An Introduction to Medical Imaging and Biophotonics

& an intro to selected works from **Prof. AUDREY K. BOWDEN**

3D reconstruction of cystoscopy videos for comprehensive bladder records, *Biomedical optics express 2017*

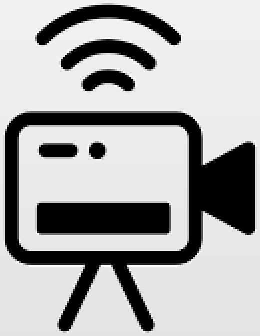
Ehsan Adeli, Ph.D.

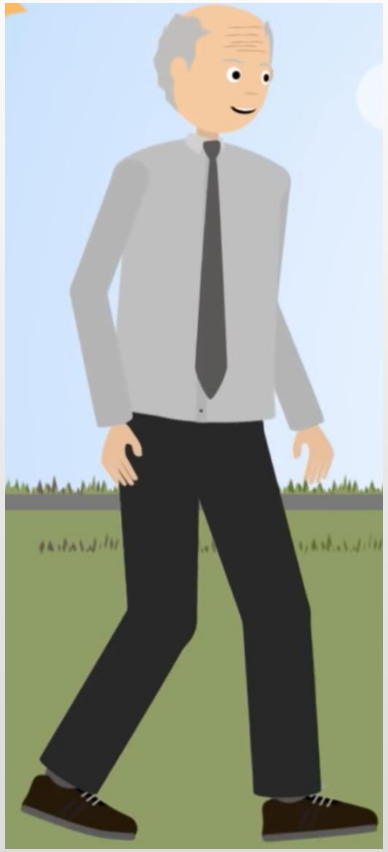
CS114/CS214

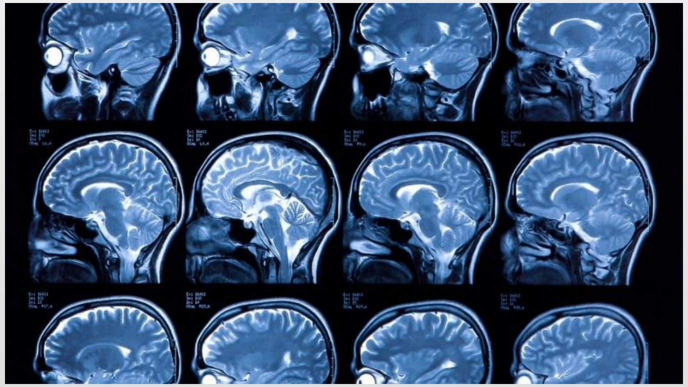
May 18, 2022

Stanford
University

Motion + Brain Circuitry







Structural & Functional MRI

Video

STANFORD VISION & LEARNING

CNSLAB

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Research Article

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Biomedical Optics EXPRESS

3D reconstruction of cystoscopy videos for comprehensive bladder records

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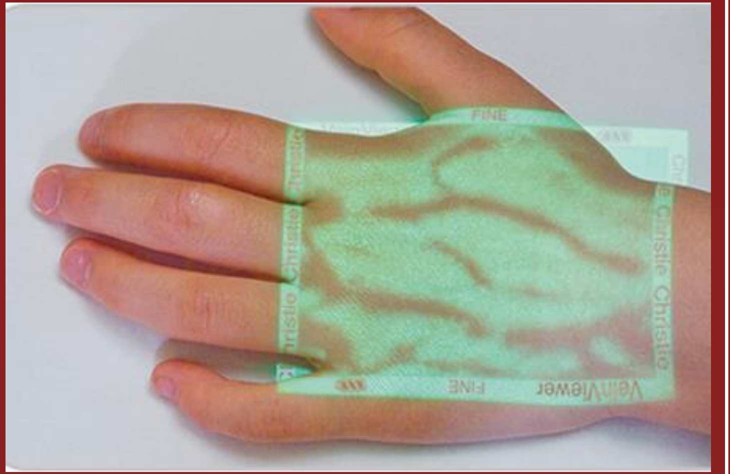
Prof. Audrey K Bowden

- Dorothy J. Wingfield Phillips Chancellor Faculty Fellow and Associate Professor of Biomedical Engineering (BME) and of Electrical Engineering (EE) at Vanderbilt University
- Prior to this, she served as Assistant and later Associate Professor of Electrical Engineering and Bioengineering at Stanford University.
- Research Focus
  - Biophotonics (light-based) tools for applications to medicine and biology, such as for early detection, diagnosis and therapy for cancer;
  - Development and deployment of low-cost, high-performing point-of-care technologies for rural and global health applications



IMAGING IN MEDICINE

Imaging

- Everyone knows about cameras…

- What else might you be interested in "imaging"?

Medical Imaging ca. 1895

Need to find a way to see inside without "light"

X-Ray

- November 8th, 1895, German scientist Wilhelm Roentgen was conducting experiments in his laboratory on the effects of cathode rays.
- the effect of passing an electrical discharge through gases at a low pressure.
- when passing current through the cathode ray, rays are given off that passed through different materials.

he name it X-RAYS

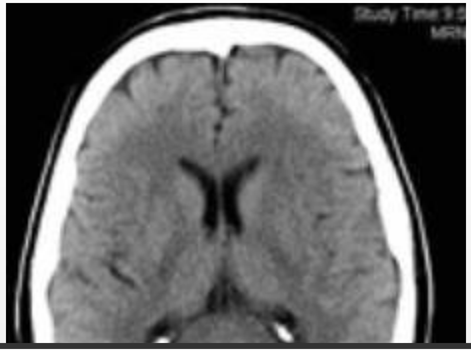
X meaning unknown

electromagnetic radiation of short wavelength produced when high-speed electrons strike a solid target

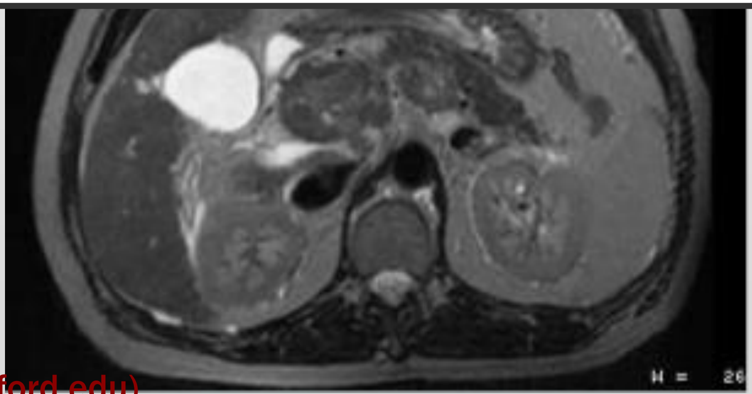
Medical Imaging Today

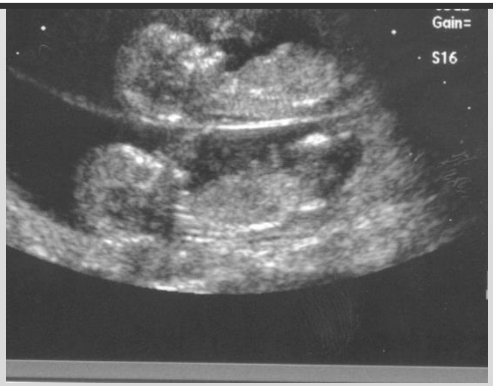
X-Ray

CT

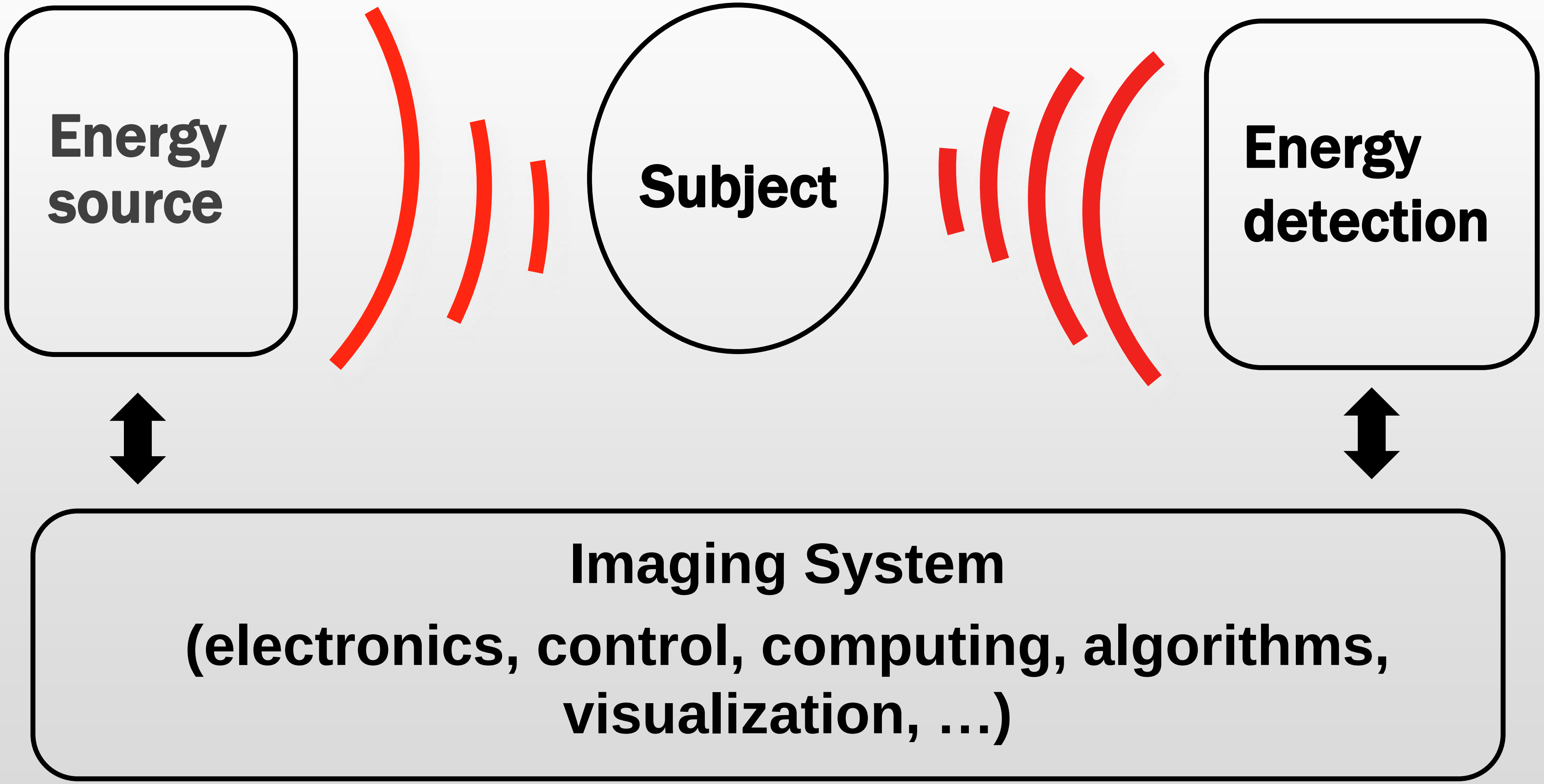


All of these were enabled/dramatically advanced by the mathematical and hardware design techniques you will learn here!

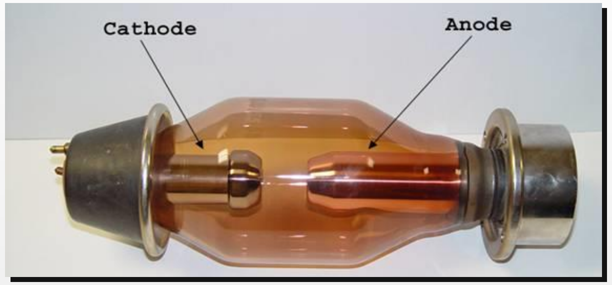


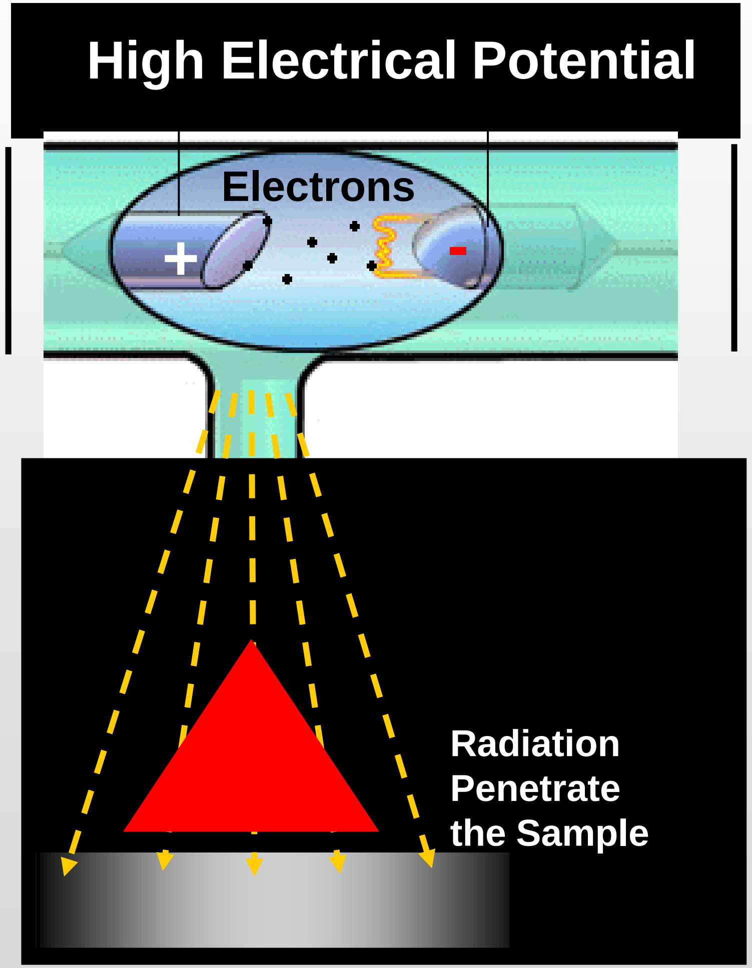


Imaging In General



Conventional X-ray Imaging.
X-ray Production.





Electrons from cathode filament are accelerated towards and impact the rotating anode.

Rapid deceleration produces heat (~ 98%) and x-rays (~2%)

Over couch X-ray Tube and Table

Conventional X-ray Image of a Hand

Normal

Arthritic

Chest X-ray

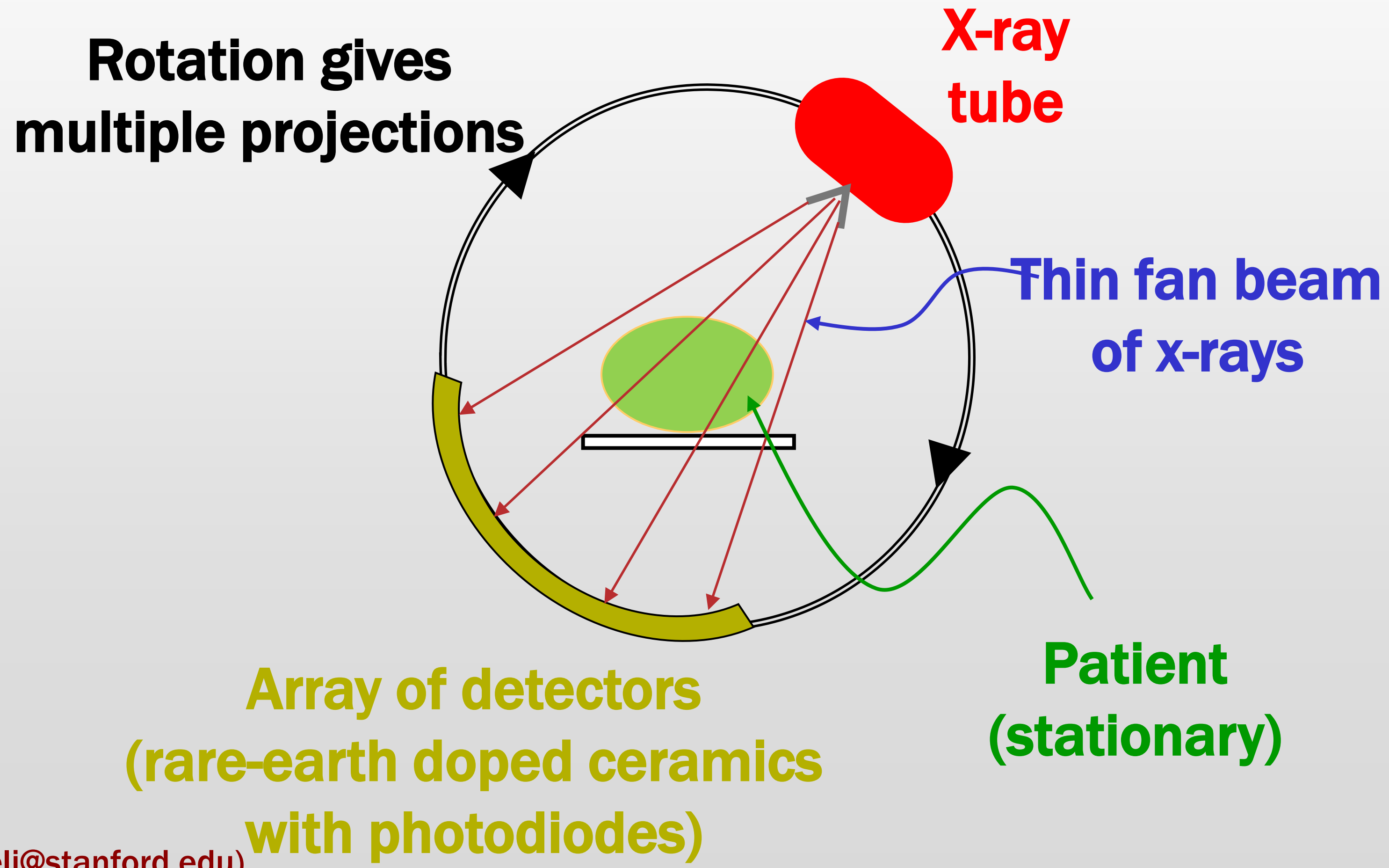
Computerized Tomography (CT)

combines special x-ray equipment with sophisticated computers to produce multiple images of the inside of the body.

CT Scanner

Brain Axial Image

Computed Tomography (CT)



Fluoroscopy

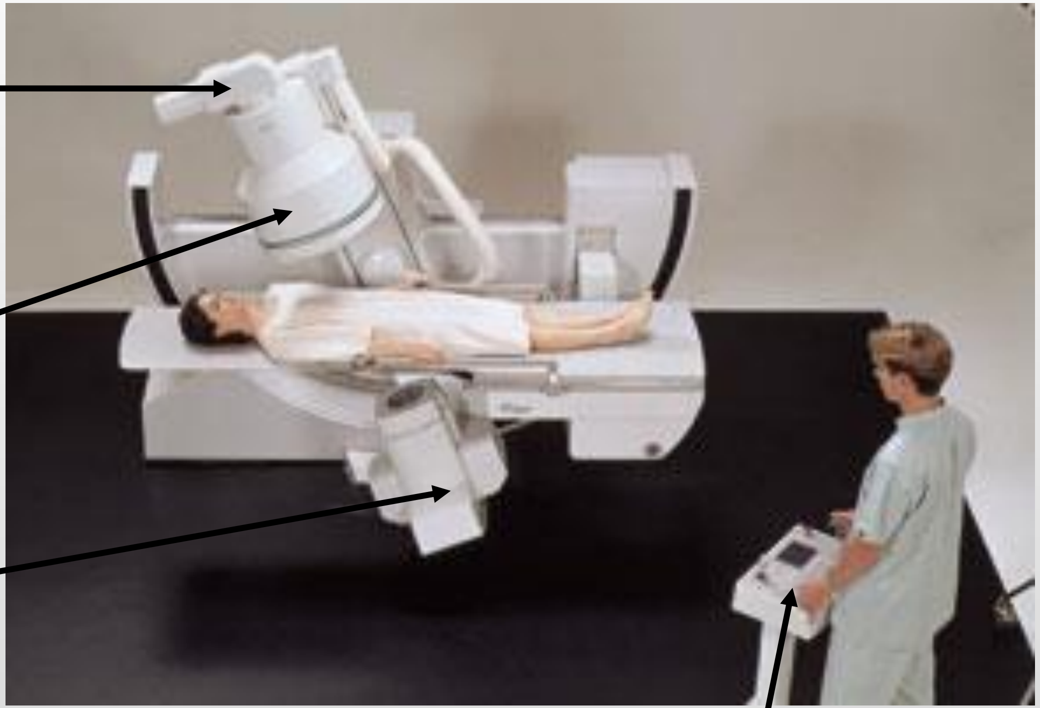
- moving body structures
- A continuous x-ray beam is passed through the body part and is transmitted to a monitor

Fluoroscopy

TV CAMERA
OR
CCD ARRAY
(for digital screening)

IMAGE
INTENSIFIER

X-RAY
TUBE



CONTROLS

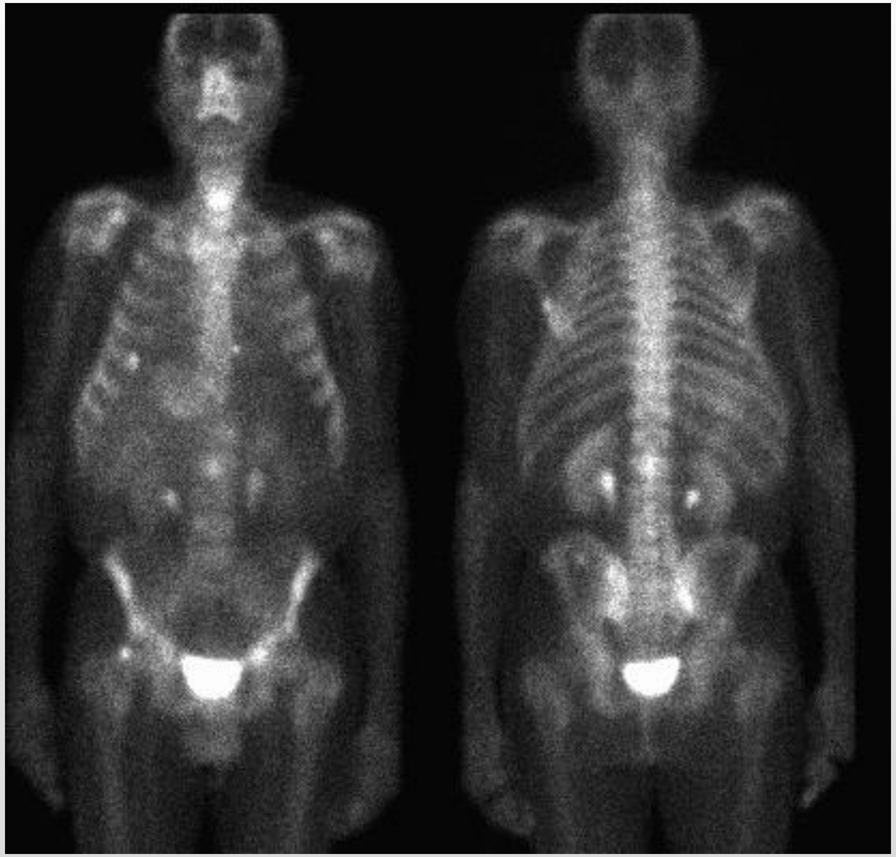
Allows dynamic imaging of blood vessels (angiography) and 'interventional' procedures

Radioisotope Imaging, Nuclear medicine (NM)

- the formation of images provides information about the function of various organs in the body,
- using internally administered radioisotopes as a radiation source.
- locate tumors or cancers and to examine the flow patterns of body fluids.

Gamma camera head

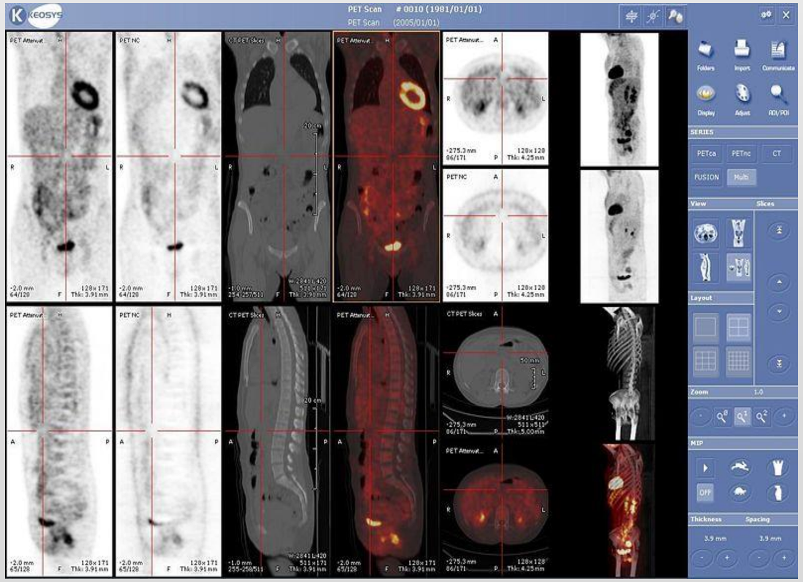
Gamma Camera Scan



Radioisotope Imaging

Positron Emission Tomography (PET)

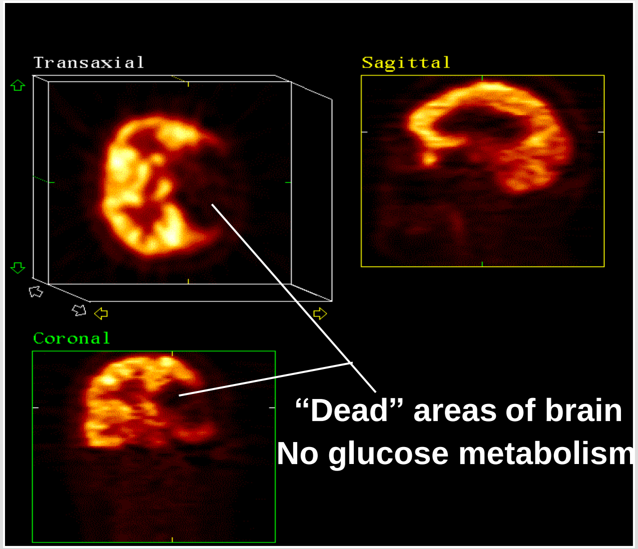
- a nuclear medicine imaging technique
- produces a 3D images of functional processes in the body



Radioisotope Imaging

Single Photon Emission Computed Tomography (SPECT)

- a nuclear medicine tomographic imaging technique using gamma rays
- similar to conventional nuclear medicine planar imaging using a gamma camera.
- Able to provide true 3D information.



Human Brain - Stroke

Ultrasound Imaging (US)

- common diagnostic medical procedure that uses high-frequency sound waves to produce images sonograms) of organs, tissues, or blood flow inside the body.
- involves using a transducer, which sends
    - a stream of high-frequency sound waves into the body
    - and detects their echoes as they bounce off internal structures.
- The sound waves are then converted to electric impulses.

Ultrasound Transducer

Ehsan Adeli, Ph.D. (eadeli@stanford.edu)

Ultrasound Image of 19 Week Old Foetus

3D Ultrasound

Magnetic Resonance Imaging (MRI)

- uses a powerful magnetic field, radio frequency pulses, and a computer
- produce detailed pictures of organs, soft tissues, and all other internal body structures.

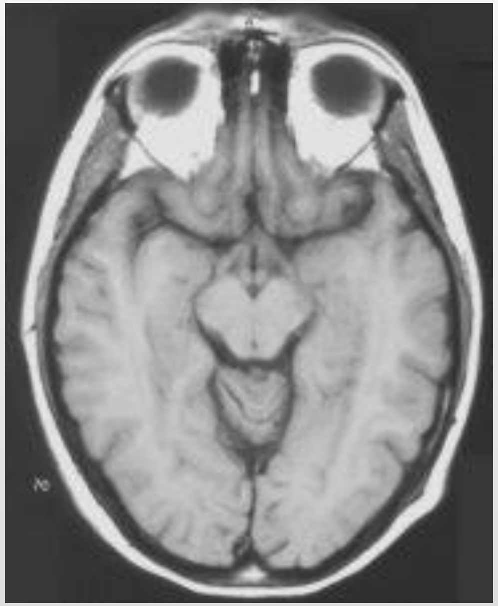
★ Big superconducting magnet (~ 1.5 tesla).

★ Gradient coils.

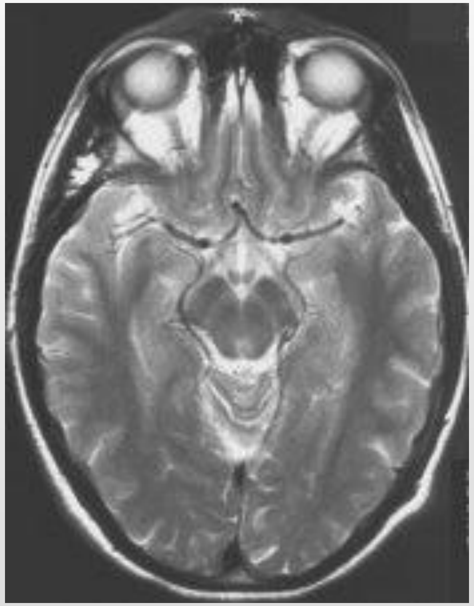
★ Radiofrequency coils.

Magnetic Resonance Imaging (MRI)

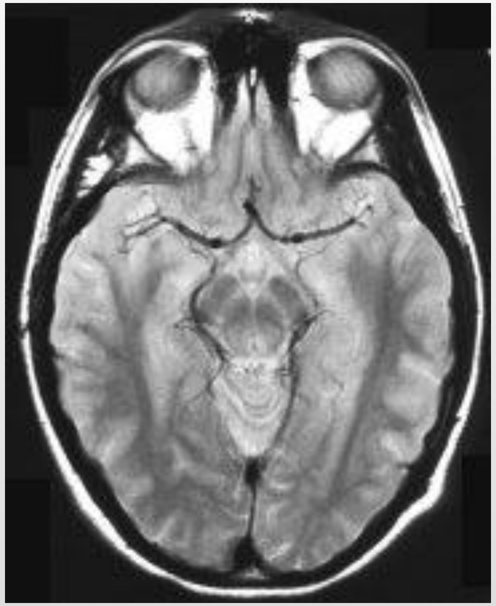
Axial Brain Images



T_1-weighted



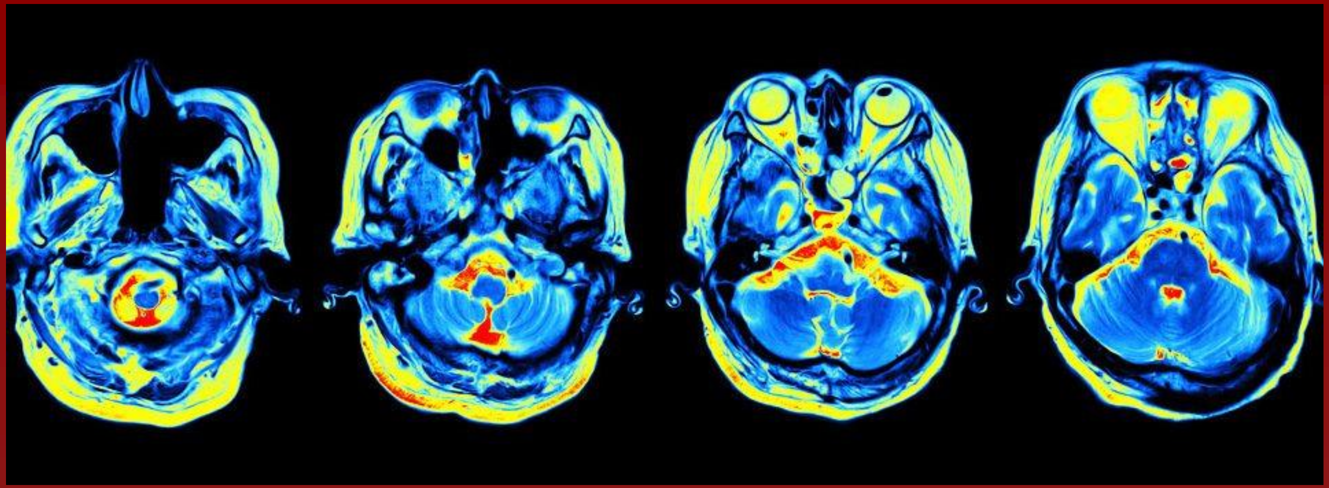
T_2-weighted

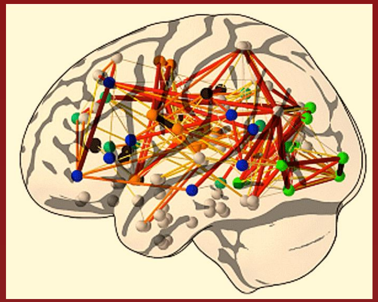


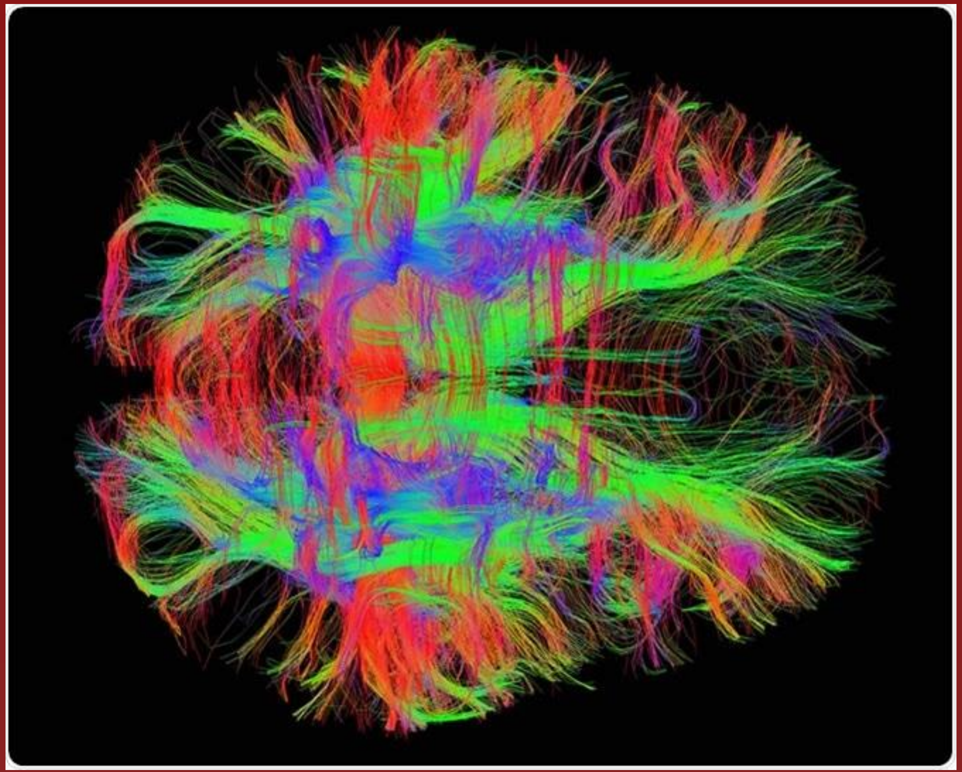
Proton density weighted

Safety

Modality	Radiation Type	Comments
X-ray imaging Radioisotope scanning	Ionising Radiation	Biological effect need protection against unnecessary doses
Ultrasound Imaging MRI	Non-ionising Radiation	Less harmful effects. Better for the foetus.



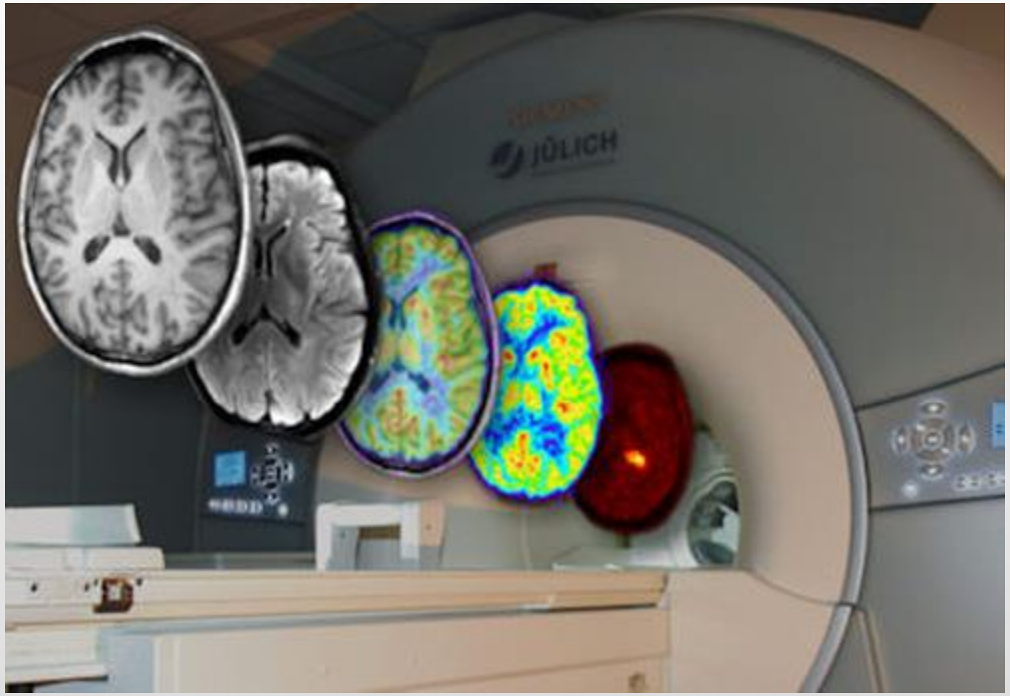




NEUROIMAGING

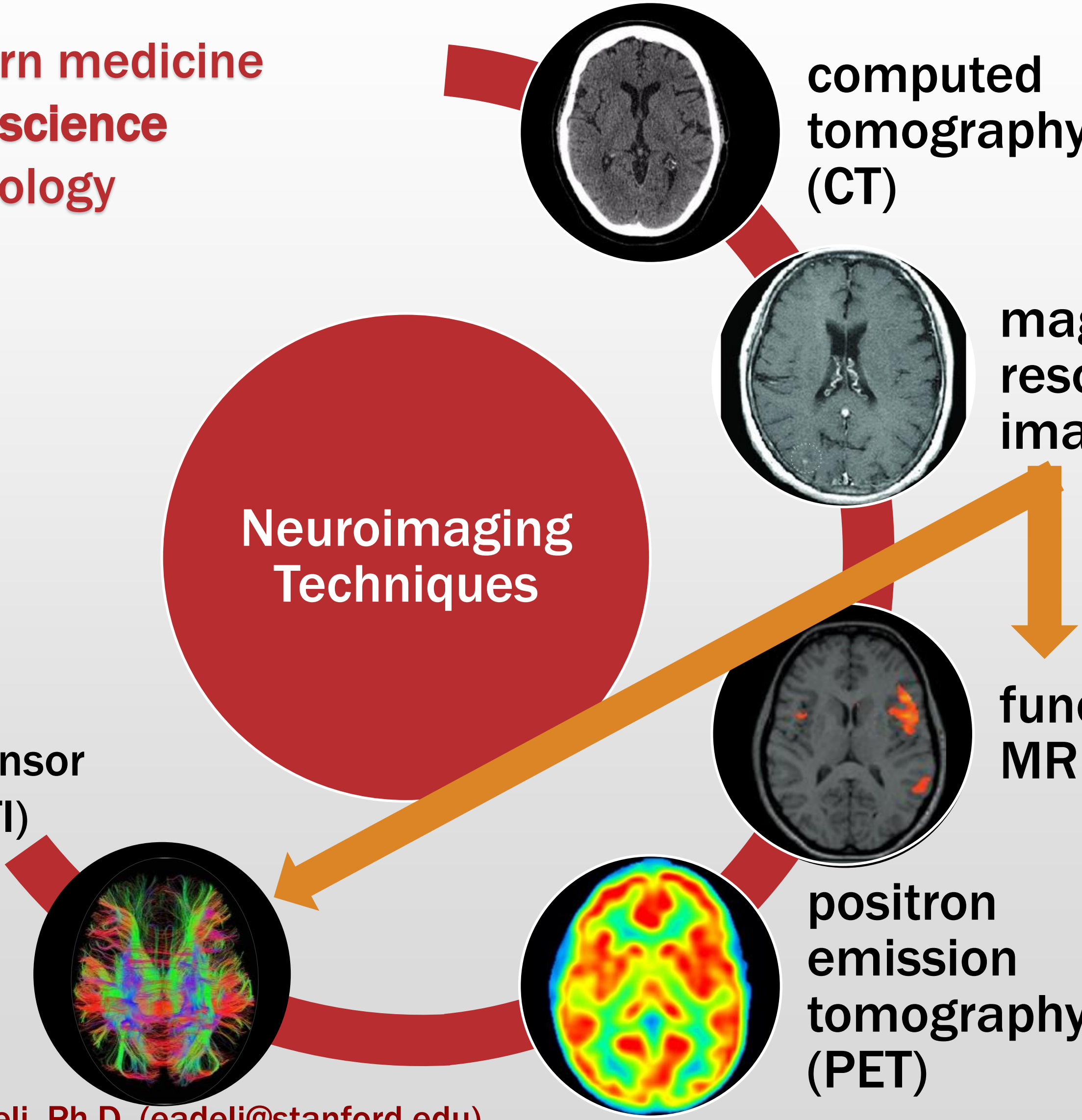
What is considered Neuroimaging?

Neuroimaging, or brain scanning, is a process of producing images of the brain or other parts of the nervous system. Current neuroimaging techniques are typically able to show both the structure and the functions of the brain.



Neuroimaging types/modalities

- modern medicine
- neuroscience
- psychology



computed tomography (CT)

- Series of x-ray images of the head
- **Relatively low resolution**
- Can see **major structural changes**

magnetic resonance imaging (MRI)

- Uses magnetic fields and radiofrequency energy
- **Better spatial resolution**
- Can see more **structural details**

functional MRI (fMRI)

- Uses different responses of oxygenated and unoxygenated blood to detect changes in blood flow
- Shows active regions (**function**)

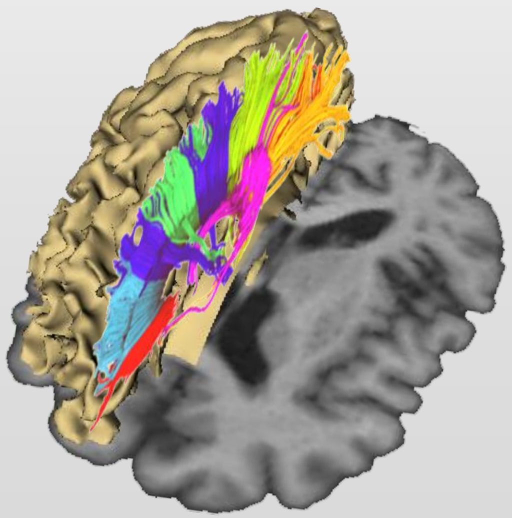
positron emission tomography (PET)

- Gives image of cerebral blood flow
- Shows which areas are most active
- A form of **functional** imaging

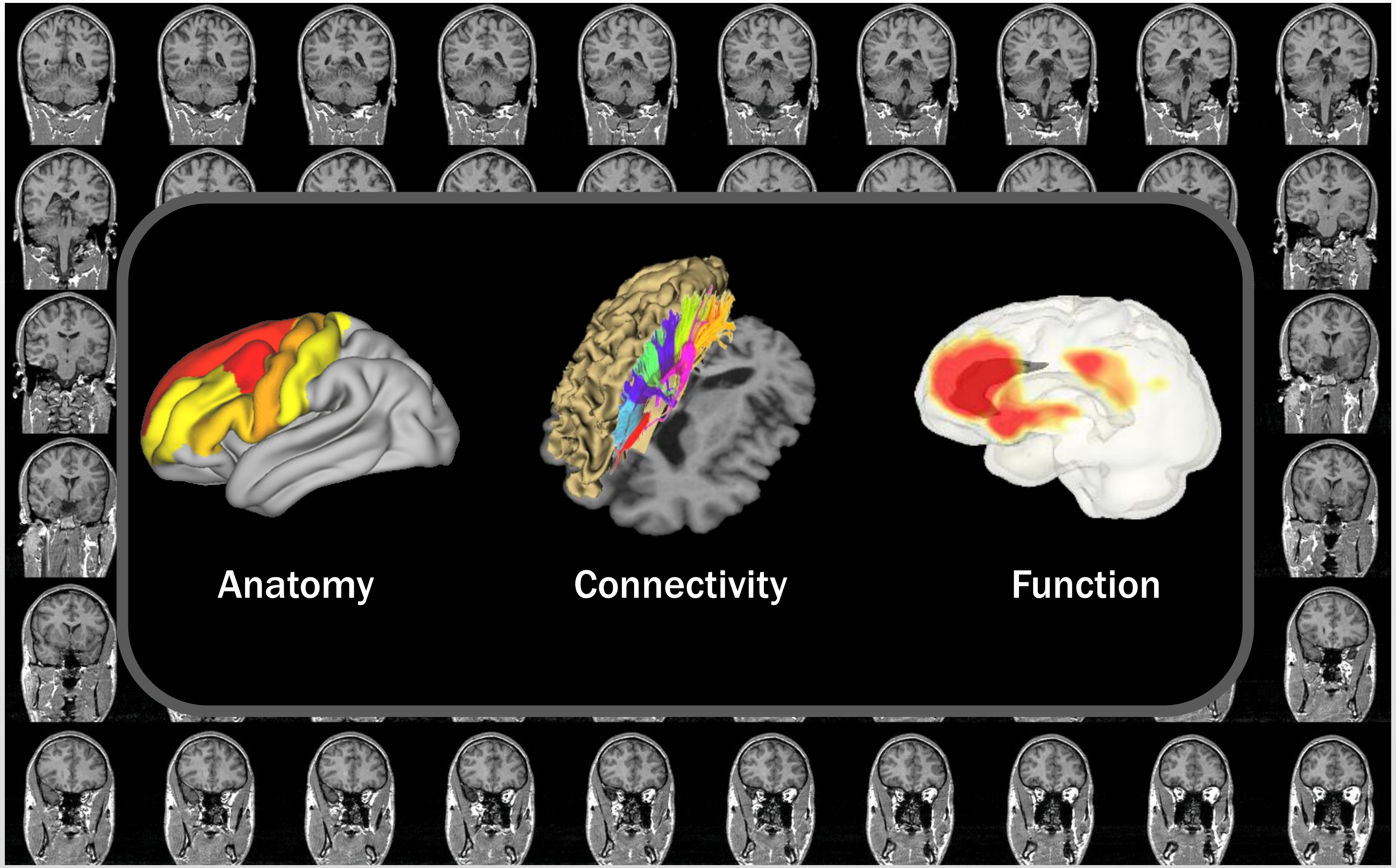
Diffusion Tensor Imaging (DTI)

Goal

Identify biomedical phenotypes
improving the mechanistic understanding,
diagnosis, and treatment
of neuropsychiatric disorders.



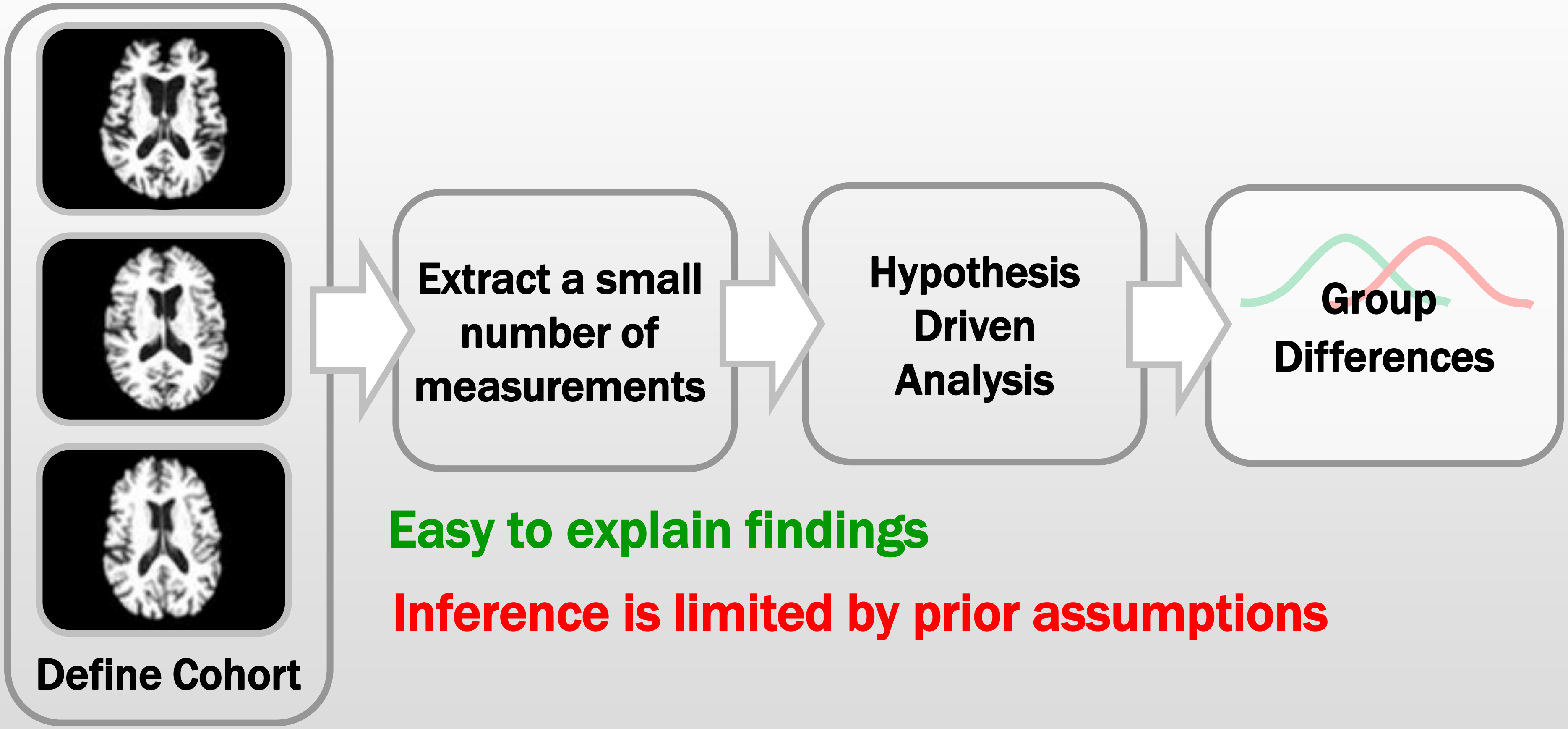
Acquire Brain MRIs



Slide courtesy of Kilian Pohl

Group Analysis: A Neuroscientific View

Zhao et al. Addiction Biology 2020

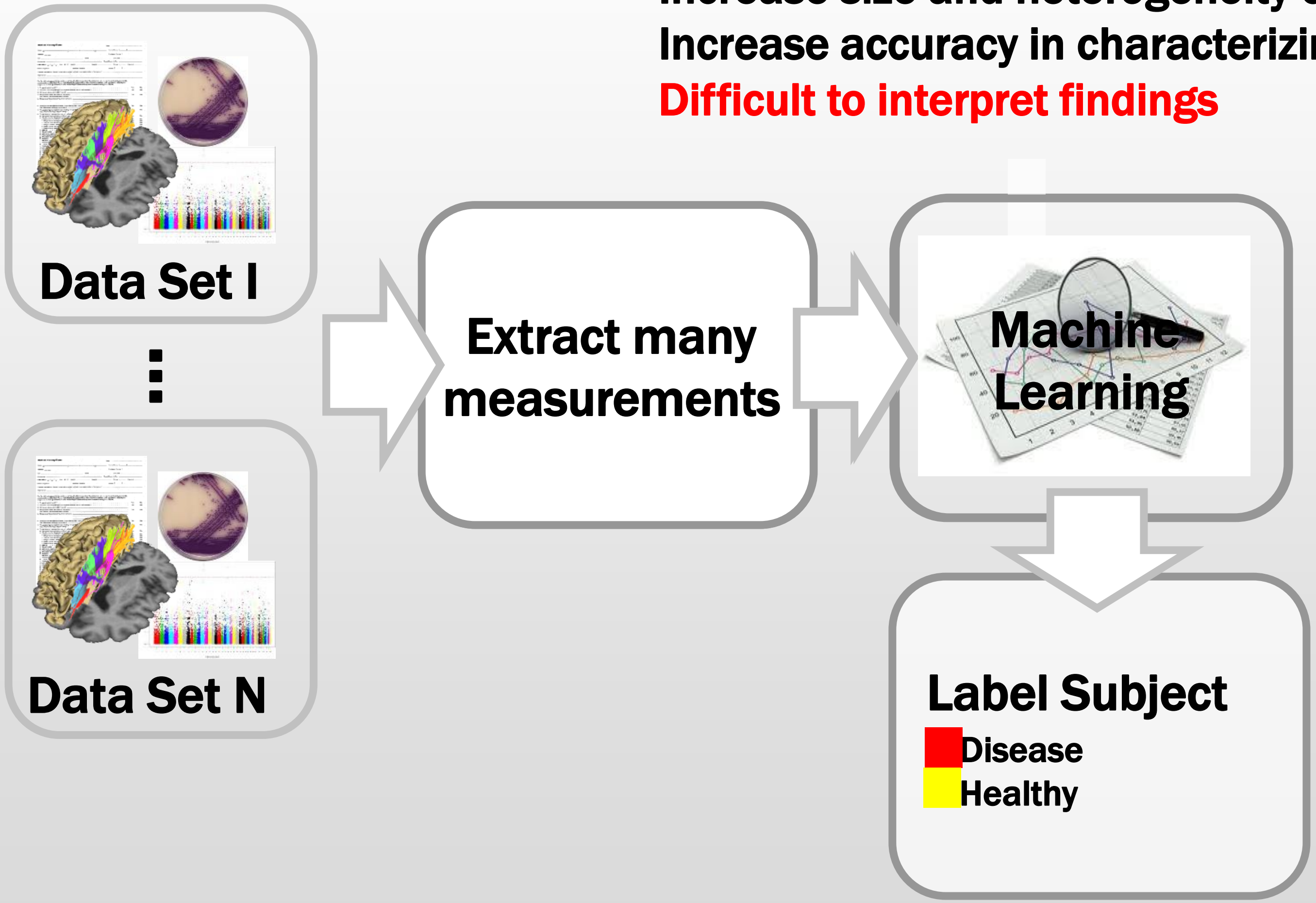


Easy to explain findings

Inference is limited by prior assumptions

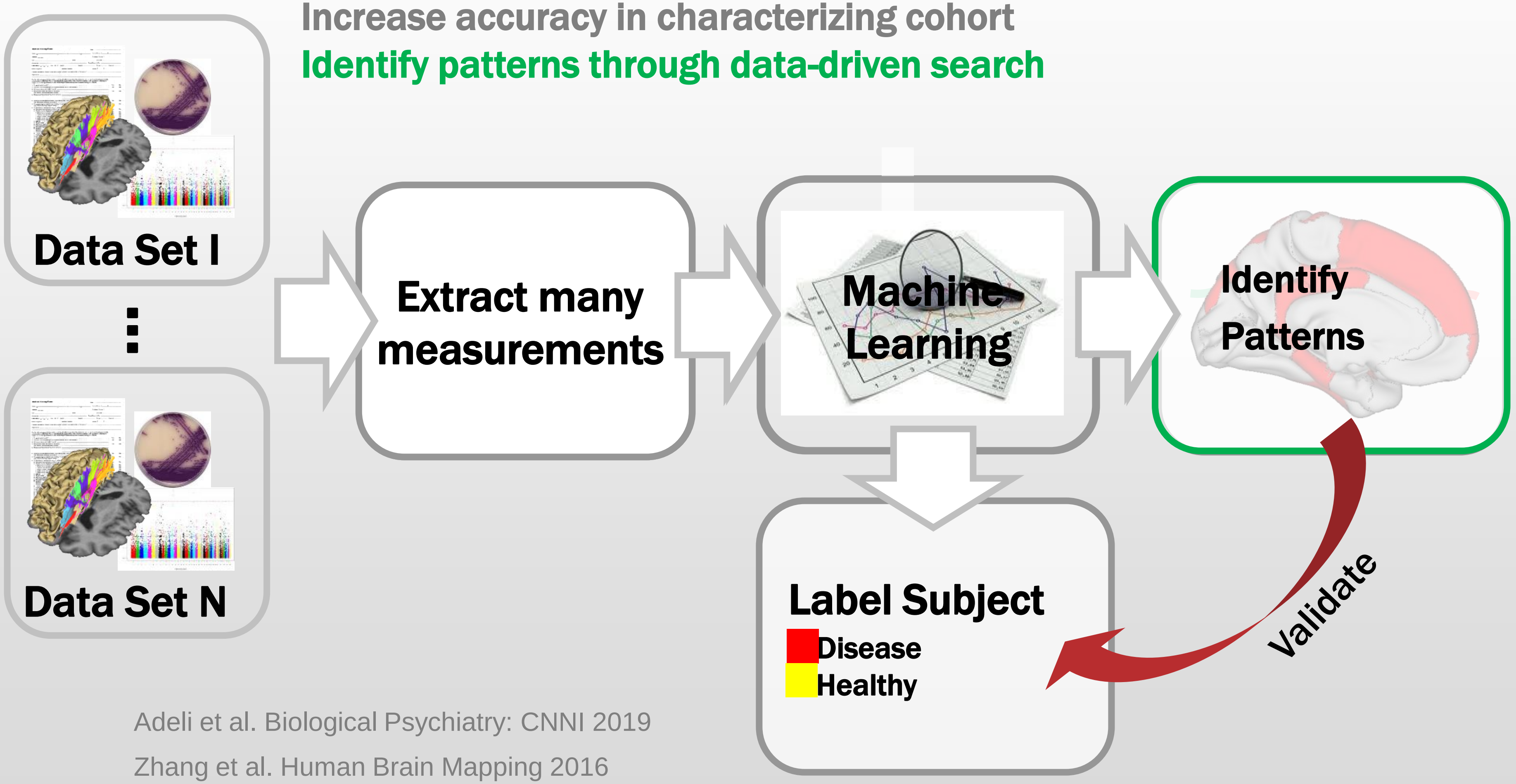
Identifying Disease Specific Markers

Increase size and heterogeneity of data set
Increase accuracy in characterizing cohort
Difficult to interpret findings



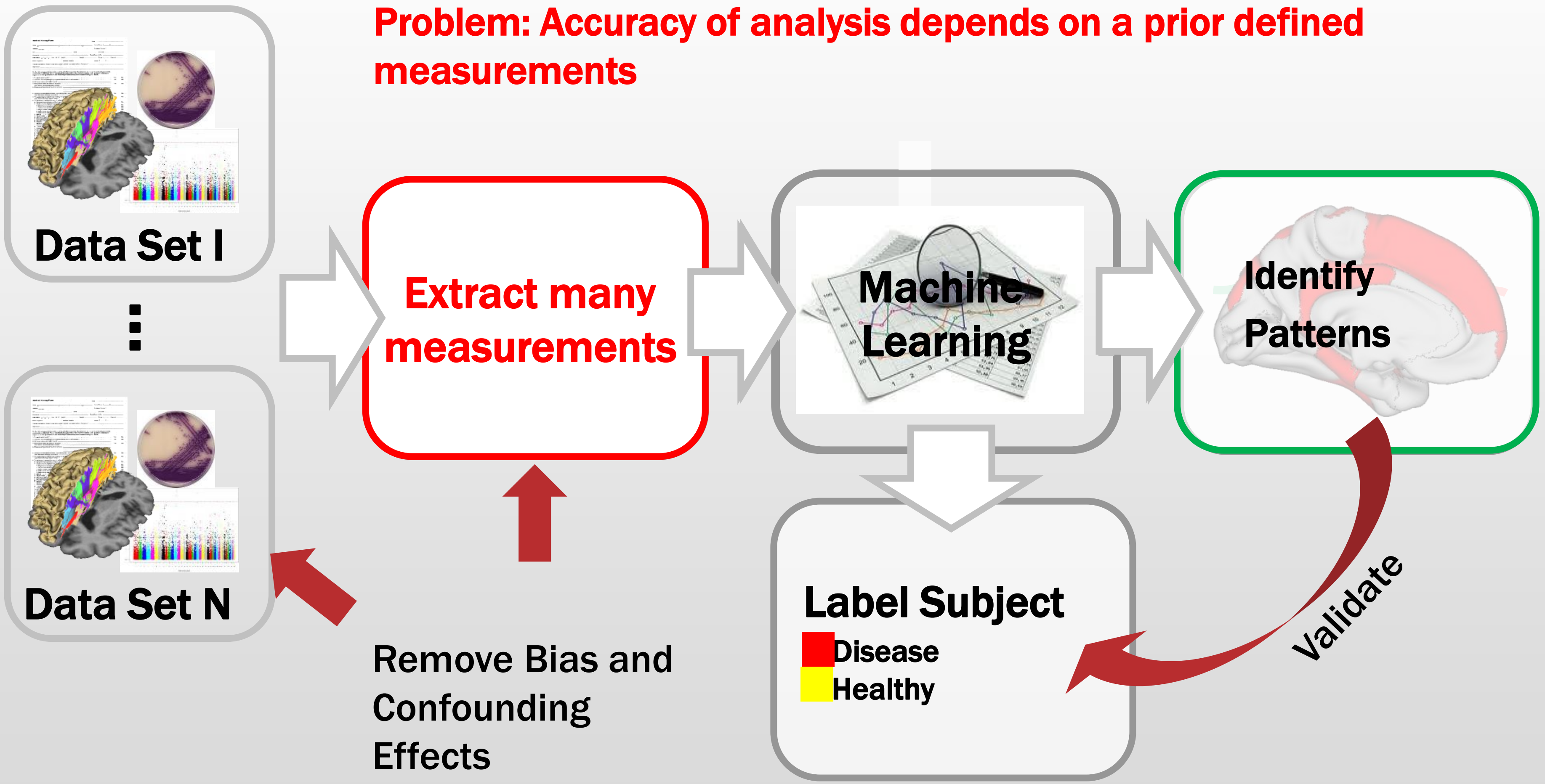
Identifying Disease Specific Markers

Increase size and heterogeneity of data set
Increase accuracy in characterizing cohort
Identify patterns through data-driven search

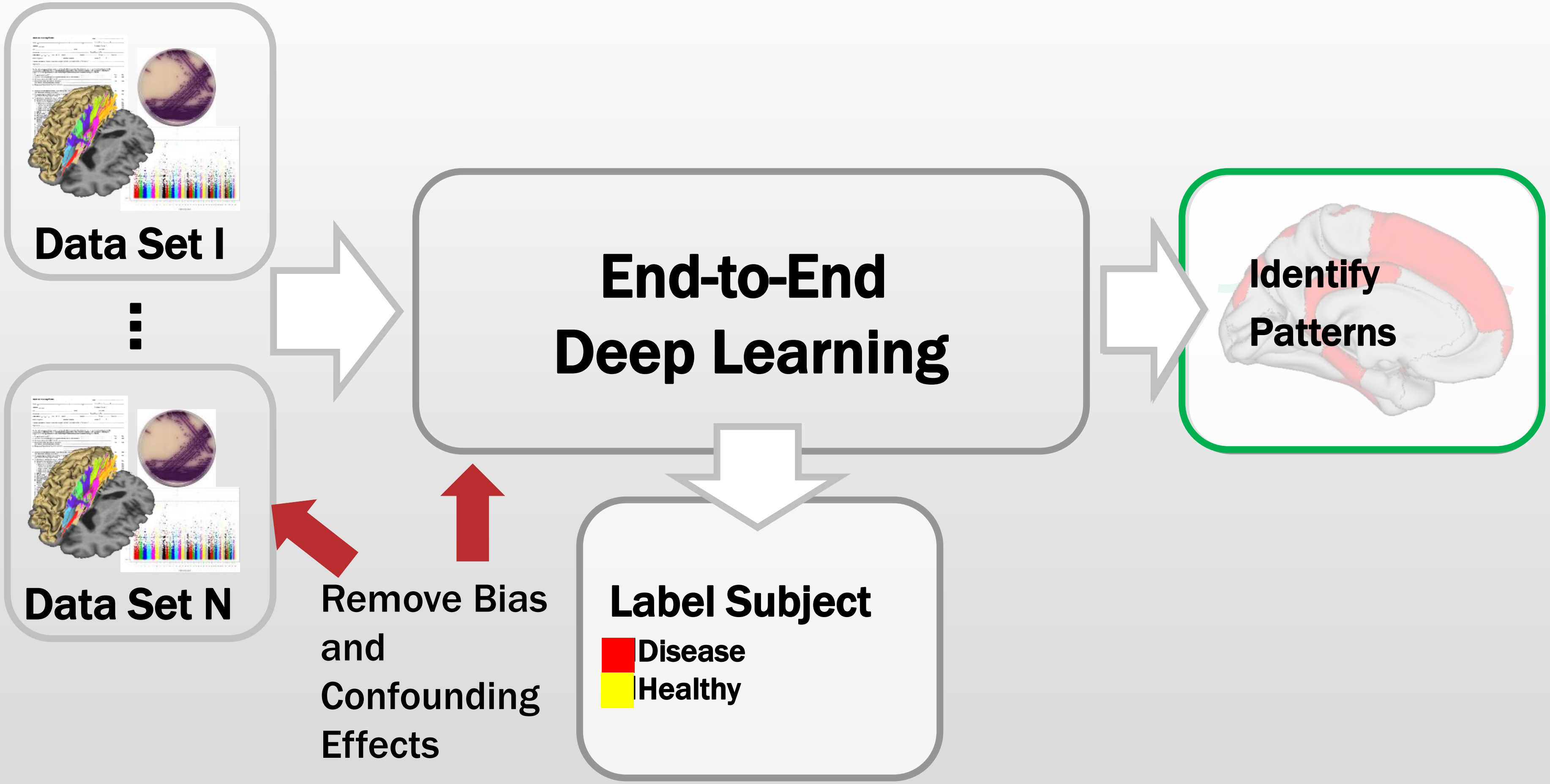


Adeli et al. Biological Psychiatry: CNNI 2019
Zhang et al. Human Brain Mapping 2016

Identifying Disease Specific Markers



Identifying Disease Specific Markers



VIDEO

Rating the motor impairments severity

MDS-UPDRS
Gait Score:

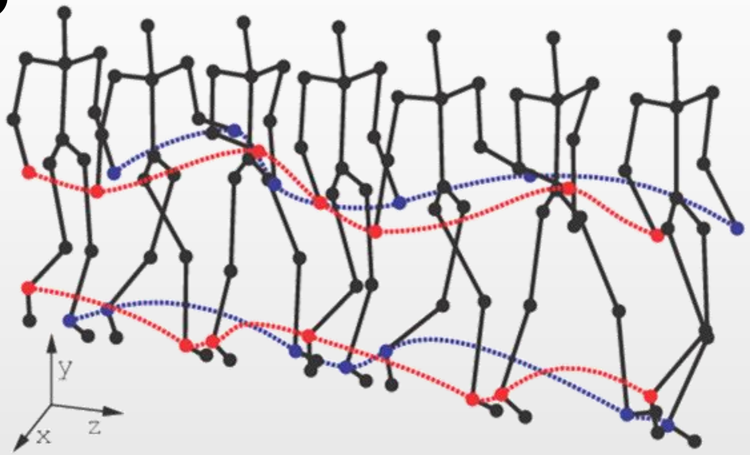
0
1
2
3
4

Movement Disorder Society Unified Parkinson's Disease Rating Scale (MDS-UPDRS) [1]

[1] Goetz et al. Movement disorders 2008

Rating the motor impairments severity

Sequence of 3D skeletons (pose) →



Estimate → MDS-UPDRS Gait Score

(+) Low-dimensionality data
(+) Efficient in required number of samples
(+) Anonymized data

(+) Entirely vision-based method
(+) Non-intrusive video recordings
(+) Scalable

Lu et al., MICCAI 2020

Original Video
Overlayed 3D Mesh/Pose
Side View
Knee Angle Over Time
left knee
right knee
160
140
120
100
80
Angle (deg)
0
50
100
150
200
250
Frame
Foot Contacts
left foot
left toe base
right foot
right toe base
0
50
100
150
200
250
Frame

Endowing healthcare spaces with ambient intelligence

Stanford Partnership in
AI-Assisted Care (PAC)

Hospital spaces

Daily living spaces

Ehsan Adeli, Ph.D. (eadeli@stanford.edu)

Haque et al., Nature 2020, Illuminating the Dark Spaces of Healthcare with Ambient Intelligence
Yeung et al., New England Journal of Medicine 2018, Bedside Computer Vision — Moving Artificial Intelligence from Driver Assistance to Patient Safety
Luo and Hsieh et al., Machine Learning for Healthcare 2018, Computer Vision-based Descriptive Analytics of Seniors' Daily Activities for Long-term Health Monitoring

Hospital

- Intensive Care Unit
- Operating Rooms
- Patient Rooms
- Administrative Space

Daily Living Spaces

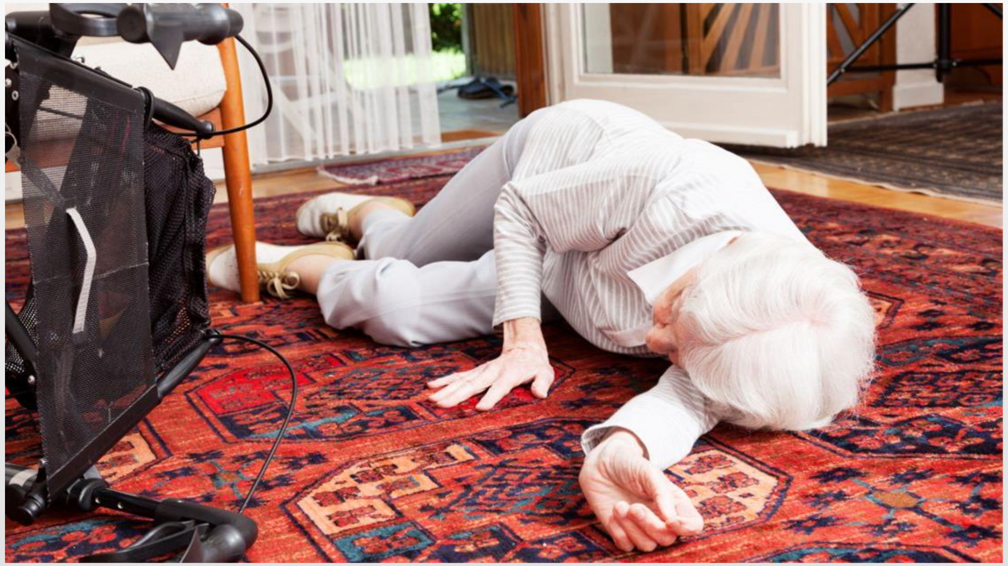
- Senior Care
- Chronic Disease Management
- Mental Health
- Homes

Recognizing Activities in Videos from Contactless Sensors using Computer Vision Technology

Alan Luo

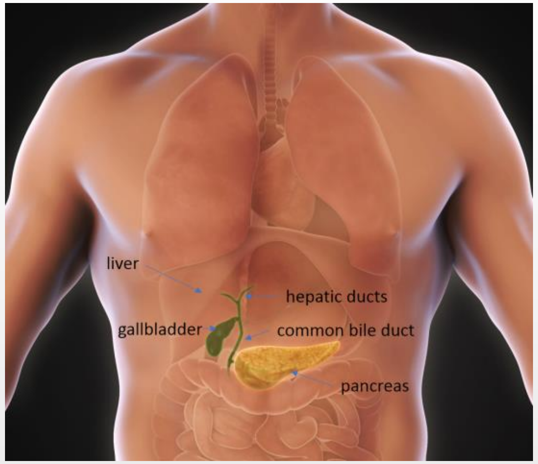
Intervene to improve care and reduce costs

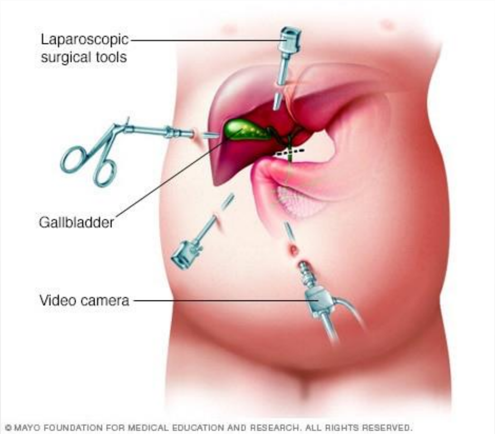
Early mobilization



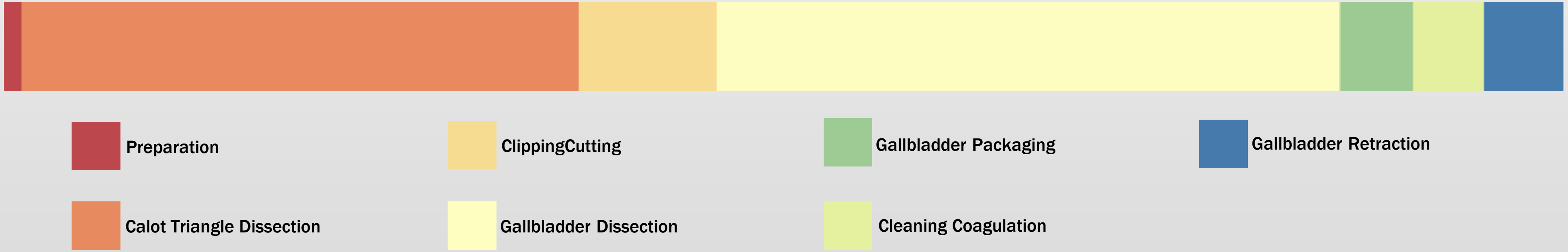
Fall detection

Surgical Phase Recognition - Cholecystectomy





Surgical Workflow

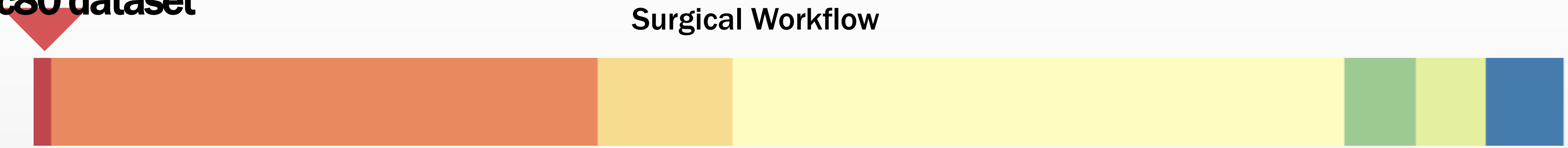


Tobias, et al. "Opera: Attention-regularized transformers for surgical phase recognition." *MICCAI* 2021.

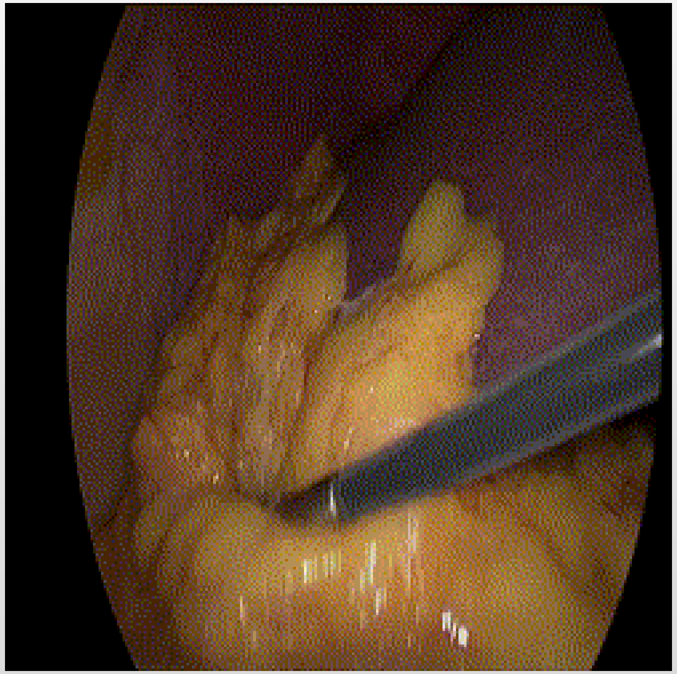
Slides Courtesy of Tobias Czempiel, Magda Paschali

Surgical Phase Recognition - Cholecystectomy

Cholec80 dataset



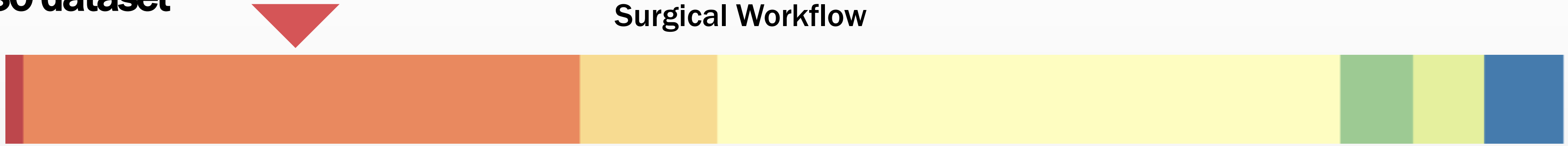
- Preparation
- Calot Triangle Dissection
- ClippingCutting
- Gallbladder Dissection
- Gallbladder Packaging
- Cleaning Coagulation
- Gallbladder Retraction



Surgical Phase Recognition - Cholecystectomy

Cholec80 dataset

Surgical Workflow



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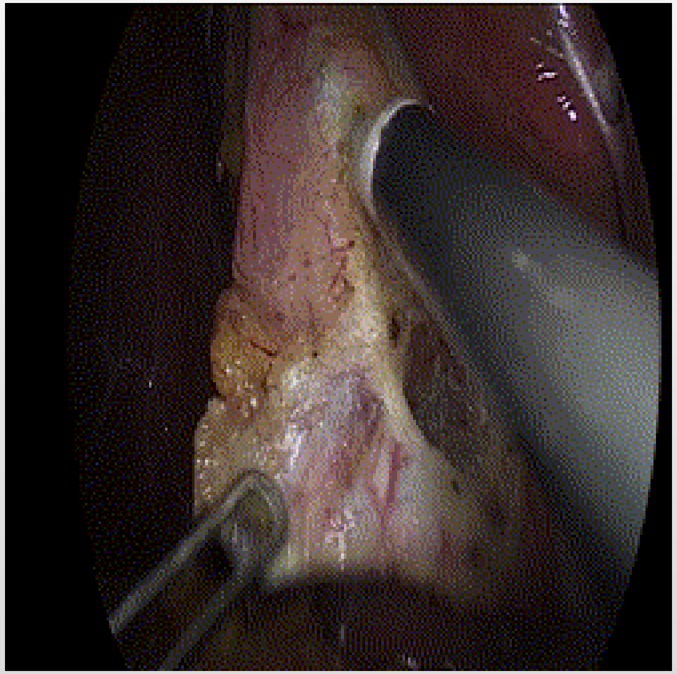

Surgical Phase Recognition - Cholecystectomy

Cholec80 dataset

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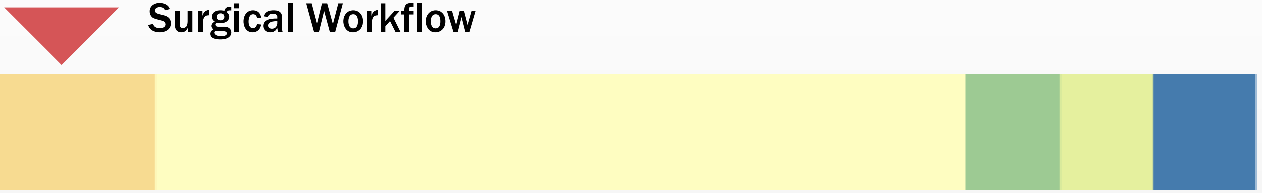

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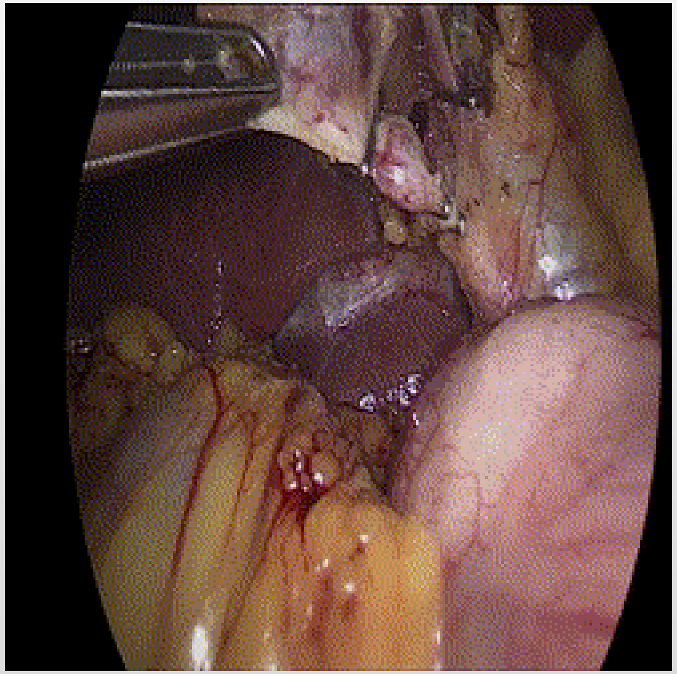

Surgical Phase Recognition - Cholecystectomy

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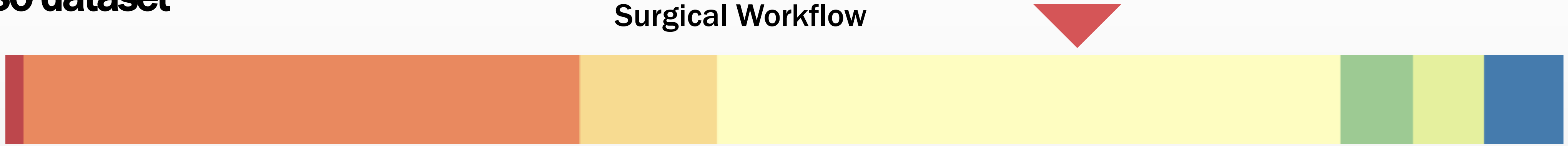

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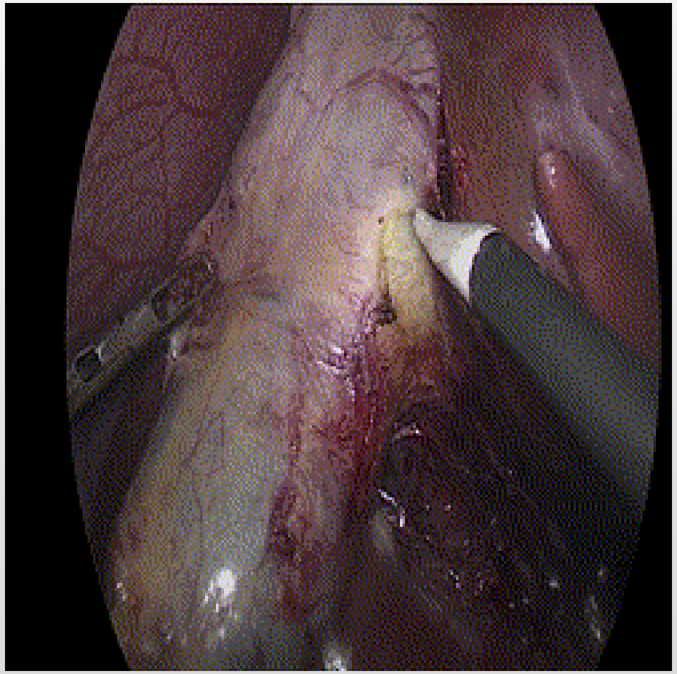

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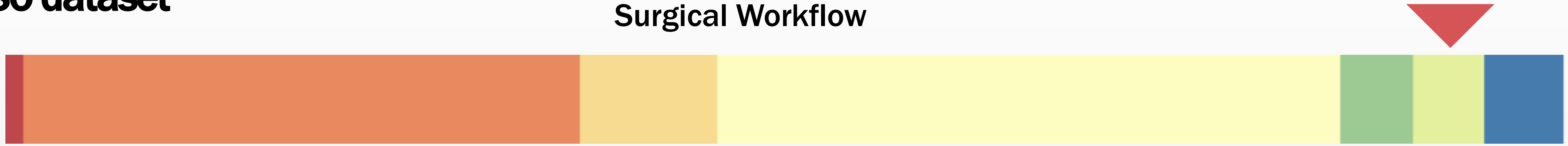

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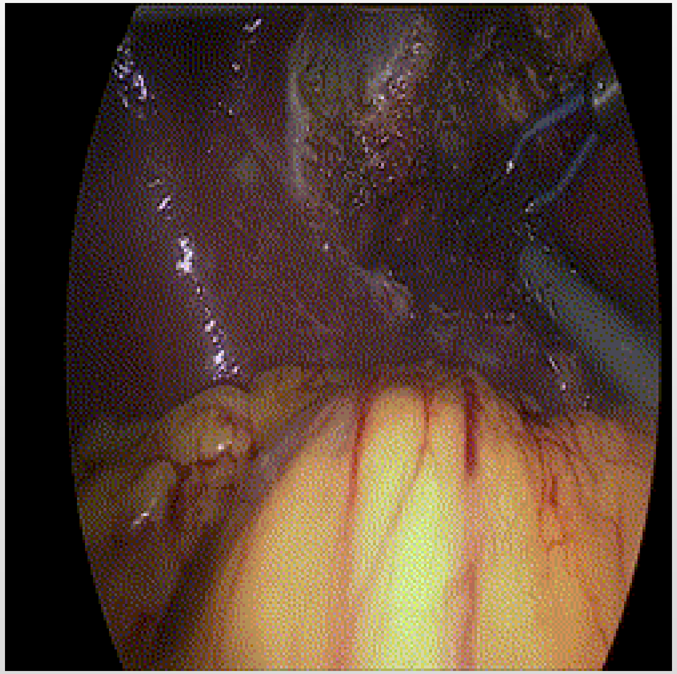

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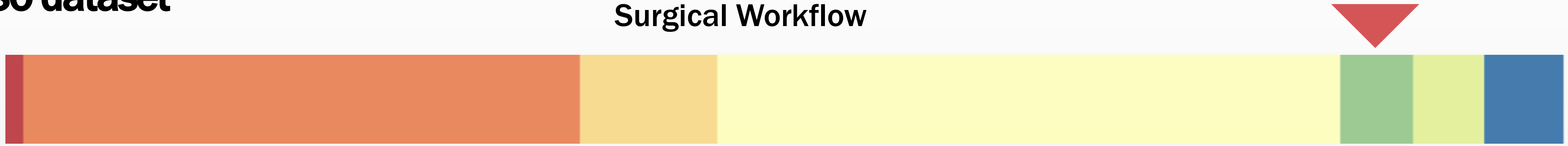

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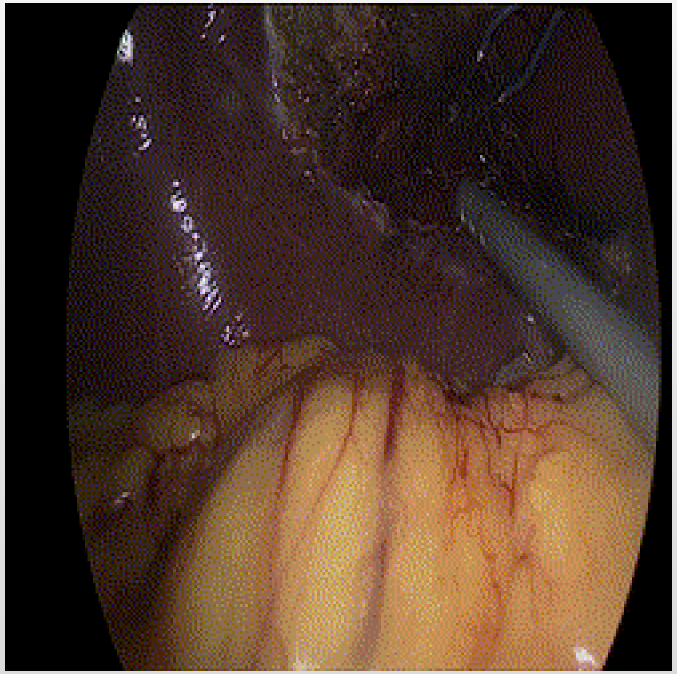

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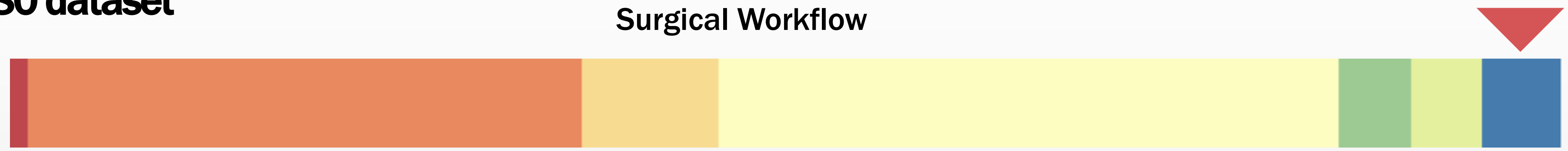
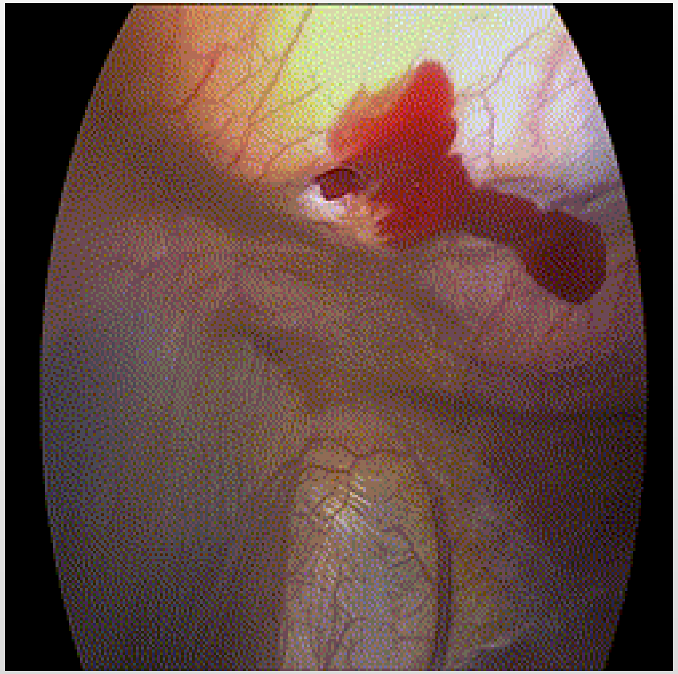
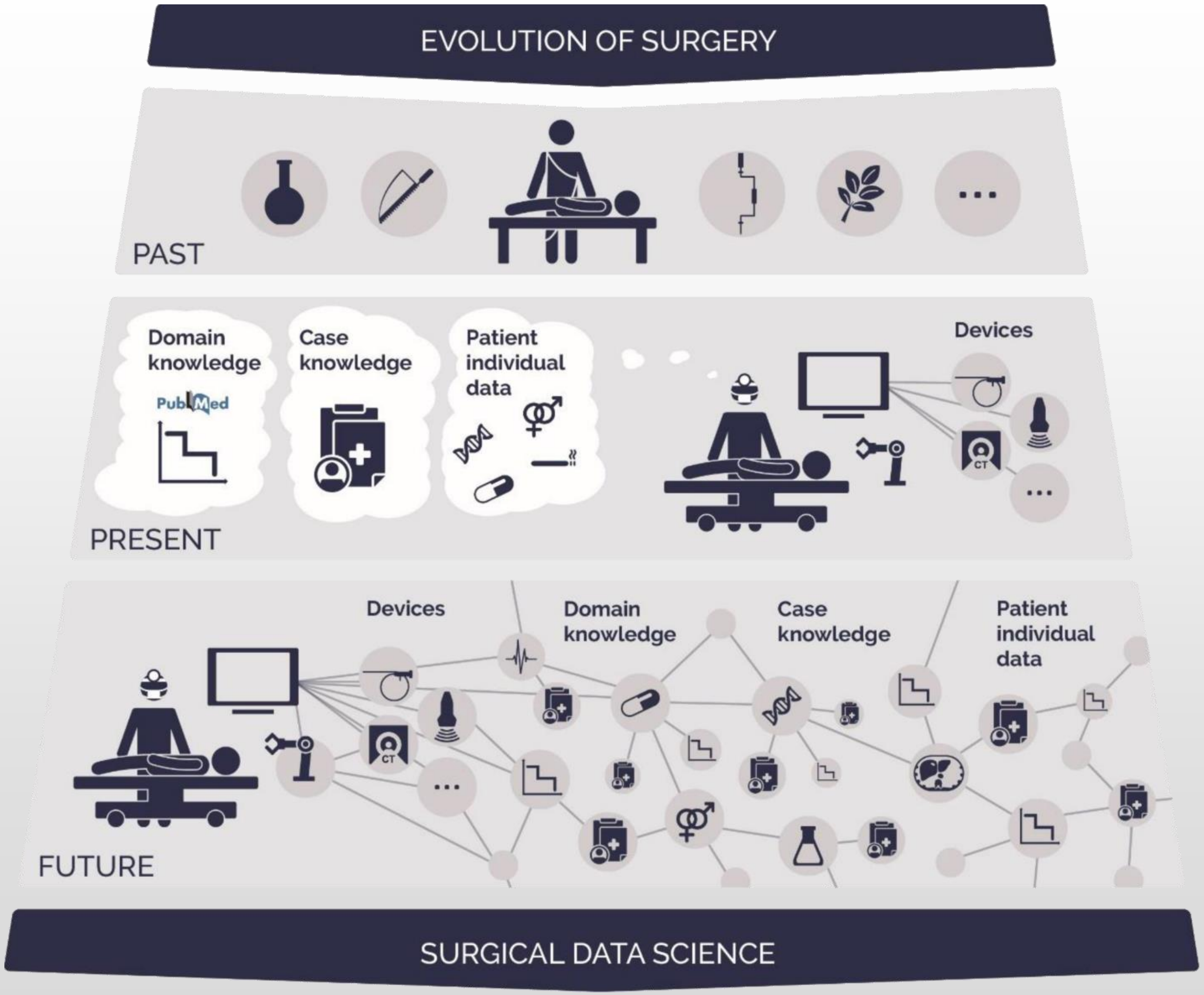




Potentials & Challenges

+ Early warnings when deviating from surgical plan
+ Context aware systems
+ Automatic archiving, surgical protocol

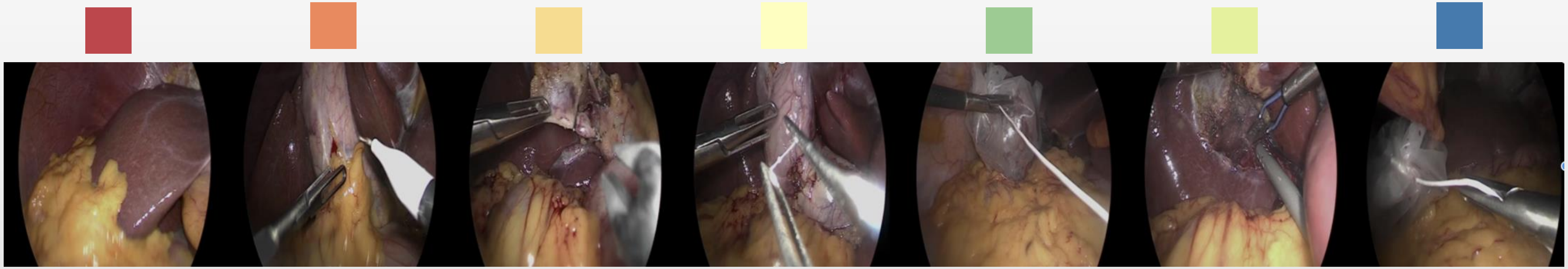


Maier-Hein, L., Vedula, S. S., Speidel, S., Navab, N., Kikinis, R., Park, A., Eisenmann, M., Feussner, H., Forestier, G., Giannarou, S., Hashizume, M., Katic, D., Kenngott, H., Kranzfelder, M., Malpani, A., März, K., Neumuth, T., Padoy, N., Pugh, C., … Jannin, P. (2017). Surgical data science for next-generation interventions. Nature Biomedical Engineering, 1(9), 691–696. https://doi.org/10.1038/s41551-017-0132-7

Potentials & Challenges

+ Early warnings when deviating from surgical plan
+ Context aware systems
+ Automatic archiving, surgical protocol

- Variability of patient anatomy and surgeon style
- Limited available training data
- Strong similarities among different phases



Descriptive

Generic

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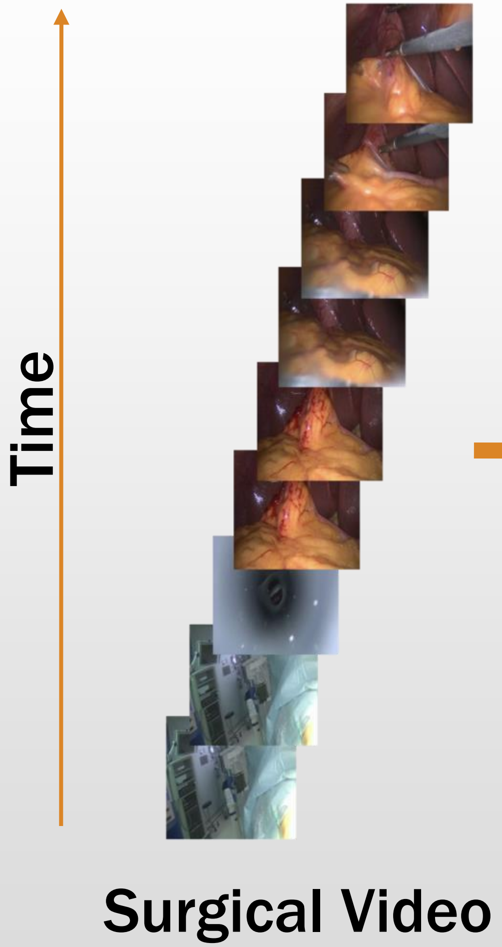
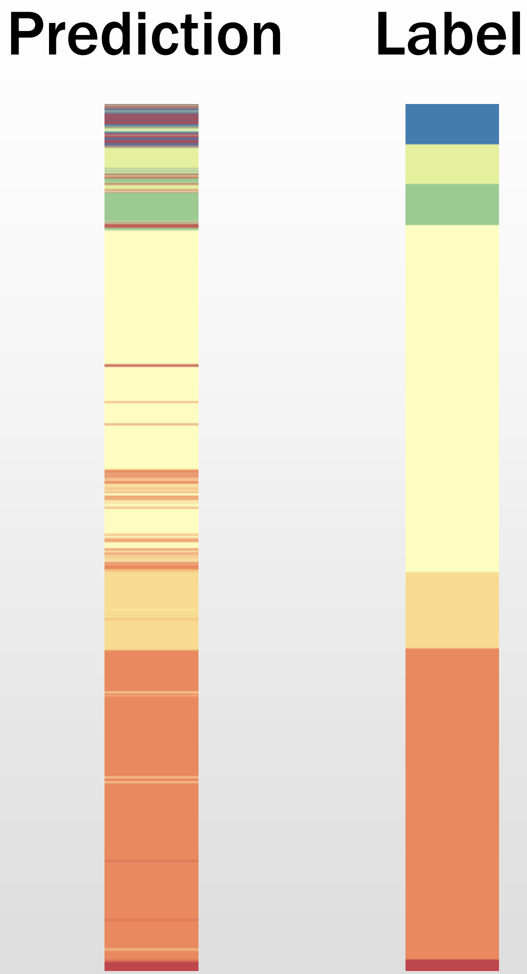
Slides Courtesy of Tobias Czempiel, Magda Paschali

Methods



2D/3D CNN, ResNet
RNN
Transformers



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3D reconstruction of cystoscopy videos for comprehensive bladder records

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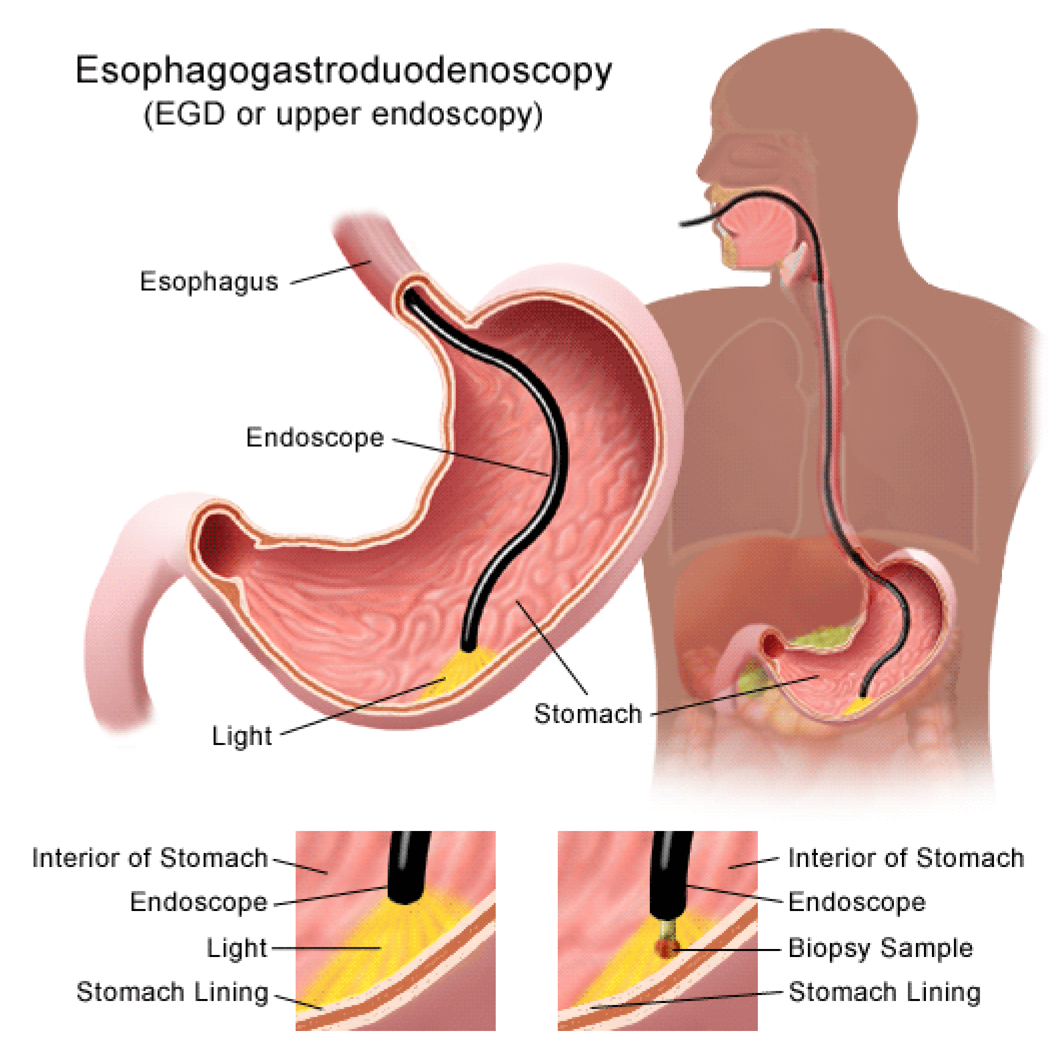
Endoscopy Videos

- Endoscopy and its organ-specific derivatives (e.g., laparoscopy, colonoscopy, cystoscopy) play a powerful role in **diagnostic imaging**, **surgical guidance**, and **cancer surveillance**.
- Rich information in endoscopy videos
- Cumbersome nature of post-session video review
- Results in condensing lengthy video data into a few still images and brief notes or drawings about the locations and appearance of suspicious lesions and scars.



Motivation

- The availability of complete organ reconstructions for other medical imaging modalities has been of powerful effect, leading to clinical advances in areas such as intraveneous injection, sleep apenea evaluation, and cervical and gastric cancer
- a comprehensive representation of the endoscopy data that enables straightforward and rapid review of a single endoscopy session or comparisons across several could better support the clinical decision-making process and enable new directions for cancer research.

Framework

- Develop comprehensive representations of cystoscopies, an important and clinically significant application,
- bladder cancer has the highest recurrence rate of all cancers and demands at least annual surveillance through cystoscopy to monitor recurrence (most expensive cancer to treat in patient's lifetime).
- Three-dimensional reconstructions that can capture both the 3D organ shape and appearance can enable depiction of full organs and localization of individual regions to anatomical locations in the organ.

Challenges

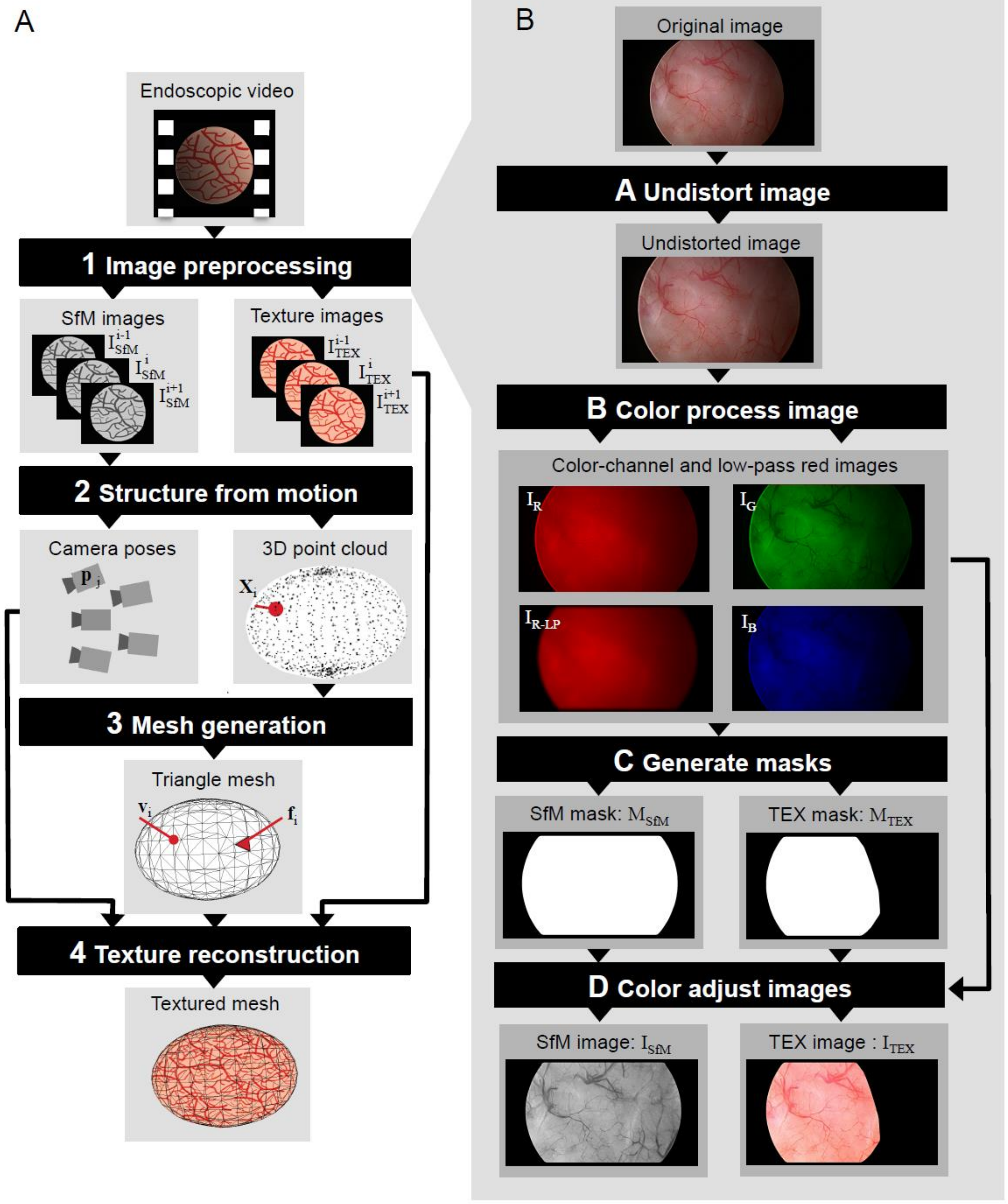
1. The shape of the bladder is not known a priori; further, the bladder may change shape depending on its level of distension between imaging sessions.
2. While the shape of the bladder is important for orienting the physician, the surface appearance will be more carefully scrutinized by the physician than the exact shape.
3. The endoscopic light source is part of the endoscope, which means the surface illumination is constantly changing.
4. Finally, a cystoscopic video has a duration of several minutes and covers a large surface area relative to the area viewed in a single frame. As a result, a feature does not remain in the field of view for a large percentage of the video, which is problematic given that the key to reconstruction is efficiently detecting when a feature re-enters the field of view in order to reconstruct an accurate model.

This paper

- First method for dense 3D reconstruction of the bladder from white light cystoscopy (WLC) videos that uses standard clinical hardware and introduces only a minor modification to the standard clinical scan pattern.
- The four challenges are resolved by
  - (1) not utilizing any ground truth data to reconstruct the bladder surface,
  - (2) presenting a complete pipeline to convert the cystoscopic images into a 3D textured model of the bladder,
  - (3) developing an image preprocessing technique to remove lighting artifacts and thus strengthen feature matching, and
  - (4) utilizing a structure-from-motion algorithm that efficiently can detect loops.

Overview of the four-step 3D reconstruction algorithm

- SfM: Structure from motion
- TEX: texture reconstruction



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Reconstruction of tissue-mimicking phantom datasets

- Top row (blue background): original semi-cylinder phantom; bottom row (orange background): modified semi-cylinder phantom.

A. Standard digital camera images of the phantoms highlighting their shaped are compared with the

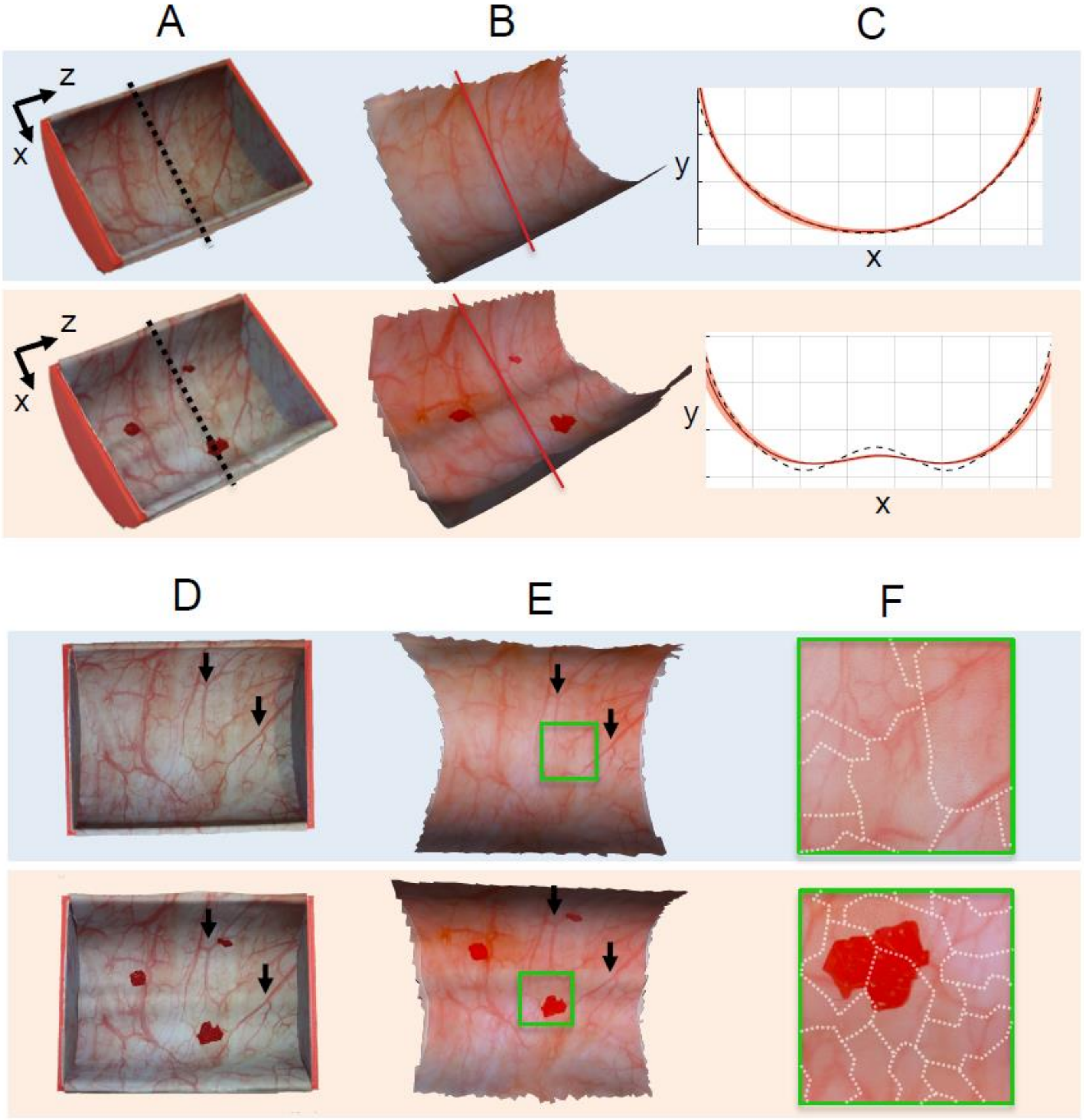
B. reconstructed mesh.

C. Cross-sections of the expected mesh (dotted black line) and average reconstructed cross section (red) are compared.

D. Standard digital camera images of the phantoms highlighting their surface appearance

E. the reconstructed textured phantoms viewed from approximately the same camera angles. Black arrows are added to highlight similar features between the original and reconstructed images. Green boxes indicate regions of texture shown in greater detail in F

F. emphasize the seamlessness between regions composed of different images. The dotted white lines in (F) indicate boundaries between mesh faces that are composed of different original images.



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Reconstruction of clinical datasets

A. a representative, original WLC image,

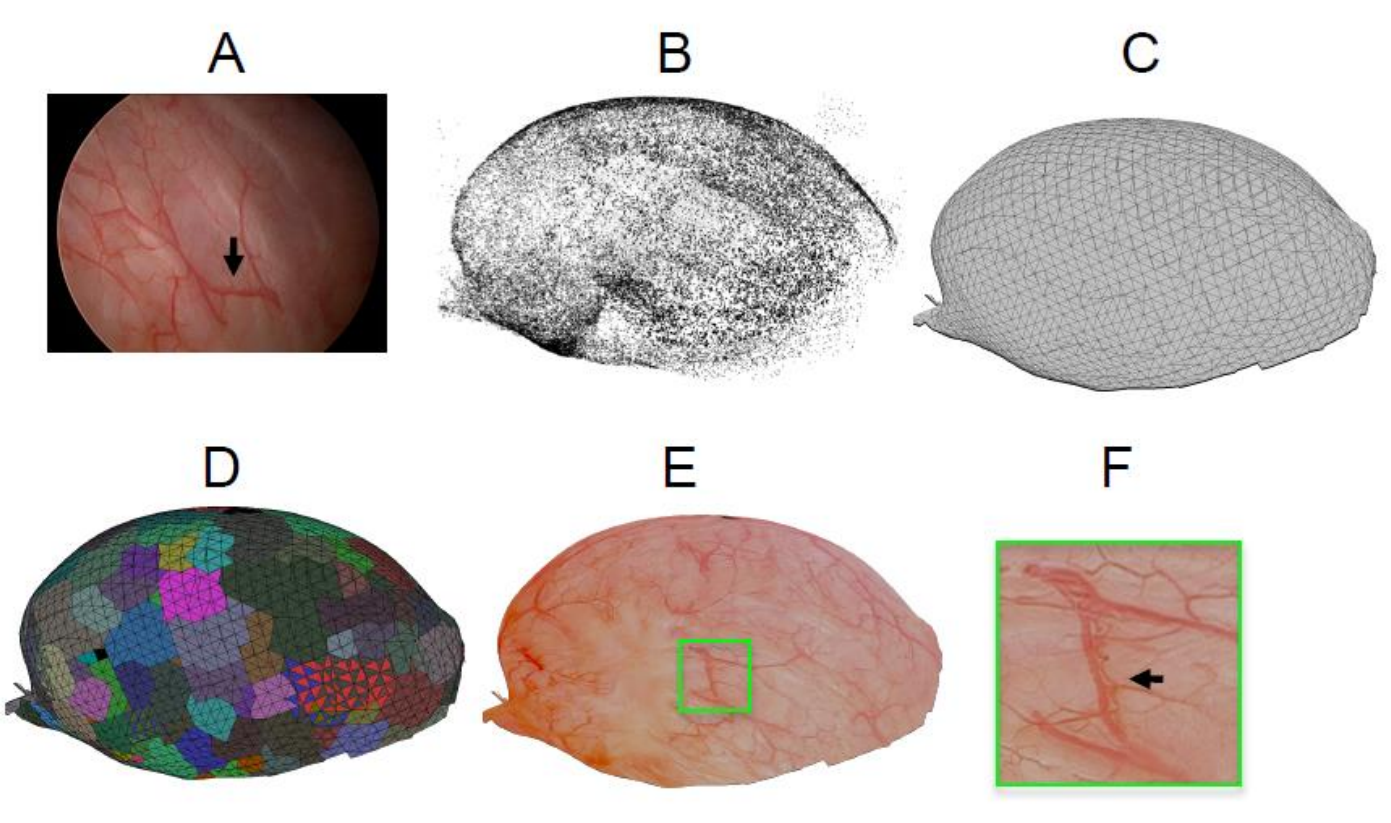
B. point cloud from the structure-from-motion step before outlier removal,

C. mesh from the mesh-generation step,

D. labeled texture (faces with the same color are labeled with the same input image)

E. textured mesh from texture-generation steps. The green box shows a similar region between subfigures indicating clear continuity of vessels despite the use of multiple input images to construct this region. The green box is approximately the size of a single WLC image.

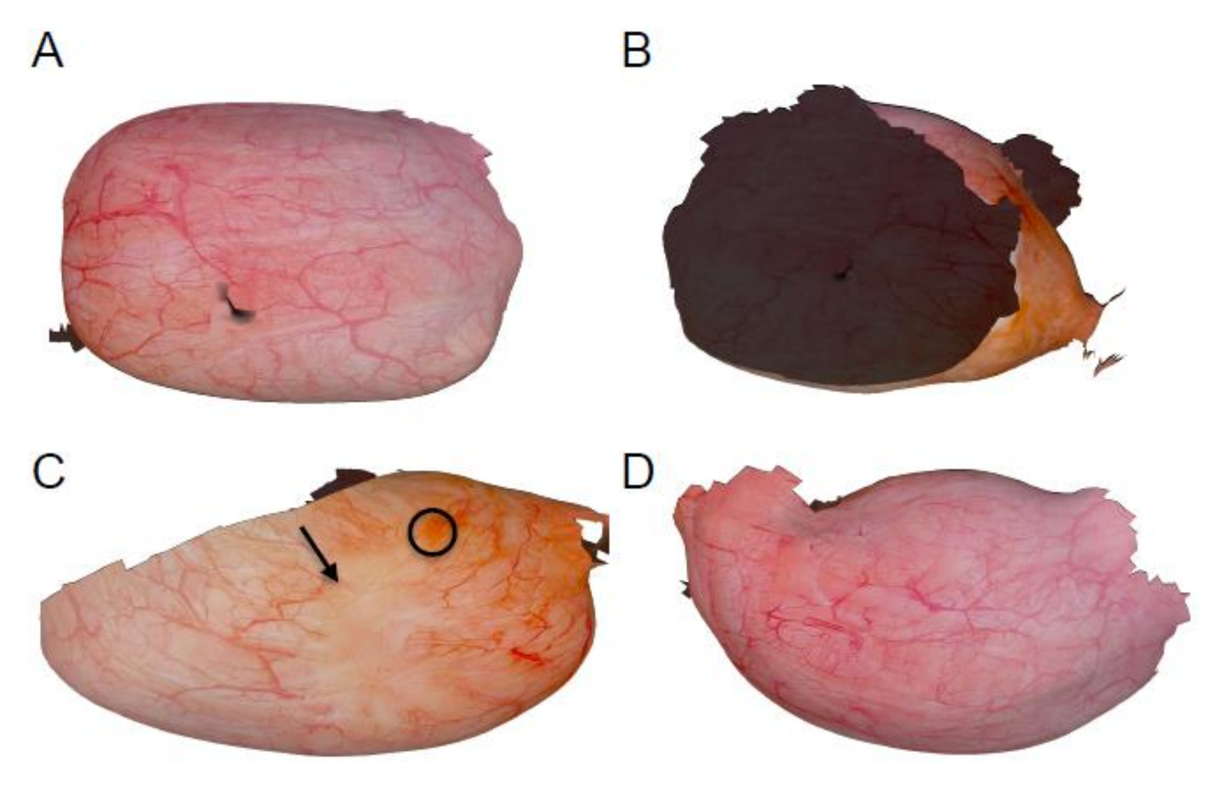
Black arrows in (A) and (F) indicate similar regions of the bladder.



Reconstruction of clinical datasets

A. anterior,
B. posterior,
C. left lateral,
D. right lateral walls

Black circle and arrow in (C) show regions of a papillary tumor and scarring, respectively. Regions that appear dark represent the interior of the bladder.



Conclusion

- The proposed algorithm can serve as the foundation for surgical planning, quality assessment of the procedure, optical annotation, and integration with other optical technologies.
- A longitudinal record of the bladder appearance can enable new quantitative studies of the time-varying appearance in the bladder wall (for example, to predict the location of early tumors or to stratify patient outcomes).
- The reconstructions presented in this work are based on rigid cystoscopies, but the proposed method is extendable to flexible cystoscopes.
- Importantly, the shape-agnostic nature of the algorithm may make it extendable to reconstructions of other organs using their respective endoscopy derivatives.

Thank You!

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Questions?