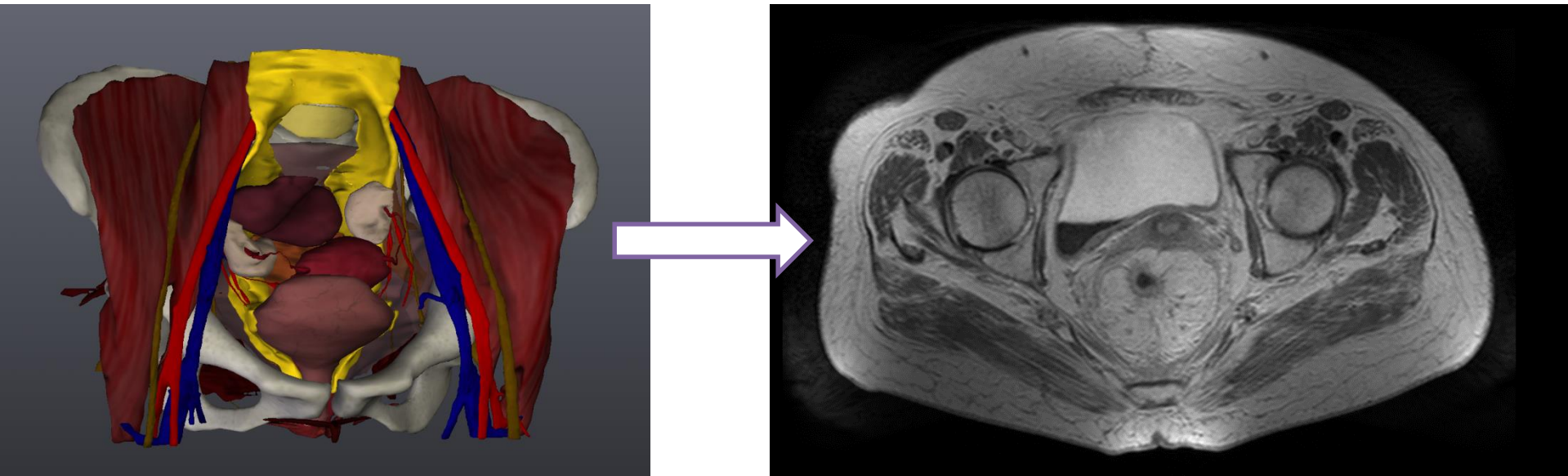
- **Massive Open Online Course (MOOC) on human anatomy via Coursera:**
  - Over 18.000 participants worldwide
  - <https://www.coursera.org/learn/anatomy>

Anatomy of the Abdomen and Pelvis; a journey from basis to clinic.

Universiteit Leiden & Leiden University Medical Center

# Personalized patient-specific model

- Atlas to MRI to build a patient-specific model





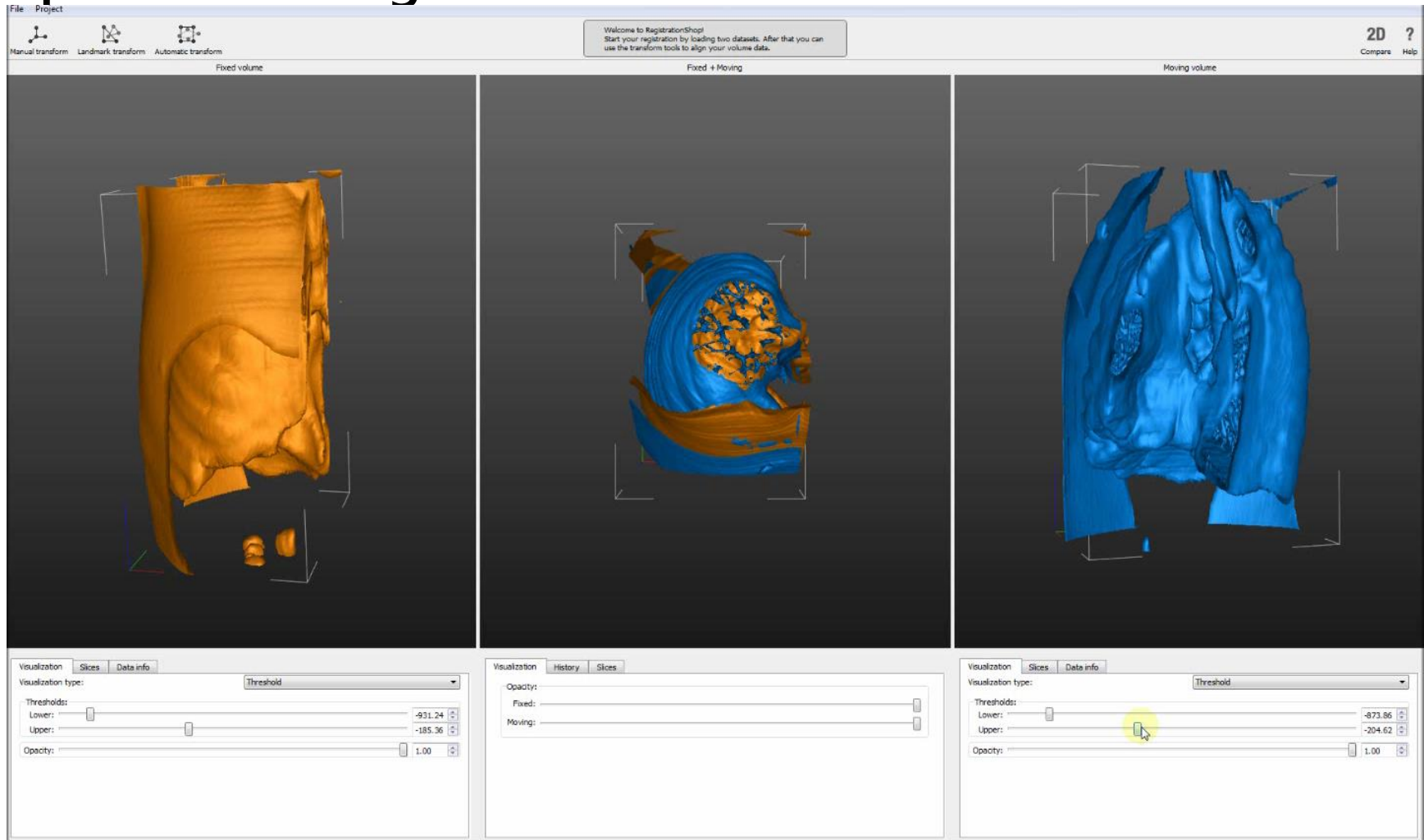
# Registration software comparison

	RS	AD	AL	FS	EZ	MT	MR	PM	SL	VV	VR
1. 3D volume visualization	✓	✓	✓	✗	✗	✓	✓ <sup>a</sup>	✗ <sup>b</sup>	✓	✓	✓
2. Multi-volume rendering	✓	✓	✓	✗	✗	✓	✗	✗ <sup>b</sup>	✗	✗	✓
3. Registration results inspection	2/3D	2/3D	3D	2D	2D	✗	2D	2/3D <sup>b</sup>	2D	✗	3D
4. 3D clipping of volumes	✓	✓	✓	✓	✗	✗	✓	✓	✓	✓	✗
5. Manual transformation	✓	✗	✓ <sup>c</sup>	✓	✗	✗	✓	✓	✓	✗	✓ <sup>d</sup>
6. Landmark transformation	✓	✓ <sup>e</sup>	✗	✗	✗	✗	✗	✓ <sup>f</sup>	✓	✗	✗
7. Non-rigid registration	✓	✓	✓	✓	✓	✓ <sup>g</sup>	✓	✓ <sup>h</sup>	✓	✓	✓
8. Deformation visualization	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗
9. GPU-accelerated registration	✓ <sup>i</sup>	✗	✗	✓	✓	✗	✗	✗	✗	✗	✗
10. Transformation history	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
11. Free software	✓	✓	✓	✗	✓	✓	✗	✗	✓	✓	✓
12. Multiplatform	✓	✓	✓	✗	✓	✓	✗	✓	✓	✓	✓

**Table 1:** Features of RegistrationShop vs. related applications (alphabetical order): RS: RegistrationShop, AD: AMIDE, AL: AMILab, FS: FusionSync, EZ: Ezys, MT: MITK, MR: Mirada Medical, PM: PMOD, SL: Slicer, VV: VolView, VR: Voreen. <sup>a</sup>: MIP only. <sup>b</sup>: In external P3D tool. <sup>c</sup>: Functionality not working in current version 3.2.1. <sup>d</sup>: Interactive transformation matrix. <sup>e</sup>: Non-interactive landmark transformation wizard. <sup>f</sup>: Limited to only one set of landmarks. <sup>g</sup>: Not included by default in MITK workbench. <sup>h</sup>: Only available for brain normalization. <sup>i</sup>: Will become available with next Elastix release [SBL\*13].

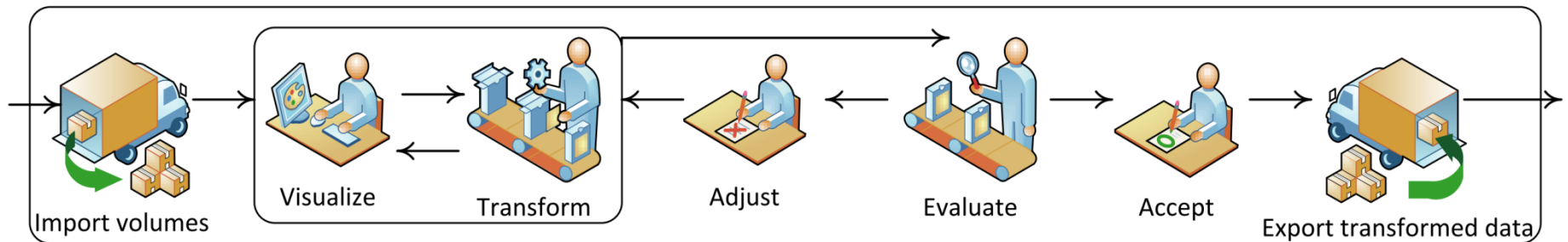
- Typically only 2D visualizations of the registration result or missing required transformation tools
- Not always suitable for non-image processing experts

## Open source registration framework



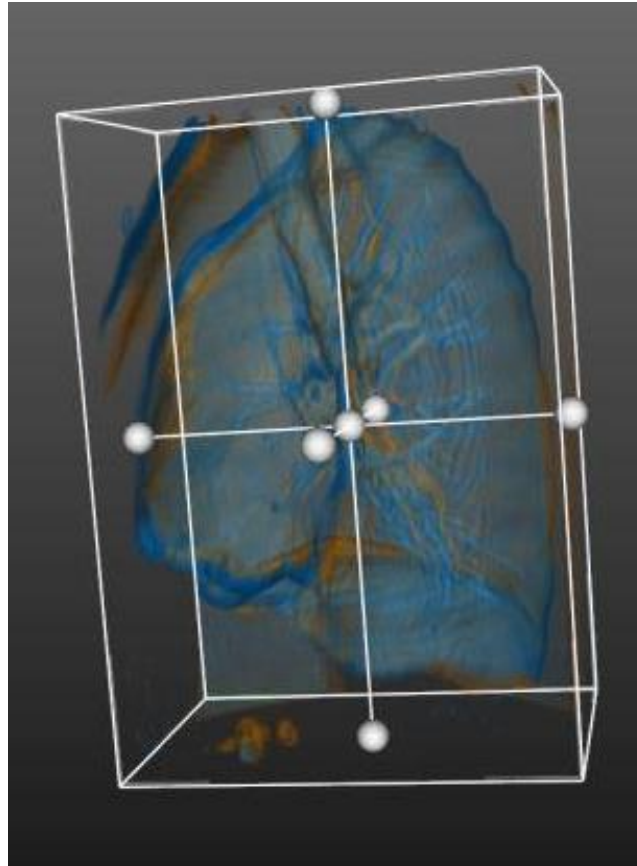
# Our idea

- simple interaction techniques
- + real-time 3D visual feedback
- = simplified registration process for novice users?



# Interactive transformations

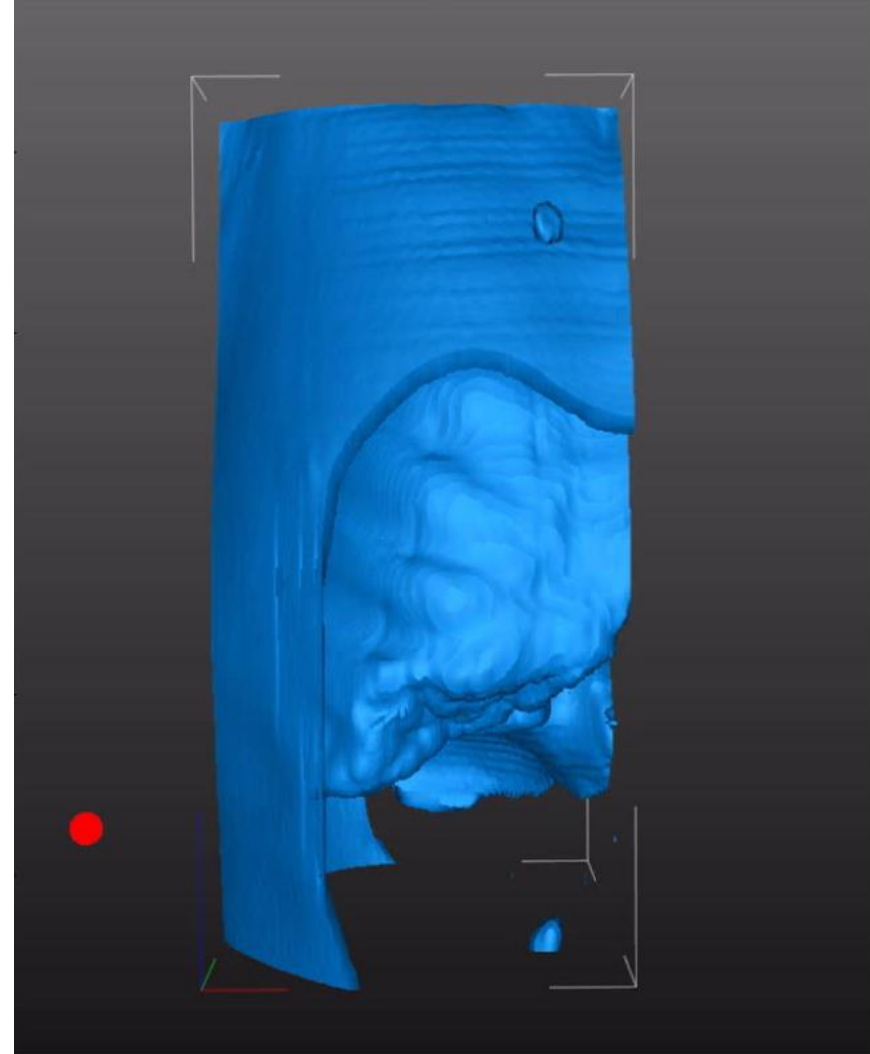
- Box widget for translation, scaling, rotation of volume





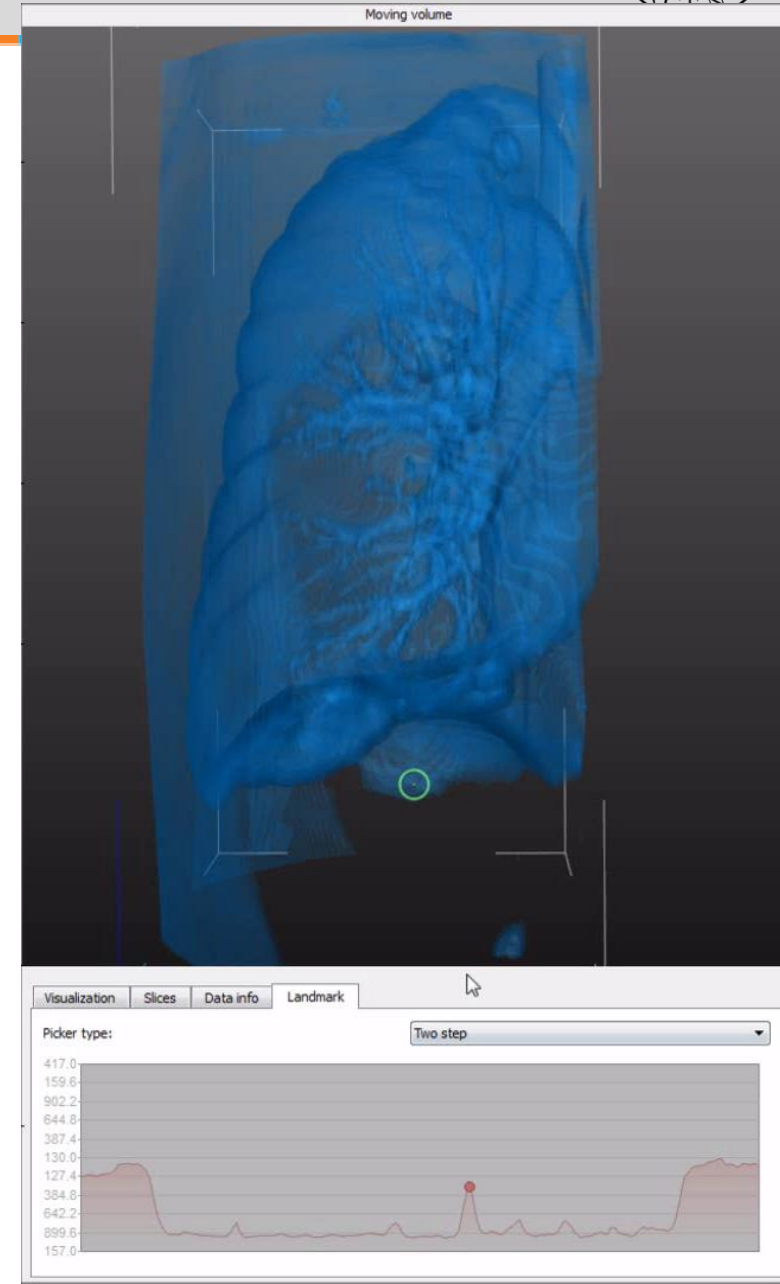
# Landmark placement

- Corresponding landmark pairs:
  - Method 1: surface picker



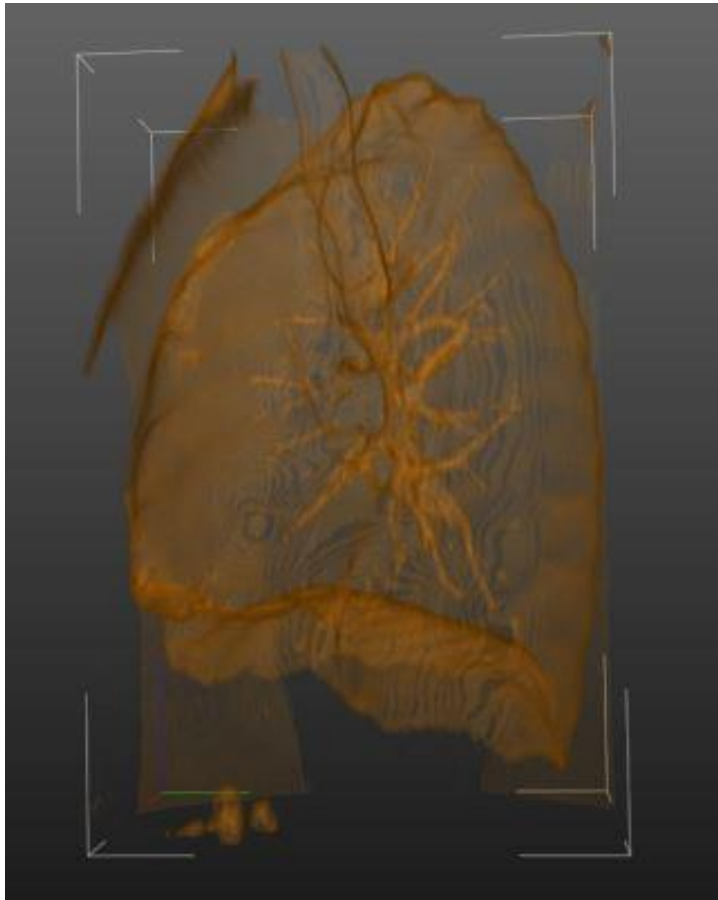
# Landmark placement

- Corresponding landmark pairs:
  - Method 1: surface picker
  - Method 2: two-step picker

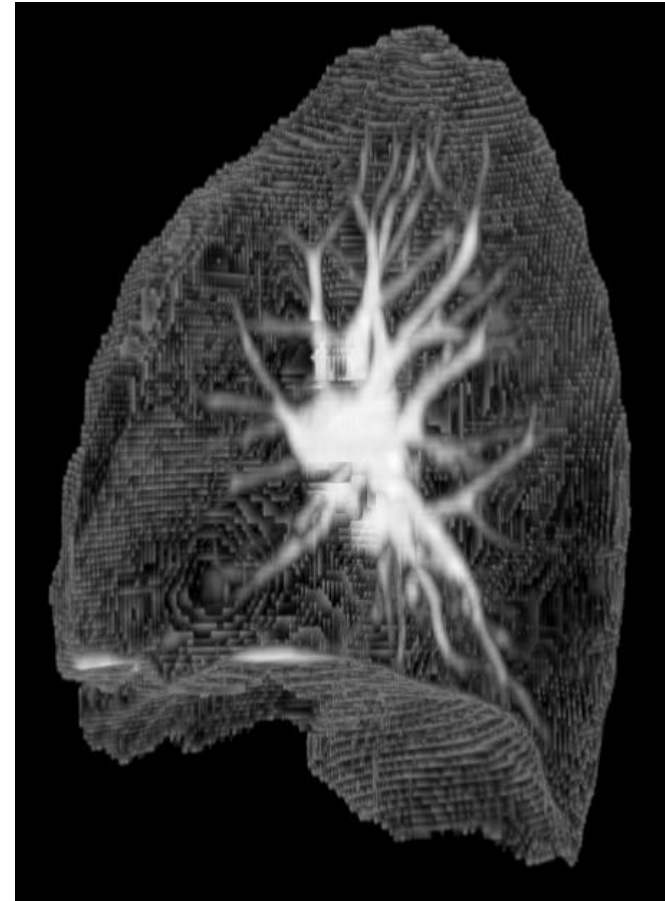


# Simple visualization techniques

## Direct volume rendering:



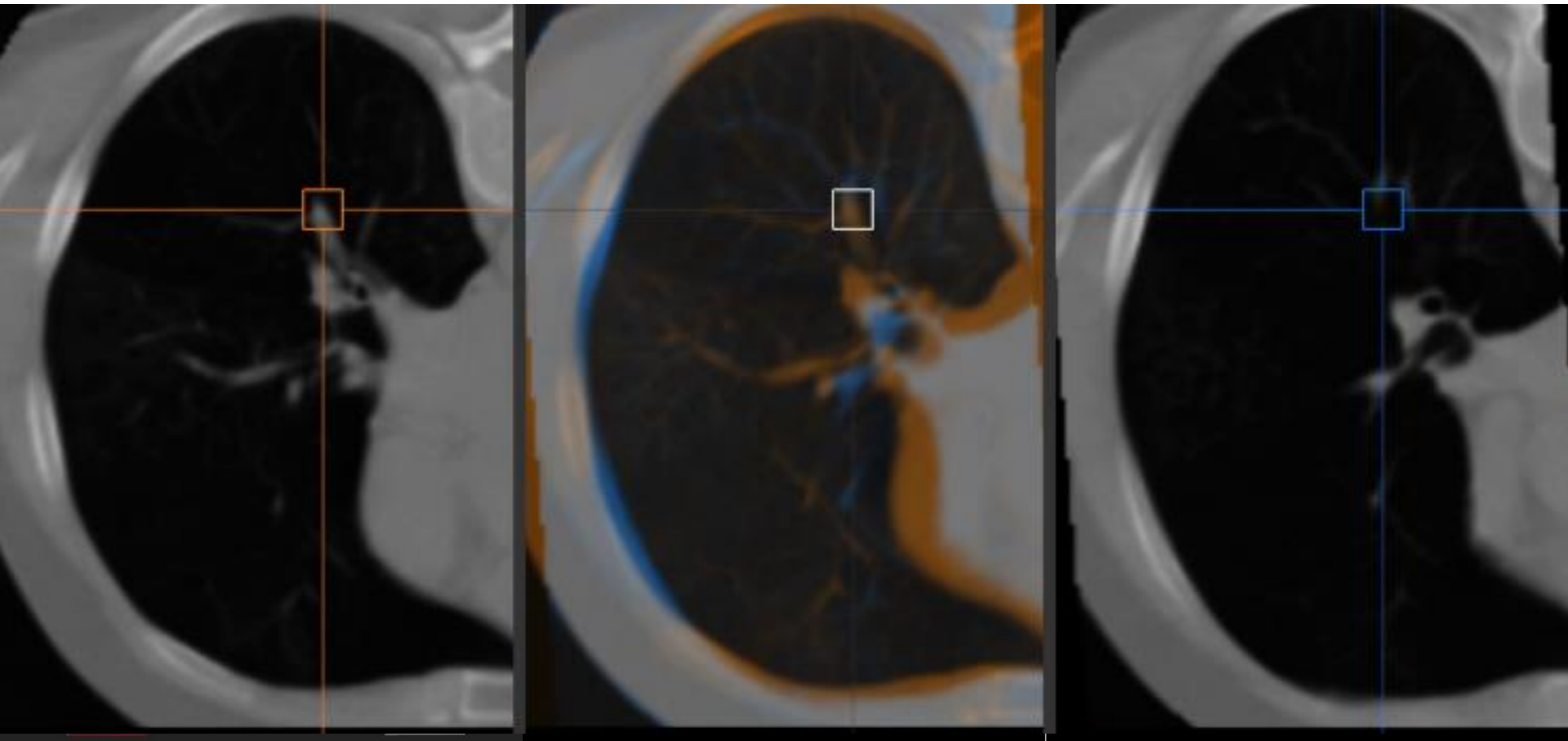
Double thresholds



Maximum Intensity Projection (MIP)

# Integrated comparative visualization

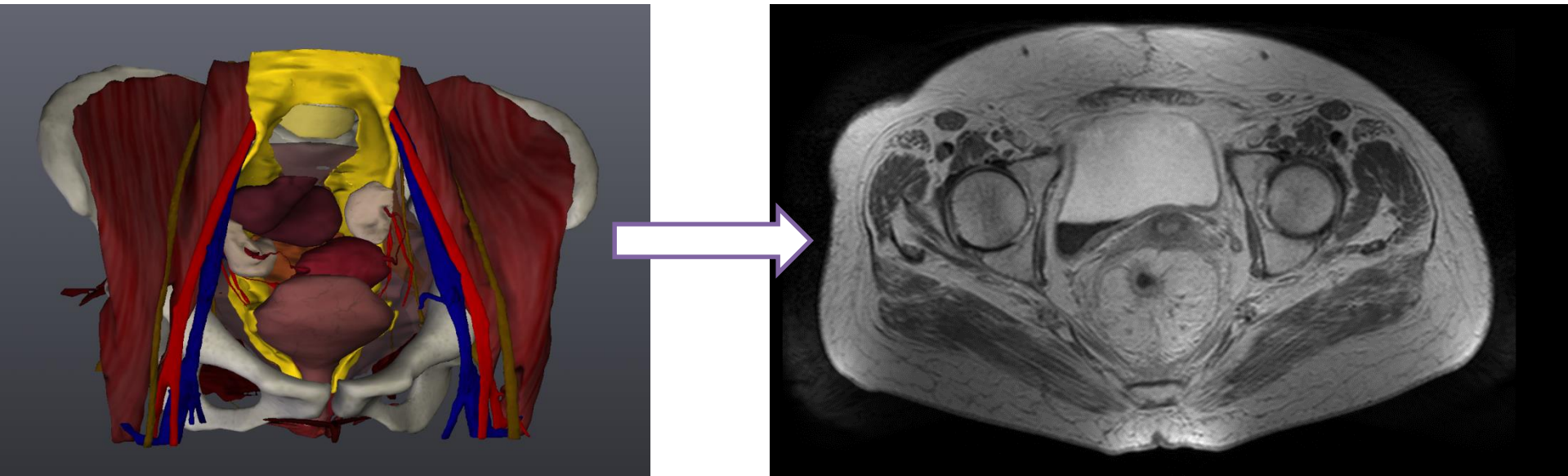
Real-time visual feedback on the current registration result:



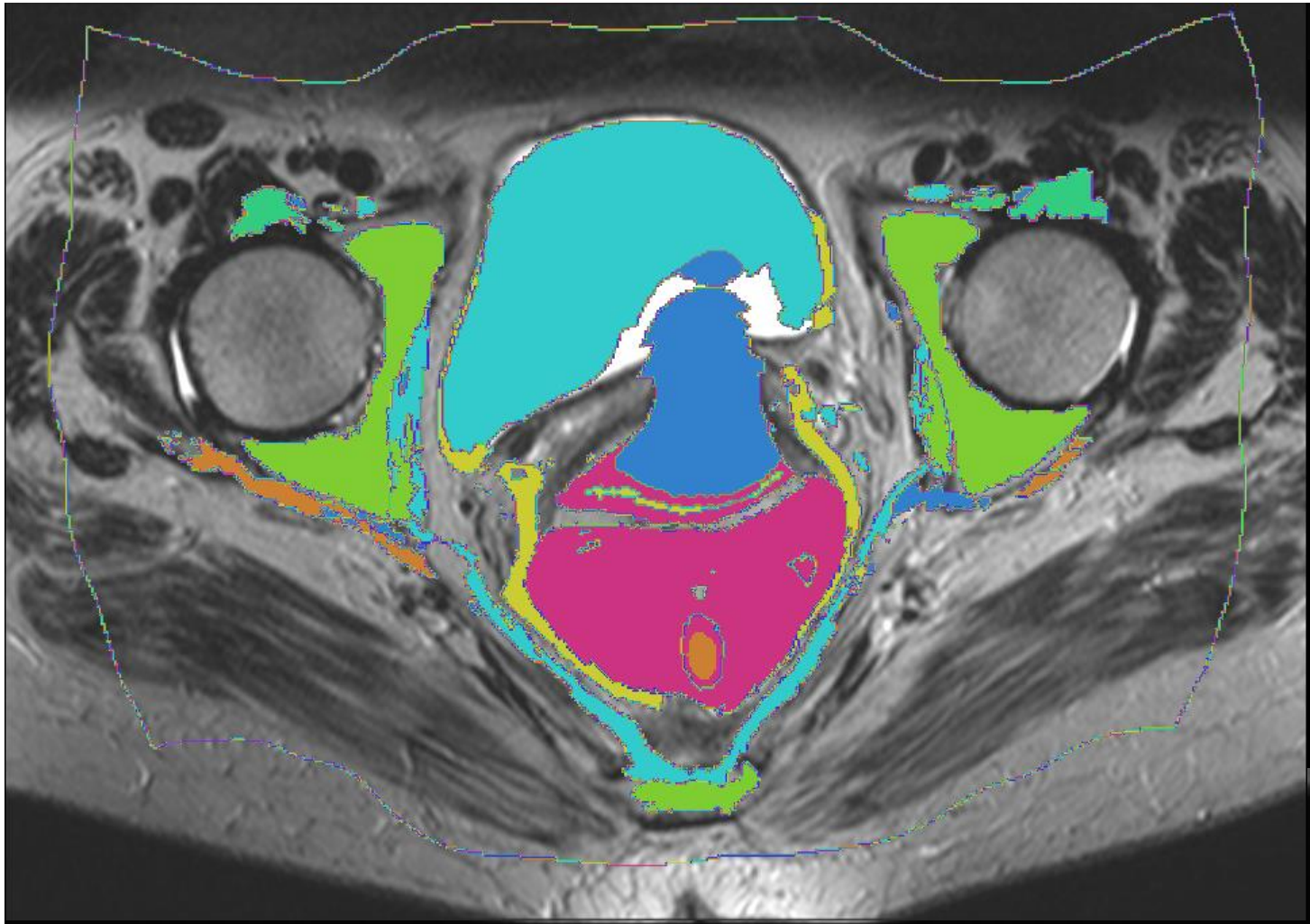


# Personalized patient-specific model

- Atlas to MRI to build a patient-specific model



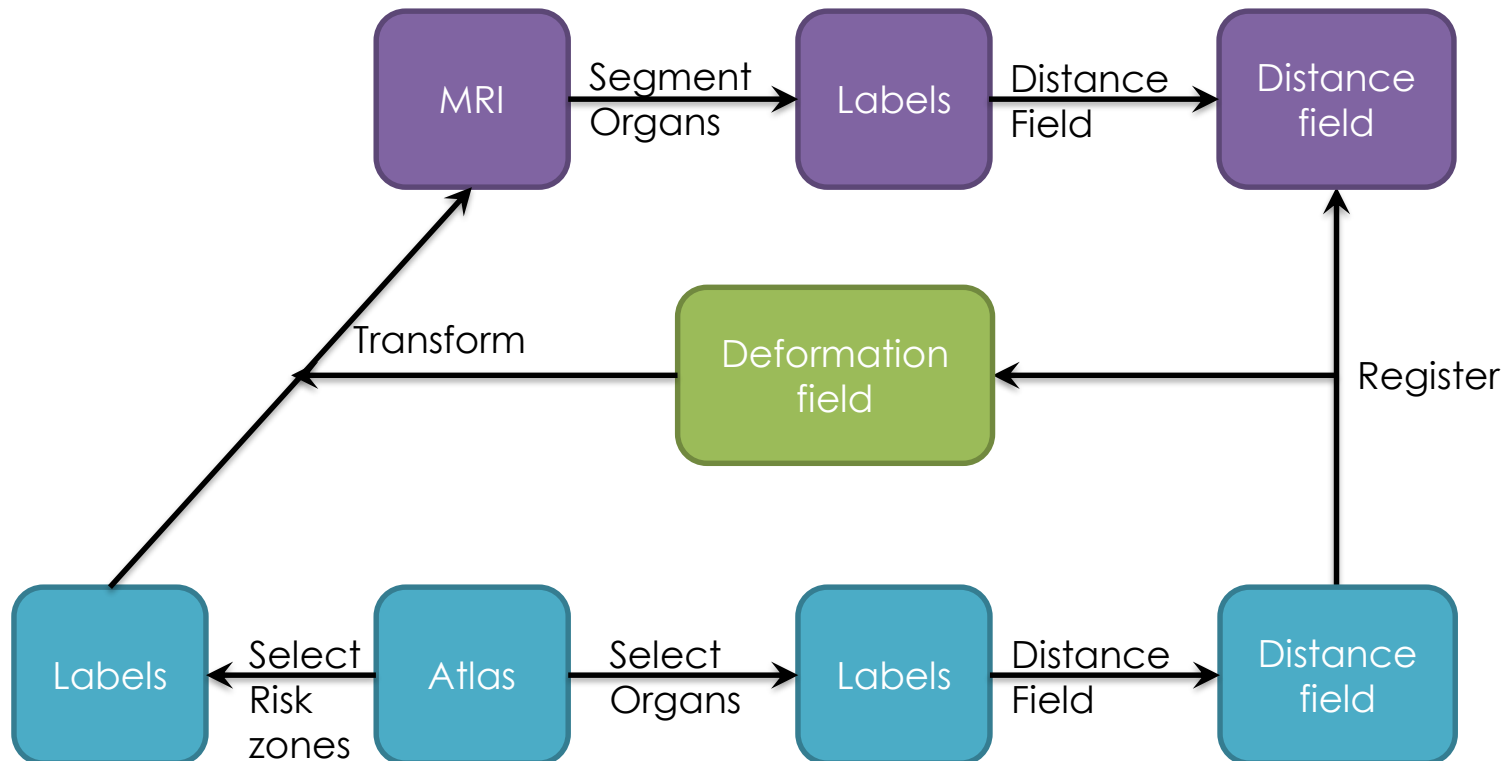
# Registering atlas to MRI



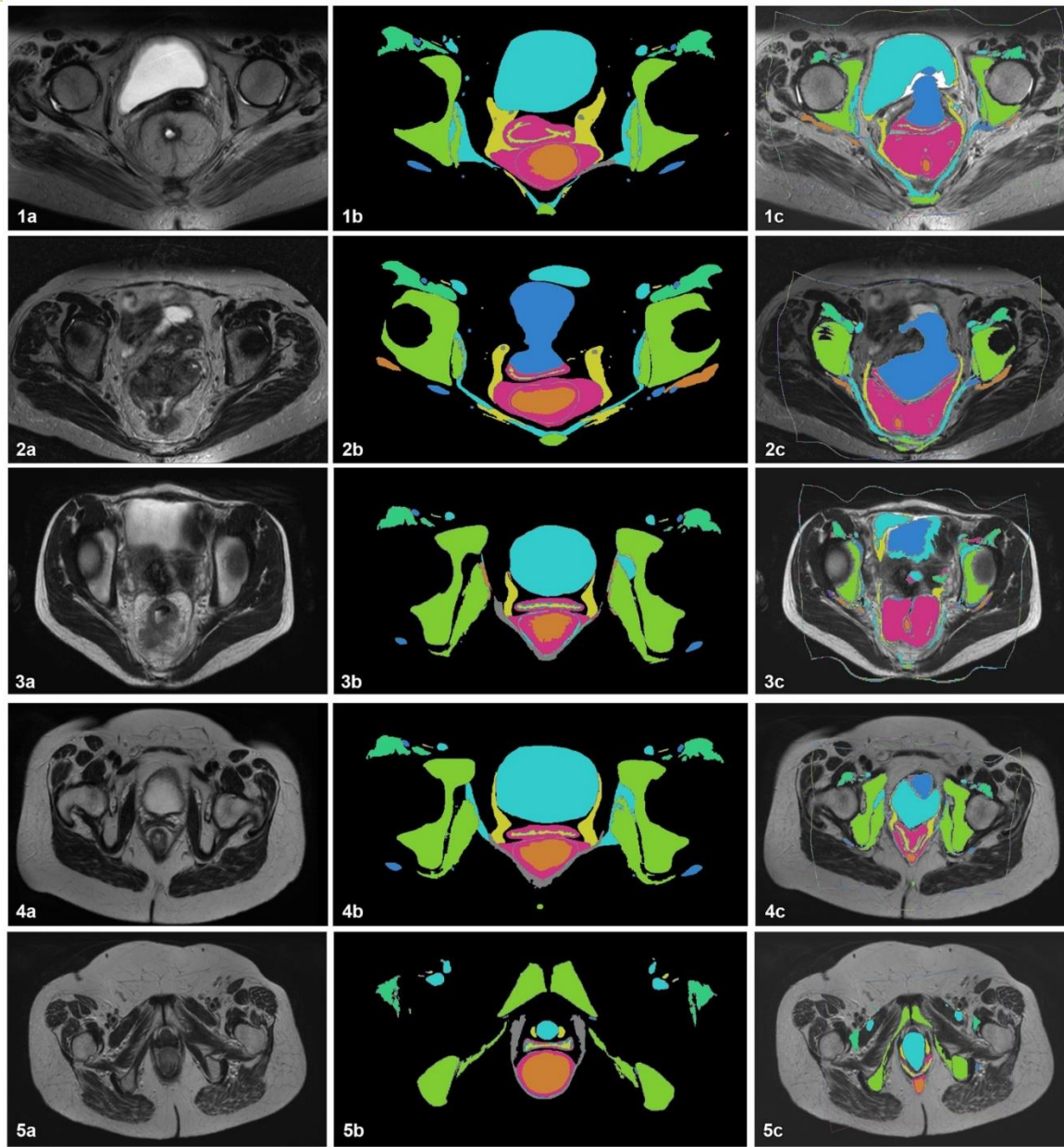
Smit, Noeska N., et al. "RegistrationShop: An Interactive 3D Medical Volume Registration System." In Proceedings of the EuroGraphics Workshop on Visual Computing for Biology and Medicine (VCBM). 2014.

# How to register the atlas to MRI?

- Assumption: While shape of organs varies, distance risk zones to organs is same between patients
- Approach : Segment organs in MRI and register atlas organs to these

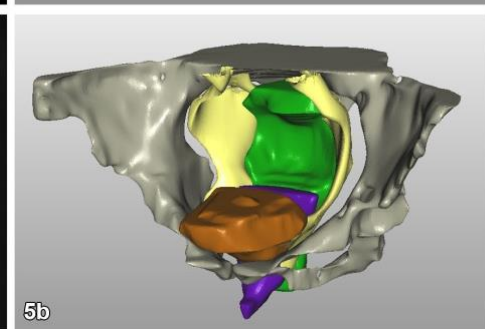
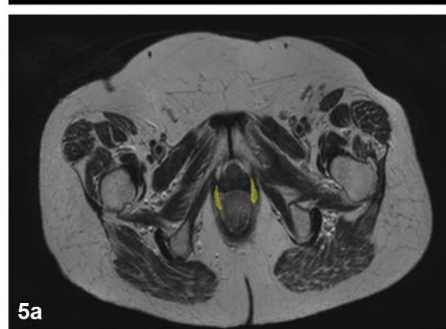
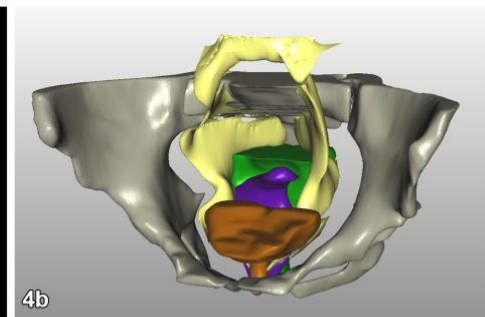
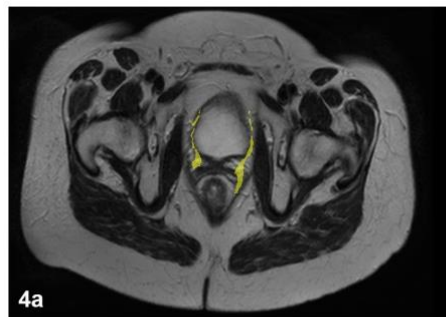
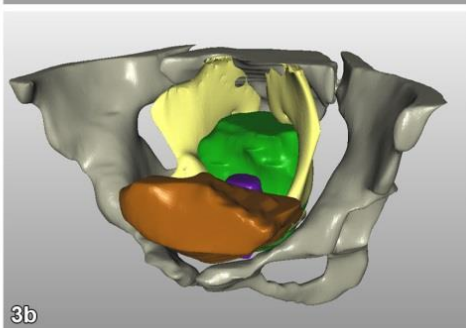
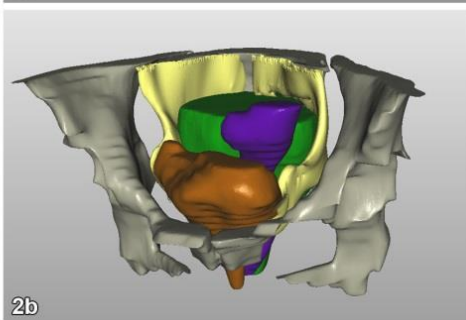
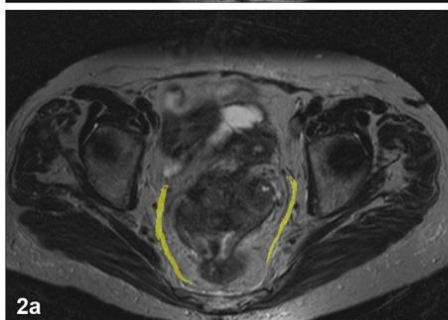
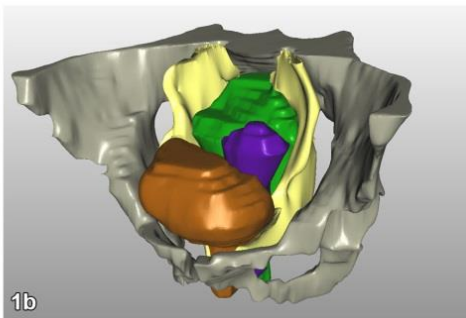
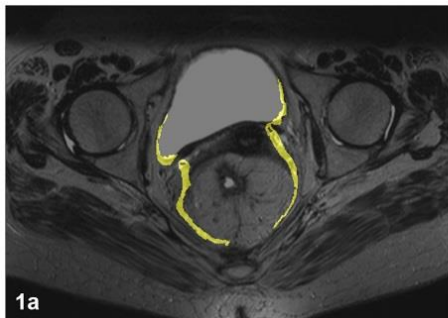


# 5 patients





# Patient-specific 3D models



# Surgically relevant information

- Tumor

Target

- Organs:

- Mesorectum

- Vagina and uterus/prostate

- Bladder

- Pelvic bones

Context

- Autonomic nerves

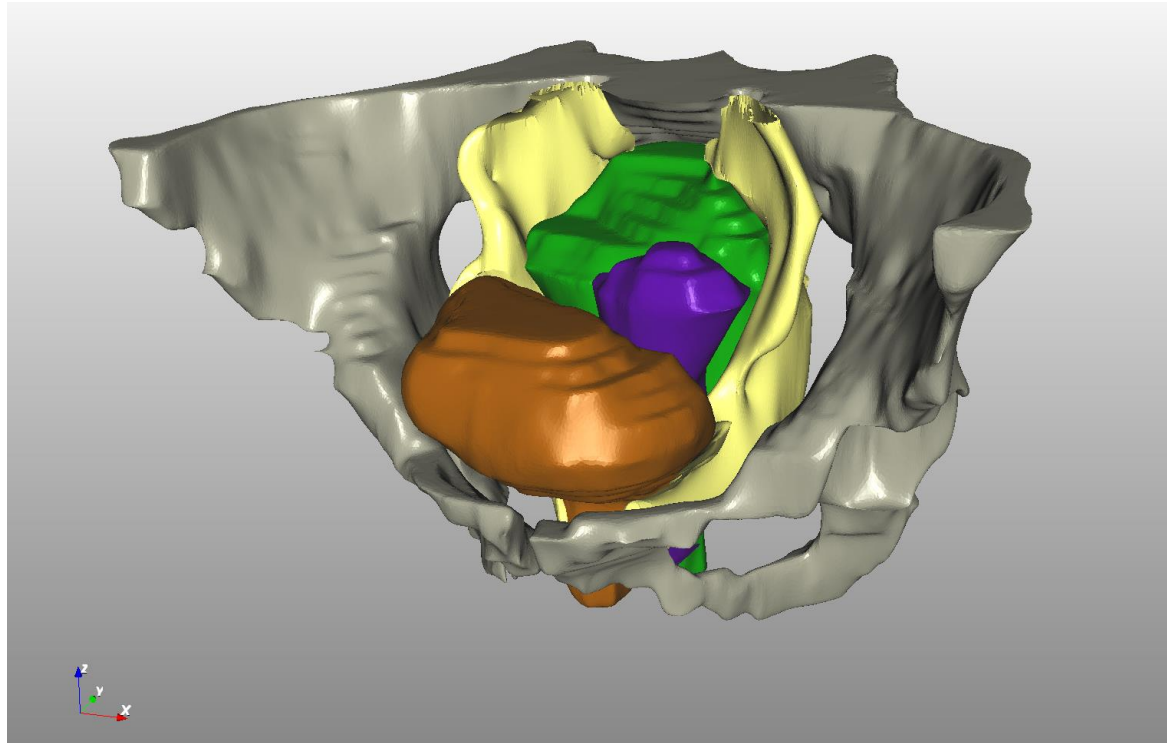
Risk

- Distances: nerves to mesorectum / tumor to mesorectum/tumor to anus

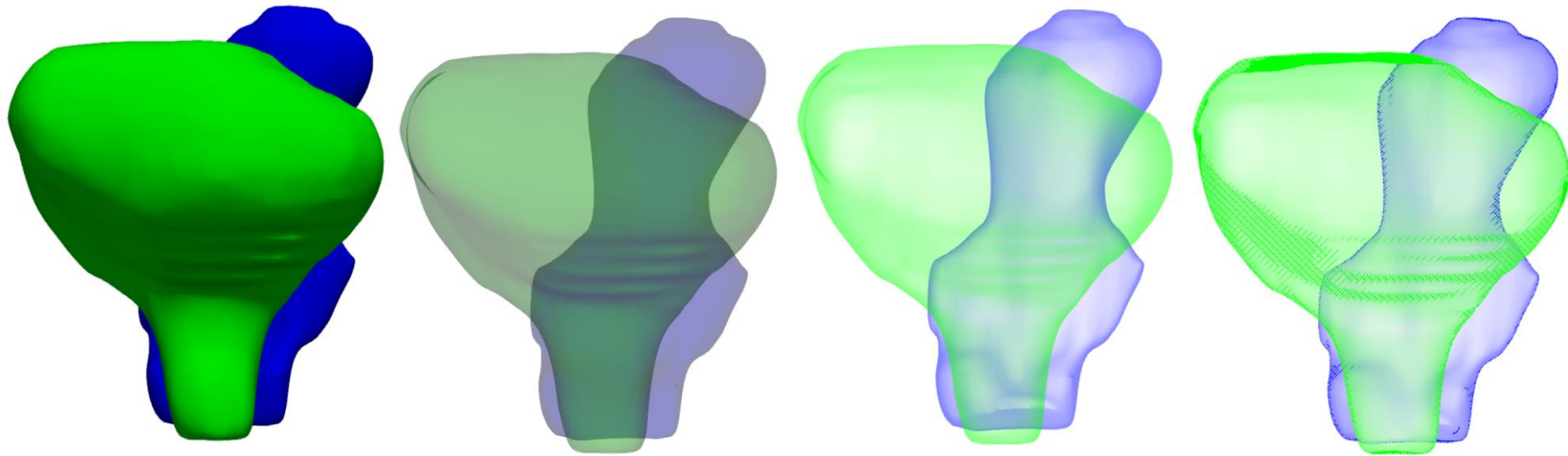
- Confidence in registration outcome?

# How to visualize all this?

- Not like this:

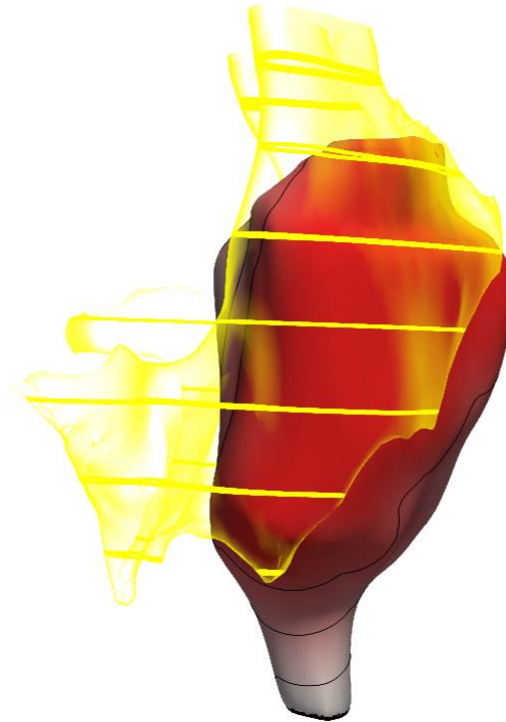
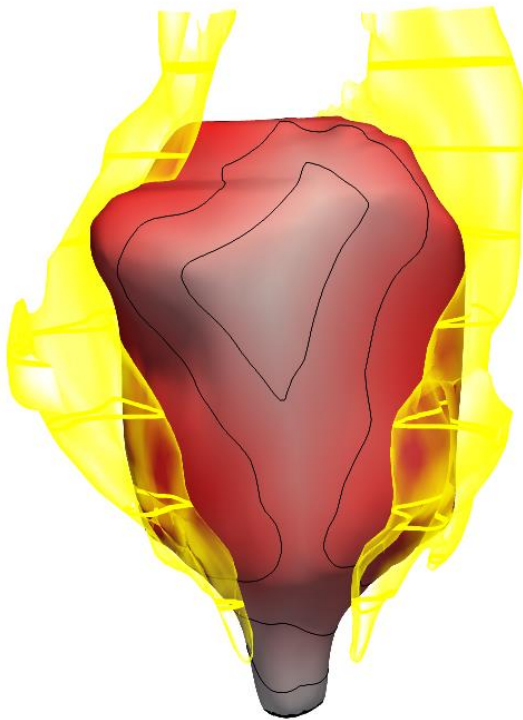


# Context visualization

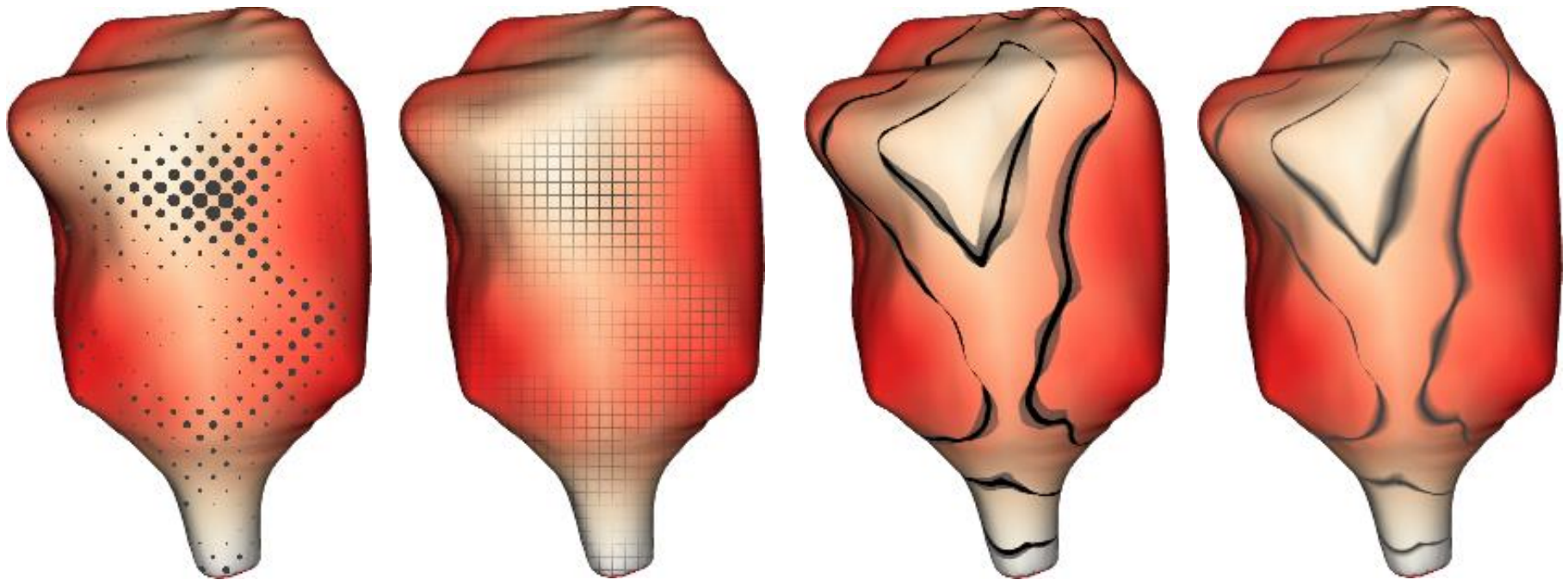




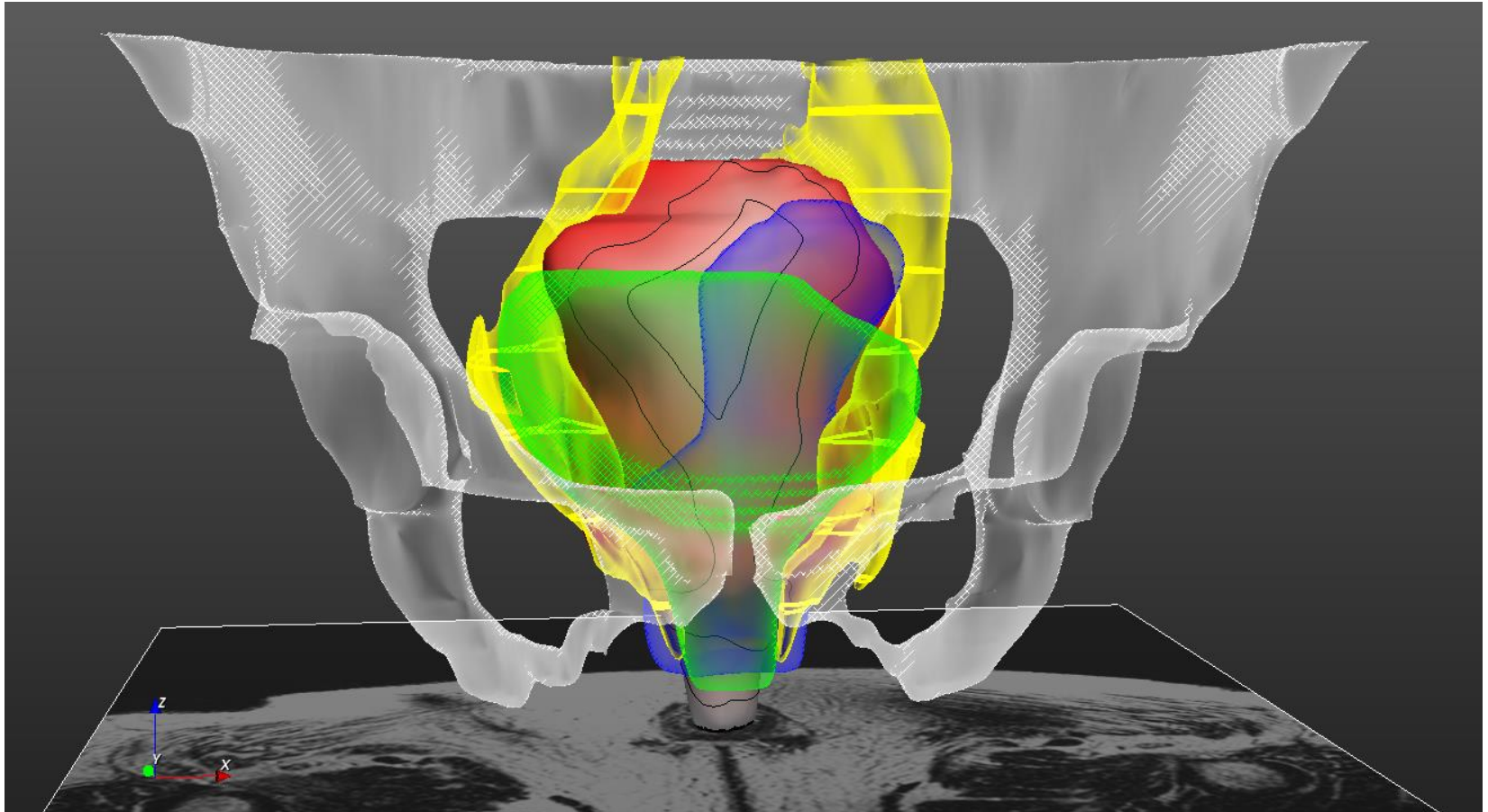
# Distance to risk zones



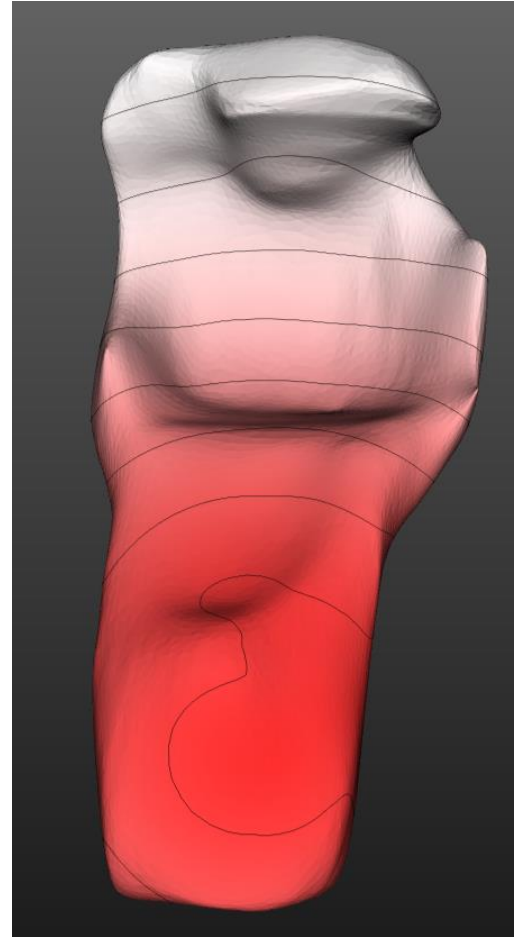
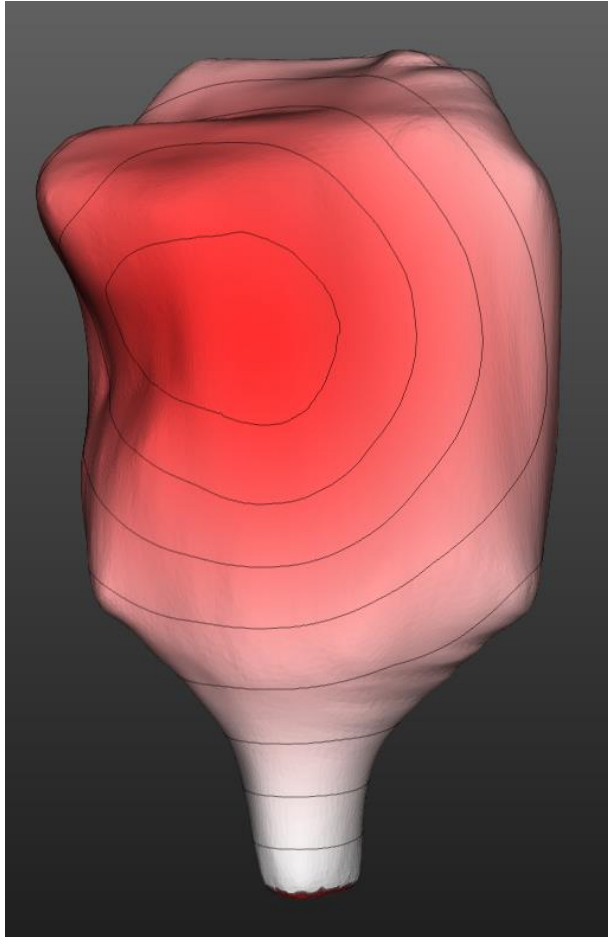
# Distance and confidence visualization



# Combined context + target visualization

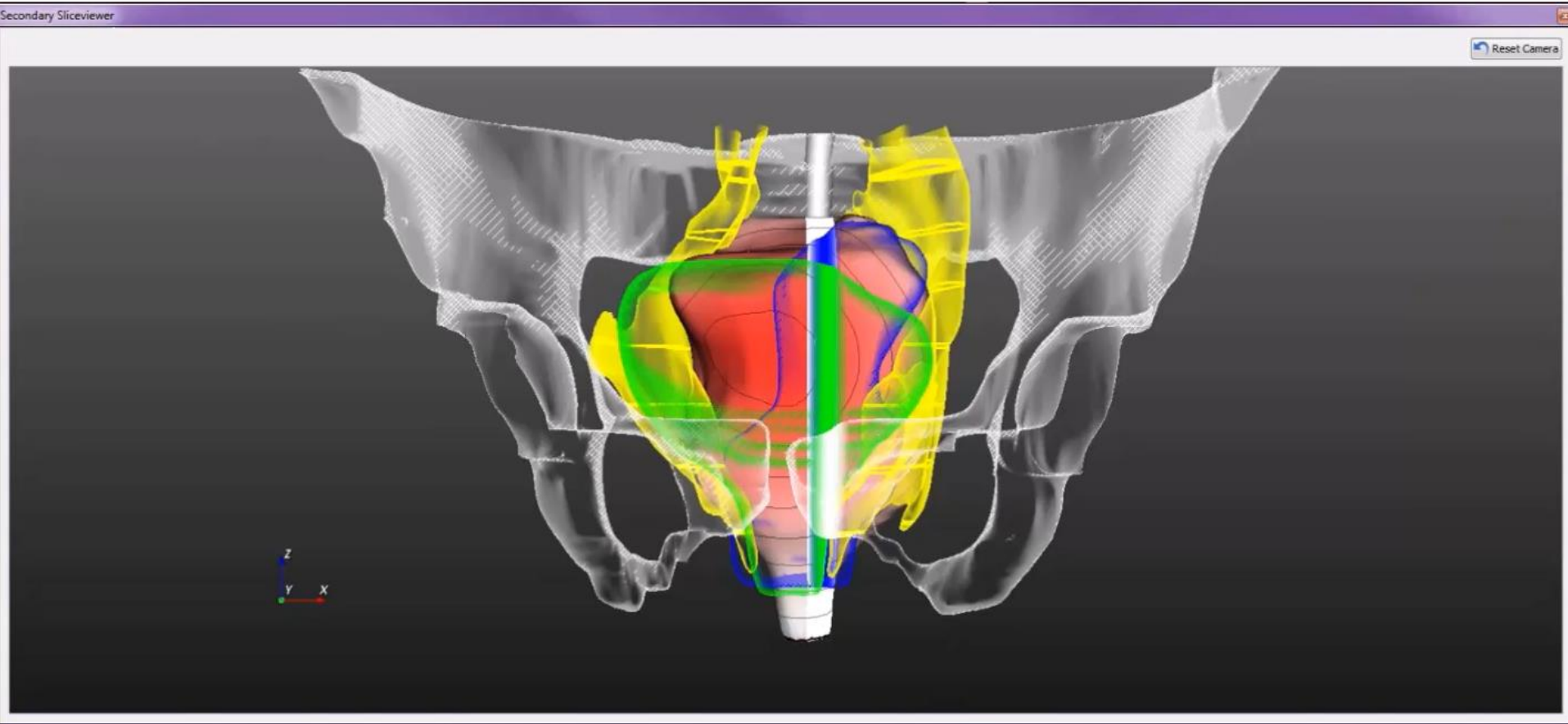


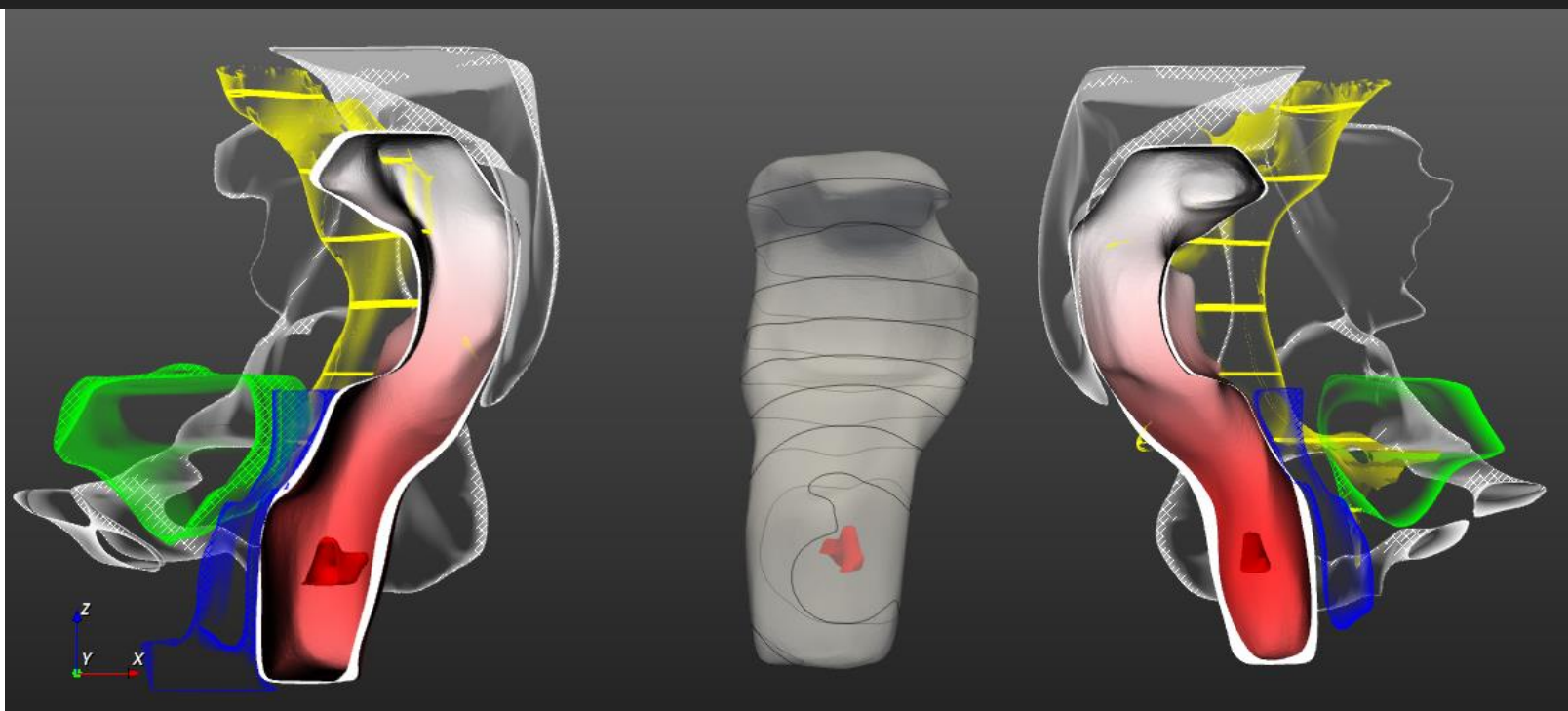
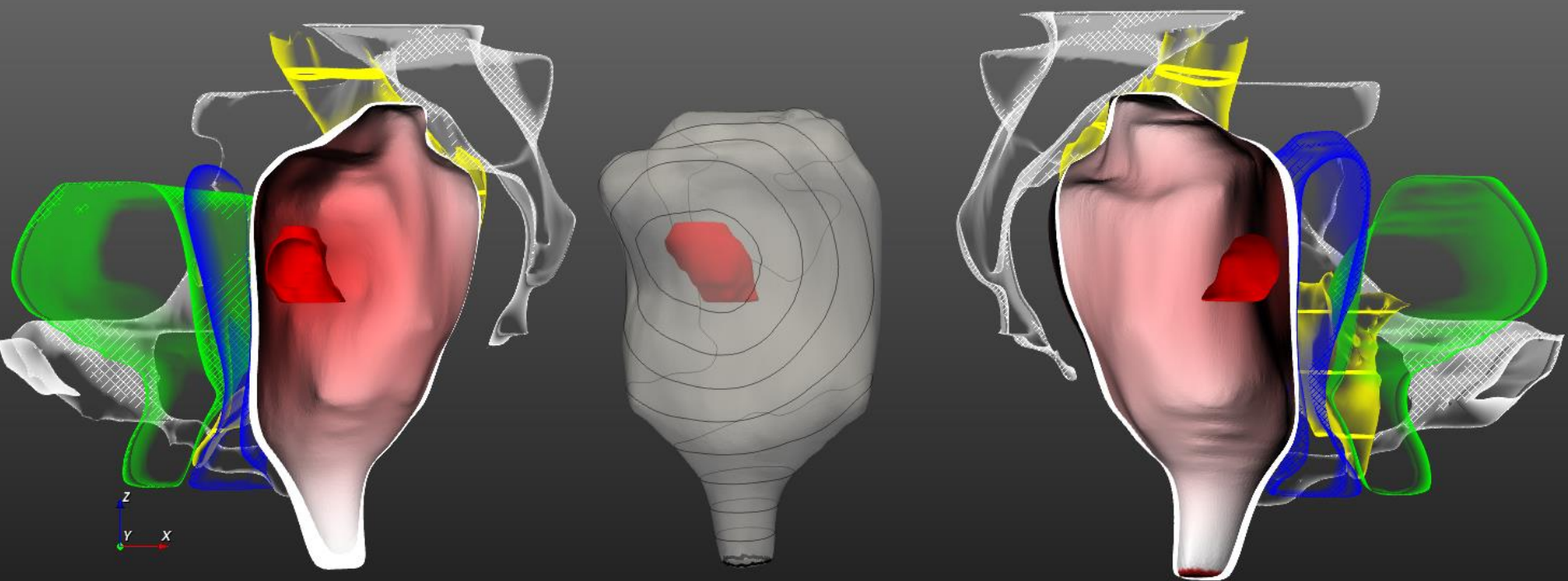
# Distance to tumor?



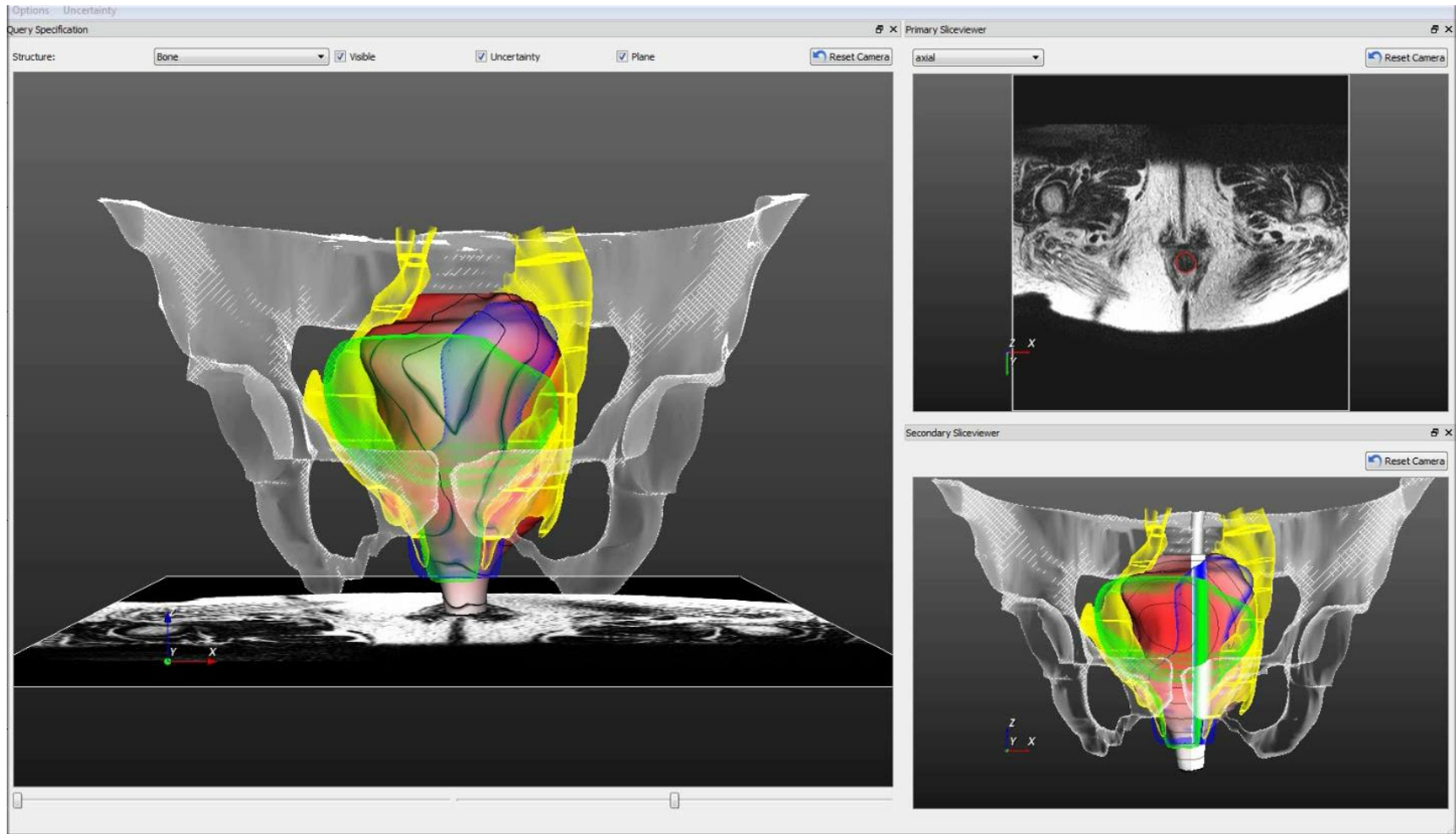


# What tumor?





# Surgical Planning Application



Smit, Noeska, et al. "PelVis: Atlas-based surgical planning for oncological pelvic surgery." *IEEE transactions on visualization and computer graphics* 23.1 (2017): 741-750.

- **'Traditional medical visualization research':**
  - Direct visualization of medical imaging data
  - For diagnostic/treatment planning purposes



- **Prediction and prevention**
  - More advanced techniques needed
  - Beyond what is available directly from medical imaging

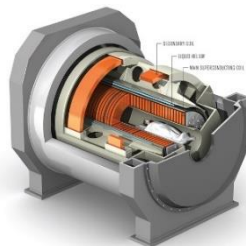


# Current Trends and Challenges

## Advances in data acquisition

High-resolution, high-throughput imaging

INUMAC MRI scanner,  
11.75 Tesla, spatial  
resolution: 0.1mm

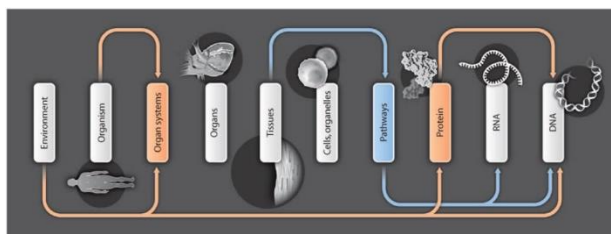


HDLive 4D  
ultrasound [GE  
HealthCare]

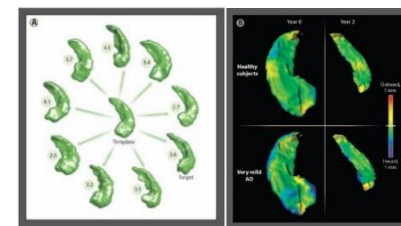
**From static to dynamic**  
4D real-time streamed data

## From anatomy to physiology

Multi-modal, multi-scale (bio)medical data



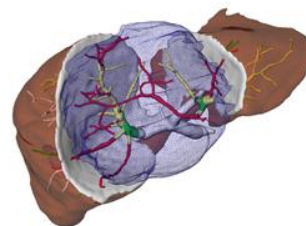
Variation of hippocampus  
shape between Alzheimer  
patients and healthy  
subjects [Csernansky et al.]



**From individuals to populations**  
electronic health records, cohort studies

## Computational medicine

Personalized simulation models



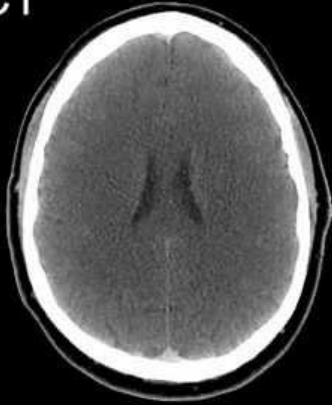
Personalized anatomical liver  
model [Fraunhofer MEVIS]

# Research Focus: Multi-Modal Medvis

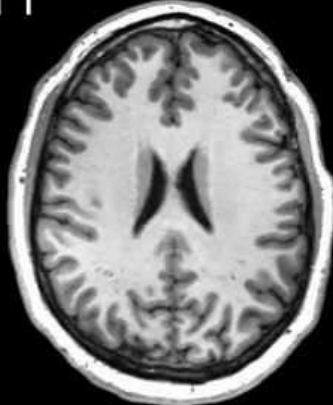


## AXIAL VIEW OF CO-REGISTERED NORMAL CT AND MRI SCANS

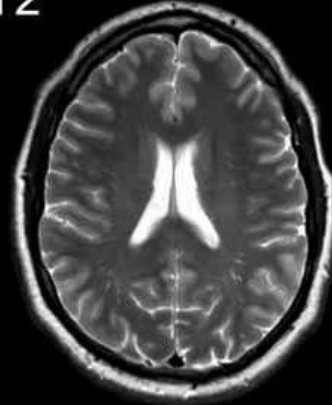
CT



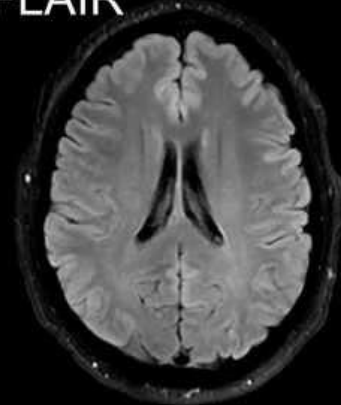
T1



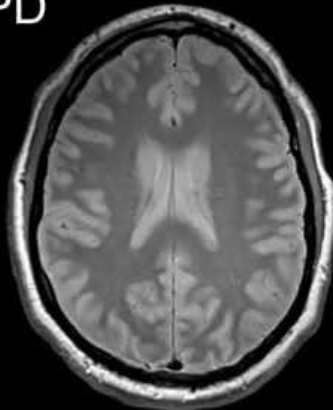
T2



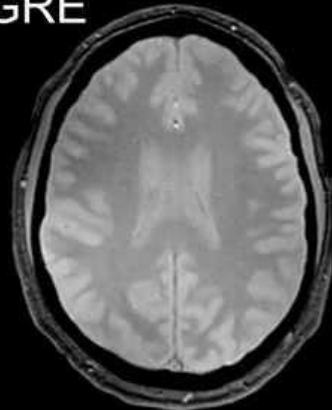
FLAIR



PD



GRE



# MMIV Centre

- Established in 2017
- Interdisciplinary collaboration between the University of Bergen and the Haukeland University Hospital



Image by Eivind Senneset, UIB

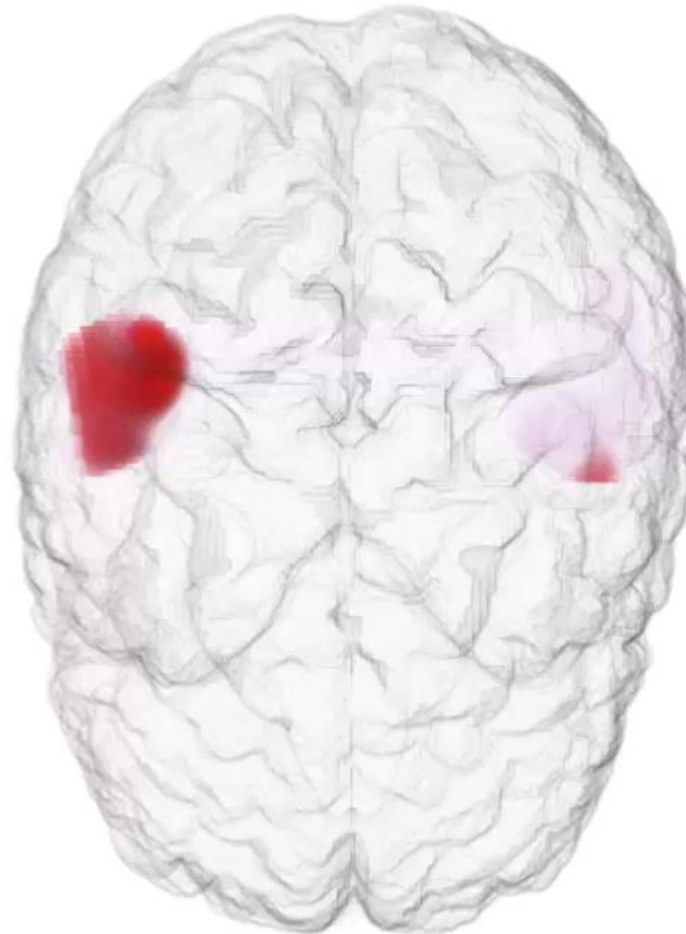
# MMIV Core Projects



- Computational Medical Imaging and Machine Learning
- Precision Imaging in Gynecologic Cancer
- Visual Data Science for Imaging Biomarker Discovery
- Advanced Neuroimaging



# Ongoing Research: Interactive Time-warping



# Take-aways



- Interactive visualization can provide a way to explore, analyze, and communicate data, complementing automatic methods
- Visualization can reveal information and patterns that are not immediately apparent from the original data
- Medical visualization can provide assistance with education, diagnosis, treatment planning and guidance, and doctor-patient communication

Thank you!



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