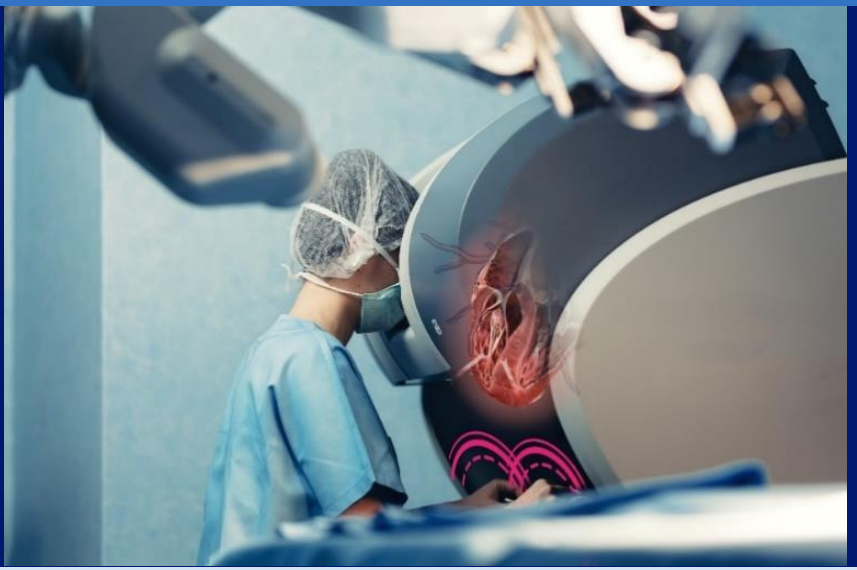
Computer- and robot-assisted Surgery
Introduction



NCT
NATIONALES CENTRUM
FÜR TUMORERKRANKUNGEN
PARTNERSTANDORT DRESDEN
UNIVERSITÄTS KREBSCENTRUM UCC

getragen von:
Deutsches Krebsforschungszentrum
Universitätsklinikum Carl Gustav Carus Dresden
Medizinische Fakultät Carl Gustav Carus, TU Dresden
Helmholtz-Zentrum Dresden-Rossendorf

Stefanie Speidel

Translational Surgical Oncology

Lecture Team

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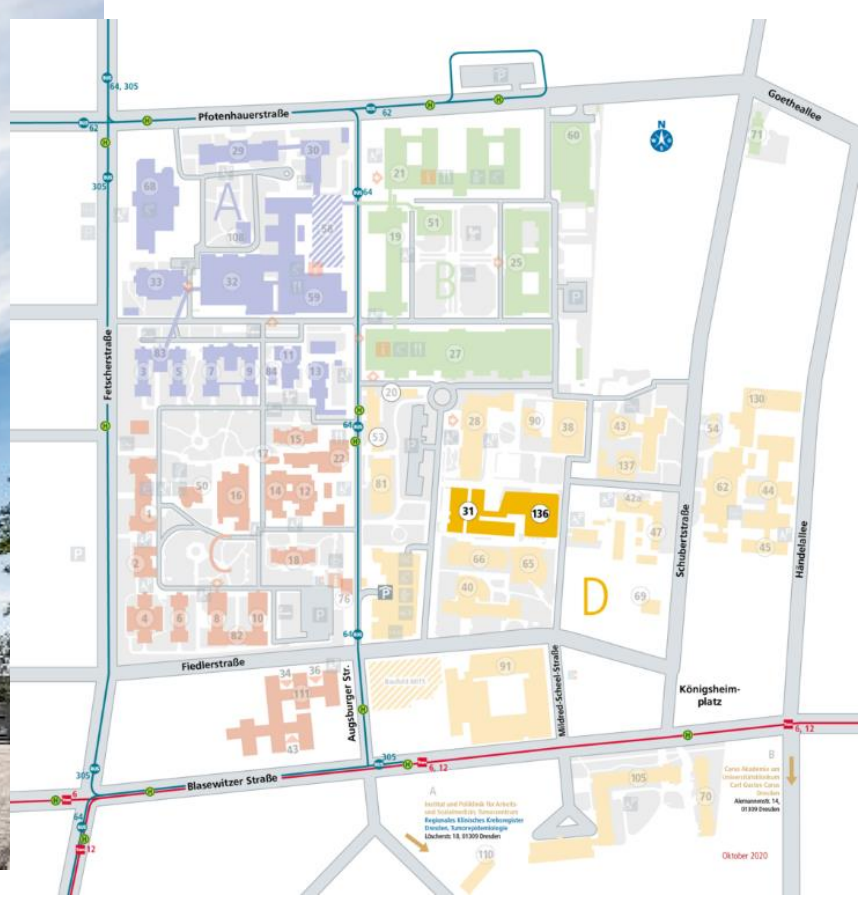
  Sebastian.Bodenstedt@nct-dresden.de

https://www.nct-dresden.de/tso.html

NCT

National Center for Tumor Diseases (NCT)



https://www.nct-dresden.de/

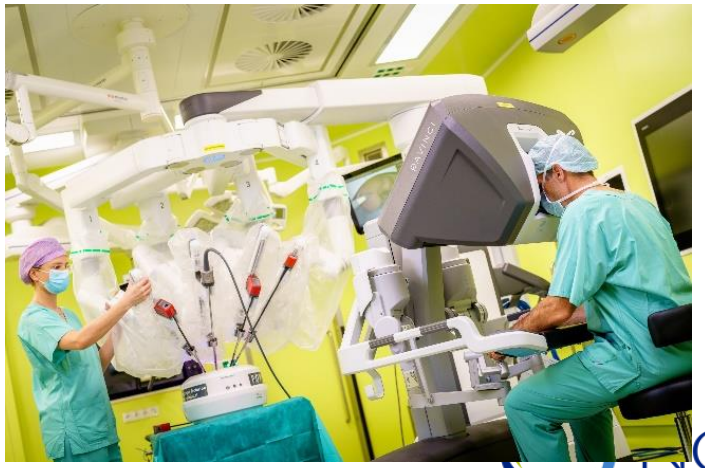
NCT


Das Nationale Centrum für Tumorerkrankungen Dresden - NCT
Zum Beenden des Vollbildmodus Esc drücken
Später ansehen
Teilen
WEITERE VIDEOS
0:00 / 4:02
HD
YouTube

Translational Surgical Oncology@NCT Dresden

- Interdisciplinary group
- Expertise
  - Computer- and robot-assisted Surgery
  - Surgical Data Science
  - Context-aware assistance
  - Data-driven Surgical Training

https://www.nct-dresden.de/



Content / goals of todays lecture

- Lecture organisation
- Overview of the lecture
- Medical imaging
  - X-Ray
  - Ultrasound

Slides for lectures and tutorial

OPAL

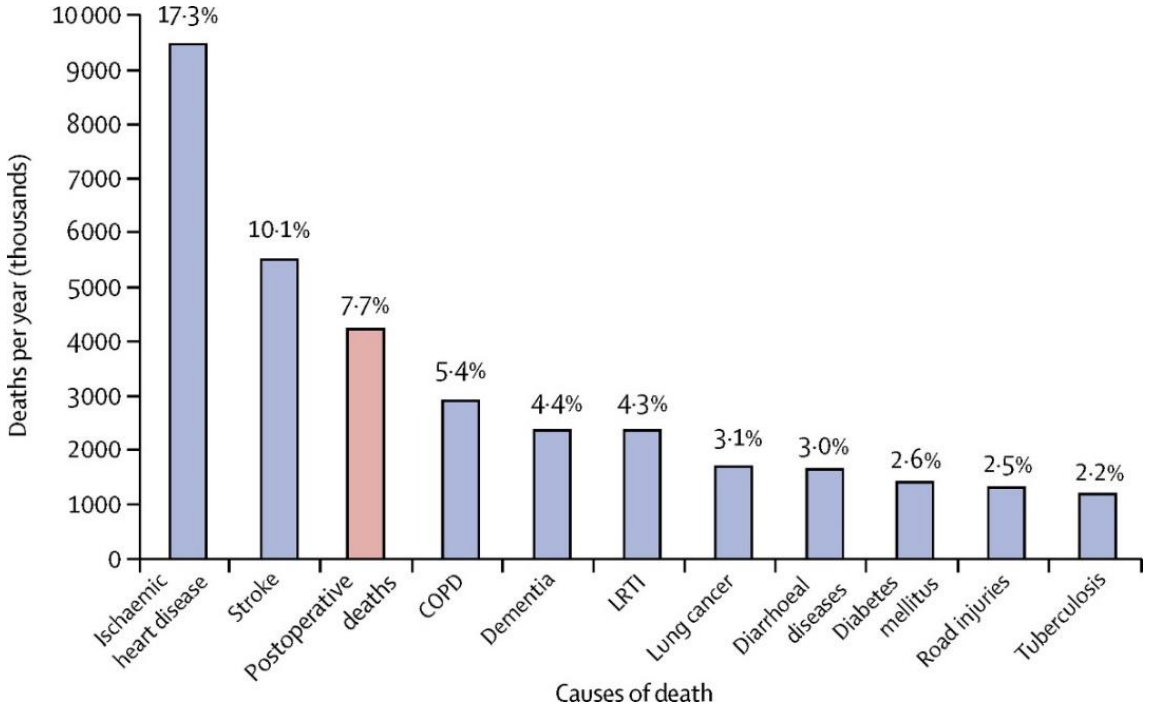
- https://bildungsportal.sachsen.de/opal/auth/RepositoryEntry/15635546112
- => https://tinyurl.com/LectureCRC

- Password: surgeryWS2425

Operating Room of the Future: Surgical Data Science

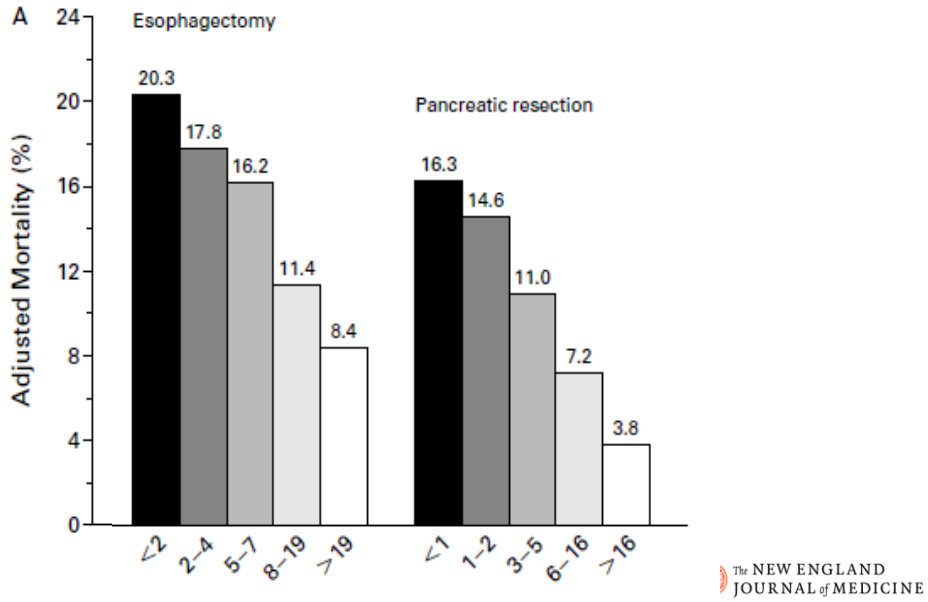
Postoperative complications amongst leading causes of deaths

4.2 Million die worldwide within 30 days of surgery



D. Nepogodiev et al., The Lancet (2019): Global burden of postoperative death

HOSPITAL VOLUME AND SURGICAL MORTALITY IN THE UNITED STATES



Birkmeyer JD et al. N Engl J. 2002: Hospital volume and surgical mortality in the United States.

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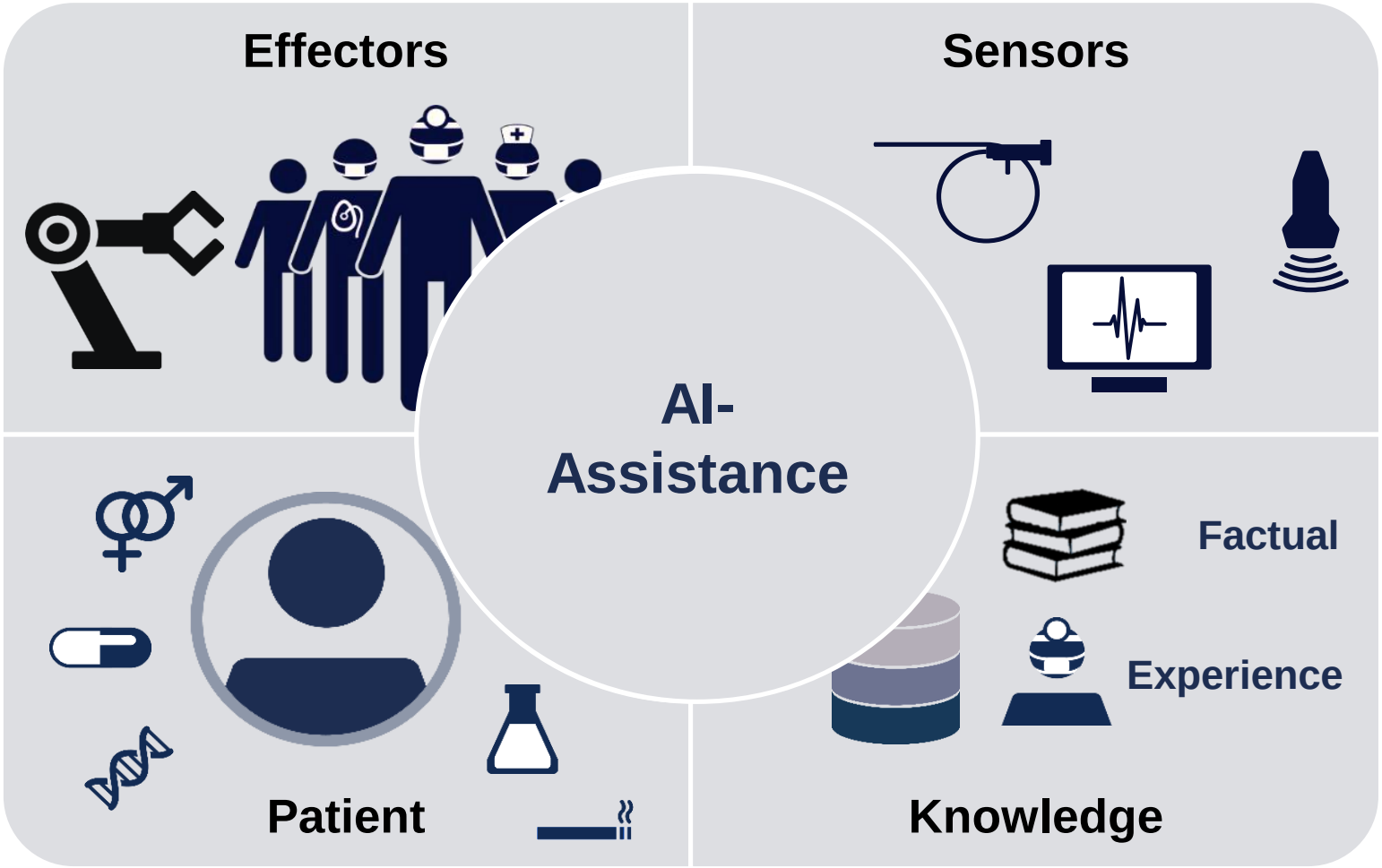
Bridging the gap with Surgical Data Science



Maier-Hein, Vedula, Speidel, et al. Nature BME 2019: “Surgical data science for next-generation interventions”
Maier-Hein, ...,Speidel. MedIA 2021: “Surgical Data Science - from Concepts to Clinical Translation”

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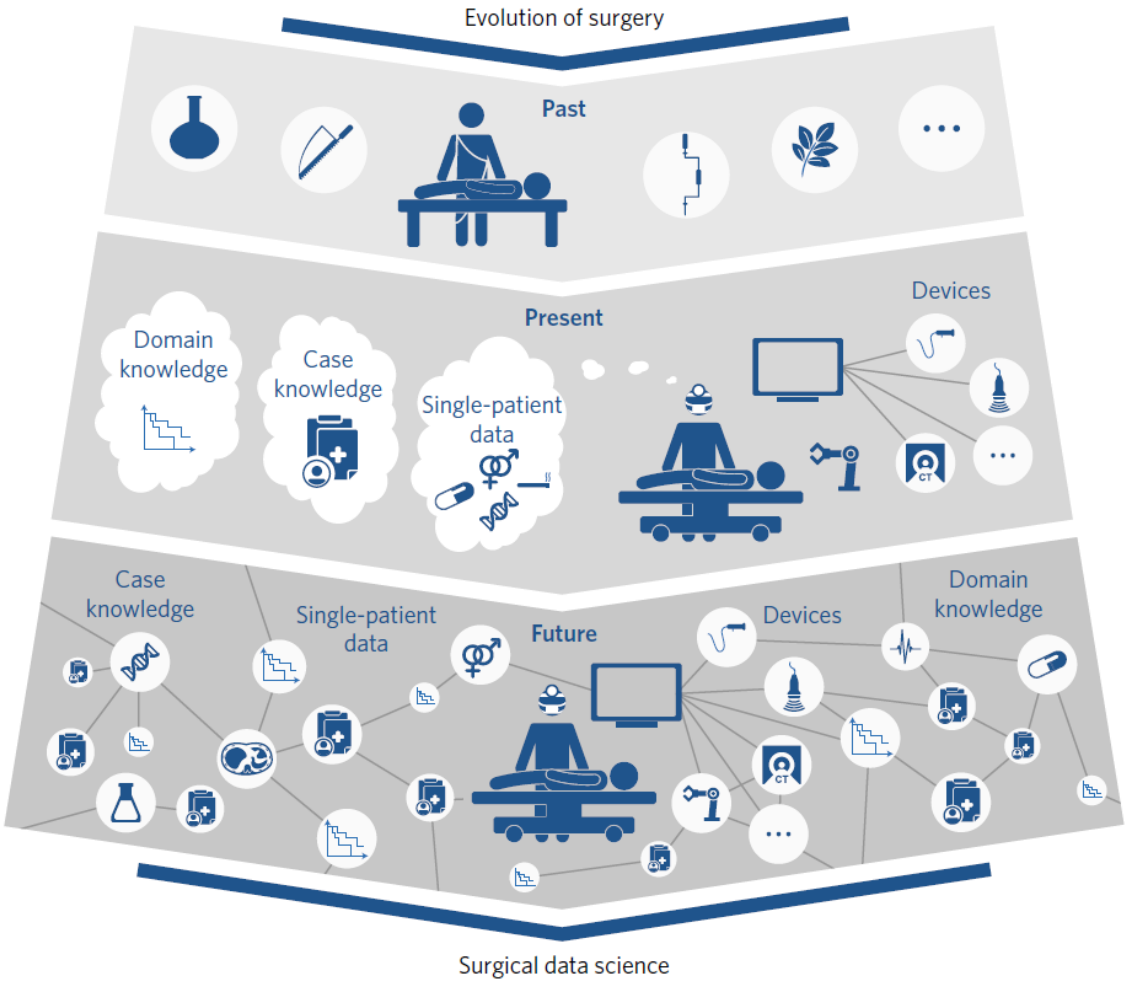
Surgical Data Science Initiative

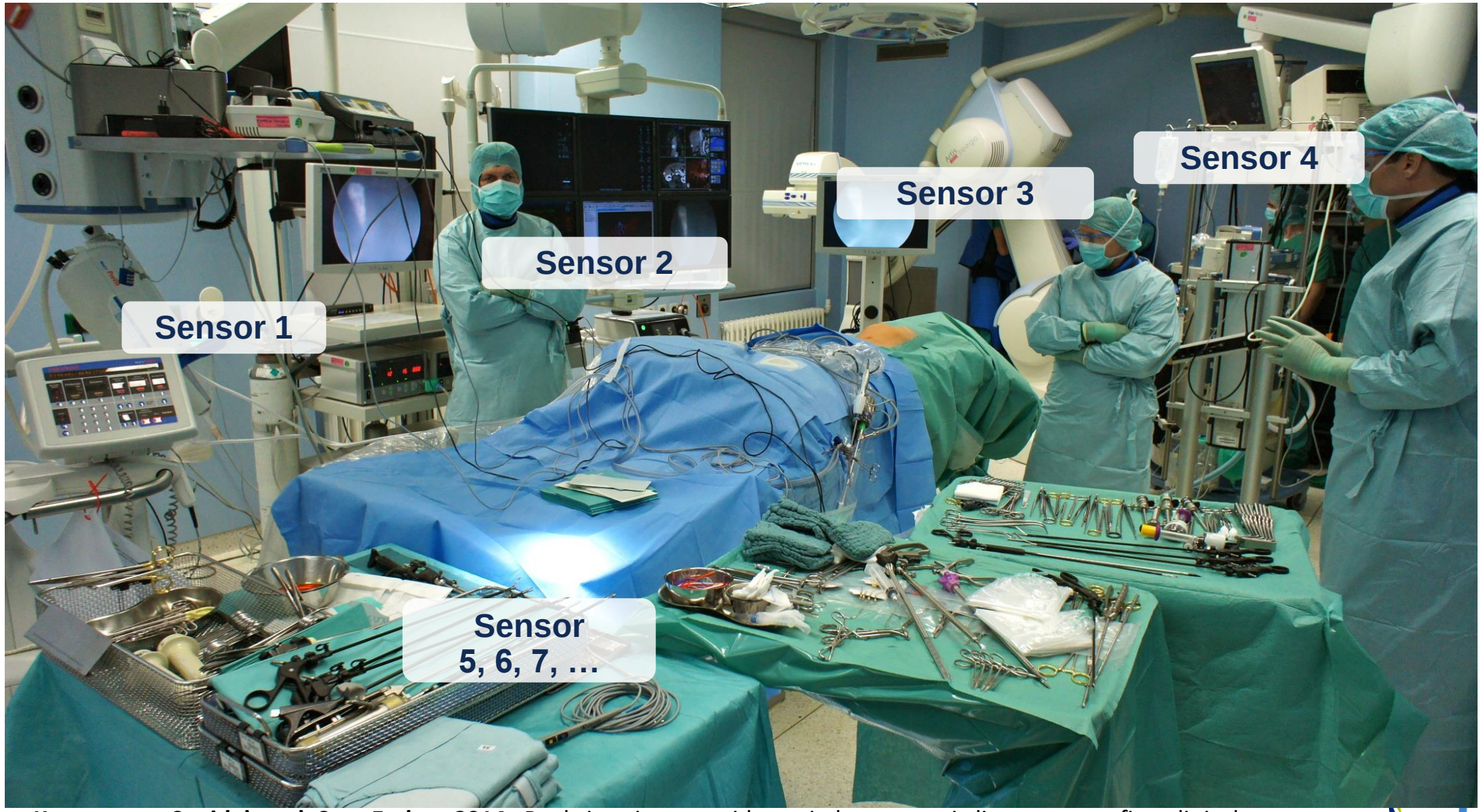
www.surgical-data-science.org

Lead: NCT



Maier-Hein, Vedula, Speidel, et al. Nature BME 2019: "Surgical data science for next-generation interventions"
Maier-Hein, ...,Speidel. MedIA 2021: "Surgical Data Science - from Concepts to Clinical Translation"

Devices: SensorOR



Kenngott,…, Speidel et al. **Surg Endosc 2014**:„Real-time image guidance in laparoscopic liver surgery: first clinical experience with a guidance system based on intraoperative CT imaging”

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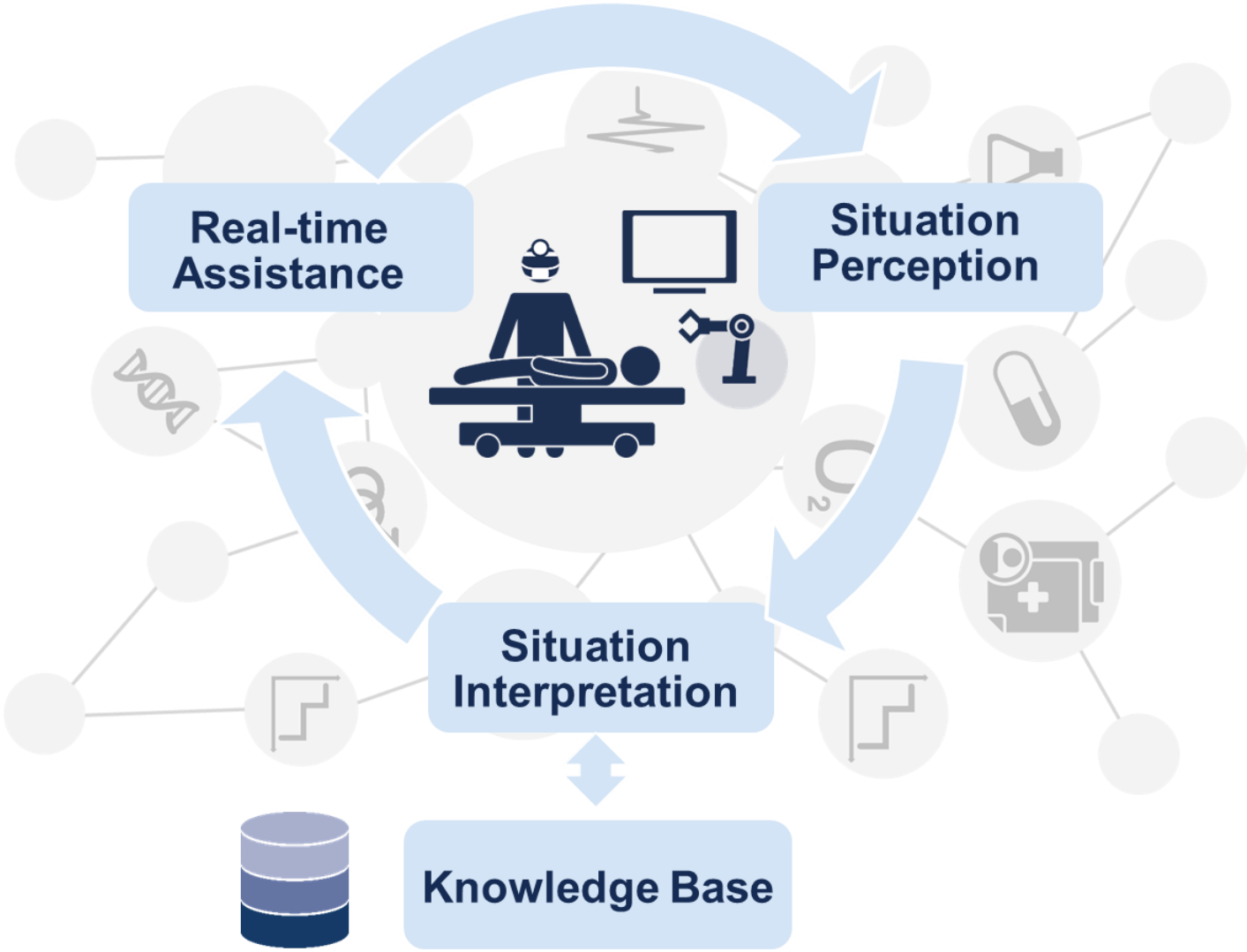
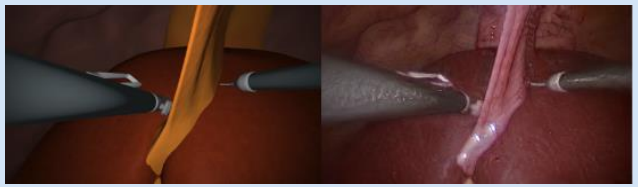
Right information at the right time



Key areas

Data



HMC

Guidance

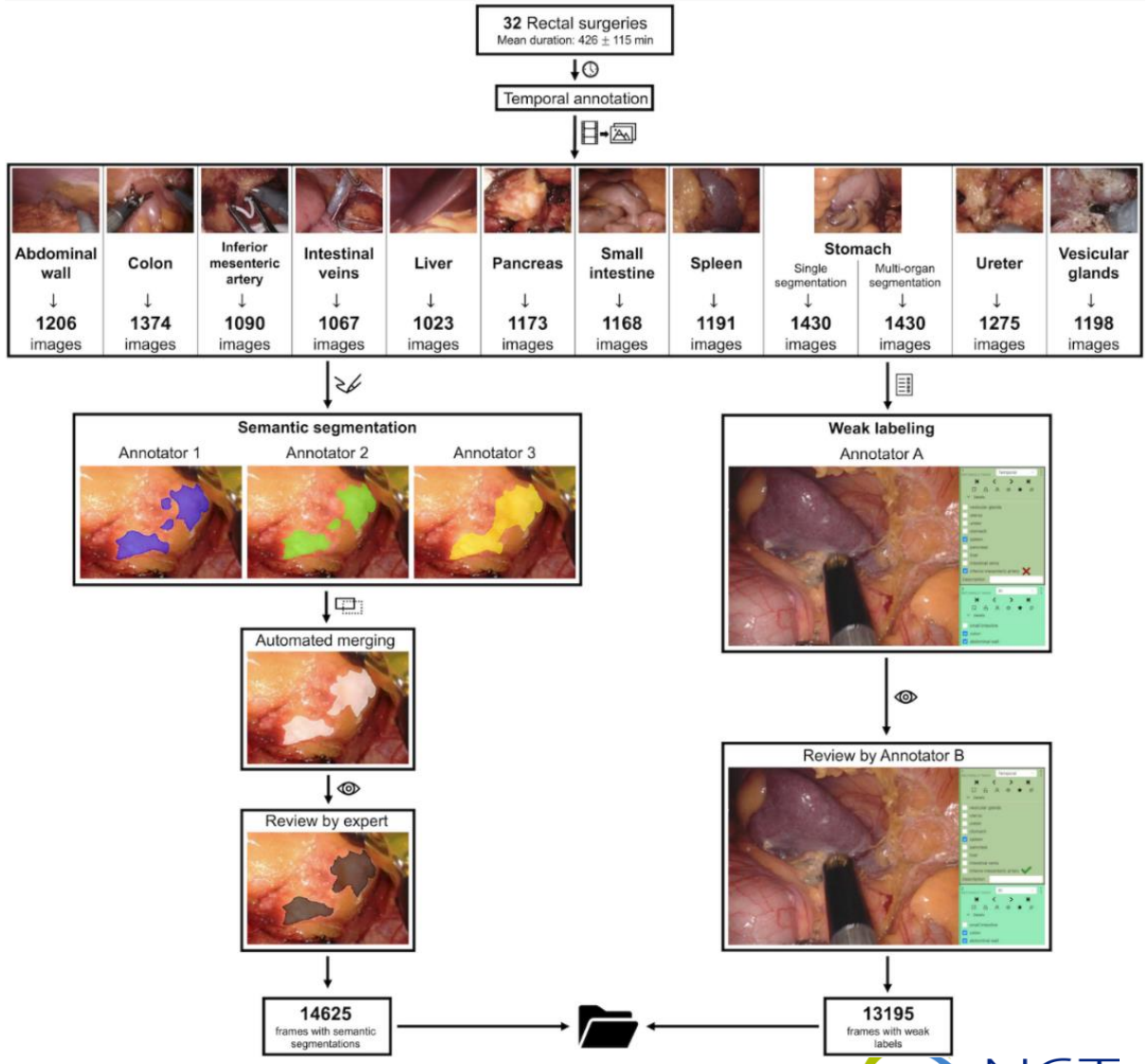
Context-awareness

Data Acquisition

Intraoperative + experimental OR recording

Ongoing recordings for different applications and studies

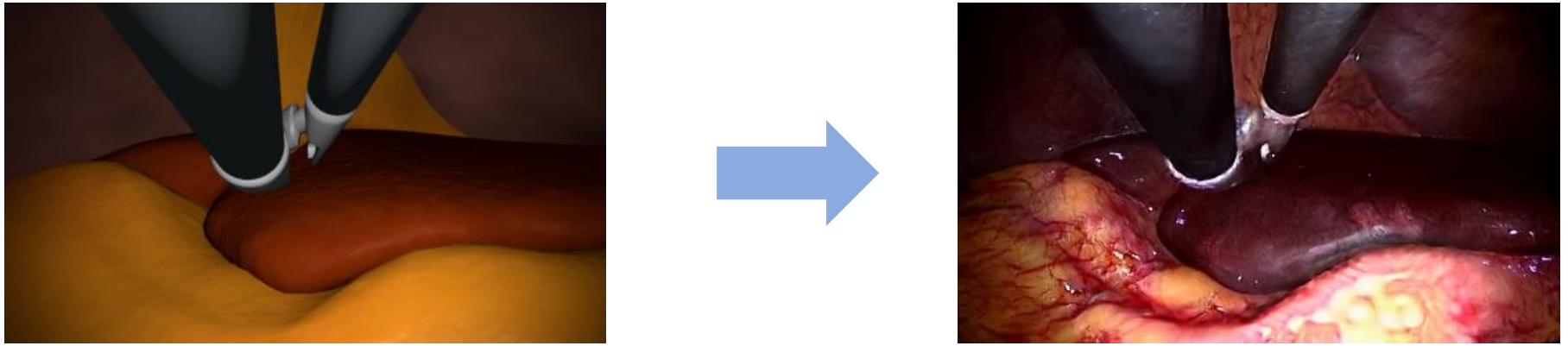
Dresden Surgical Anatomy Dataset



Carstens…Speidel, Kolbinger Nature Scientific Data (submitted): The Dresden Surgical Anatomy Dataset for abdominal organ segmentation…

Example 1: Synthetic Data Generation

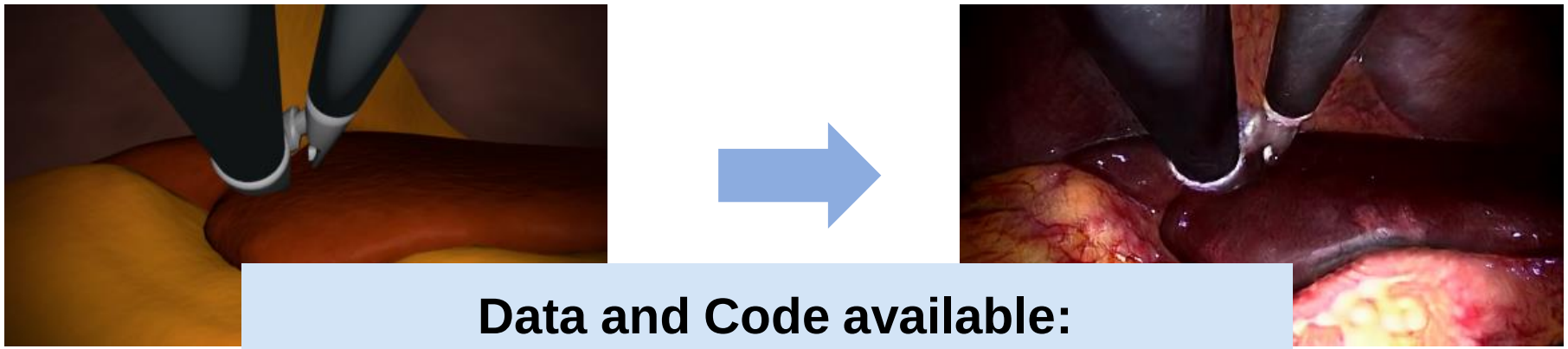
- Unpaired image-to-image translation to generate realistic *synthetic* data



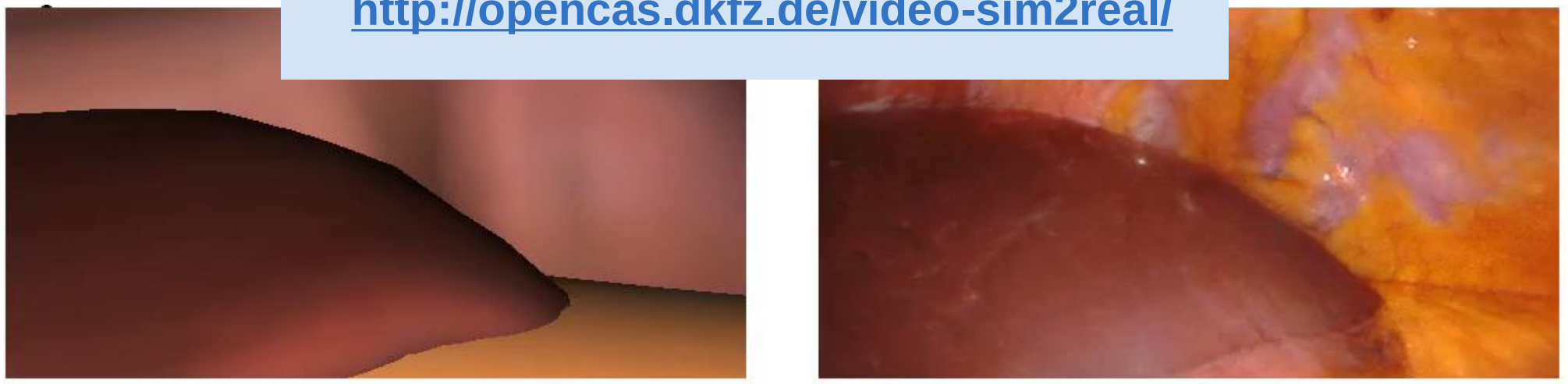
Pfeiffer,.., Speidel MICCAI 2019: „Generating large labeled data sets for laparoscopic image processing tasks using unpaired …
Rivoir, …, Speidel ICCV 2021: „Long-Term Temporally Consistent Unpaired Video Translation from Simulated Surgical 3D Data”

Synthetic Data Generation

- Unpaired image-to-image translation to generate realistic *synthetic* data



- View-Consistent La



Data and Code available:

http://opencas.dkfz.de/image2image/
http://opencas.dkfz.de/video-sim2real/

Pfeiffer,.., Speidel MICCAI 2019: „Generating large labeled data sets for laparoscopic image processing tasks using …
Rivoir, …, Speidel ICCV 2021: „Long-Term Temporally Consistent Unpaired Video Translation from Simulated Surgical 3D Data”

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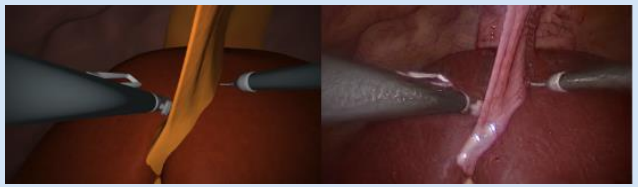
Key areas

Data



HMC

Guidance

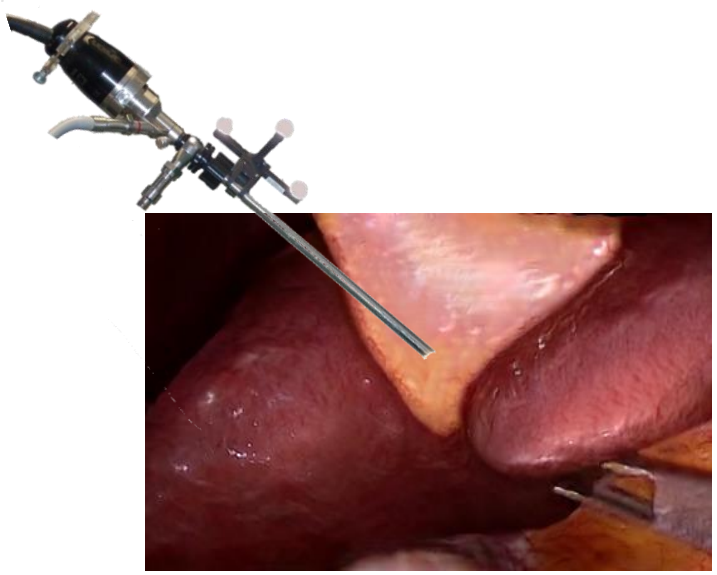
Context-awareness

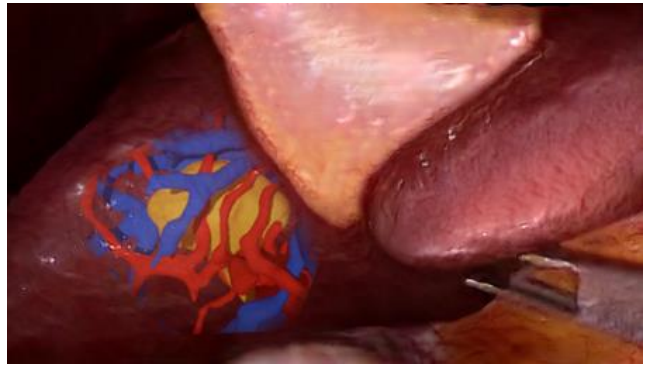
Guidance: Soft-tissue registration

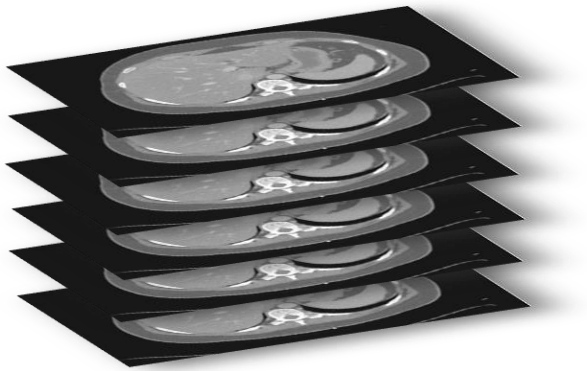
Intraoperative

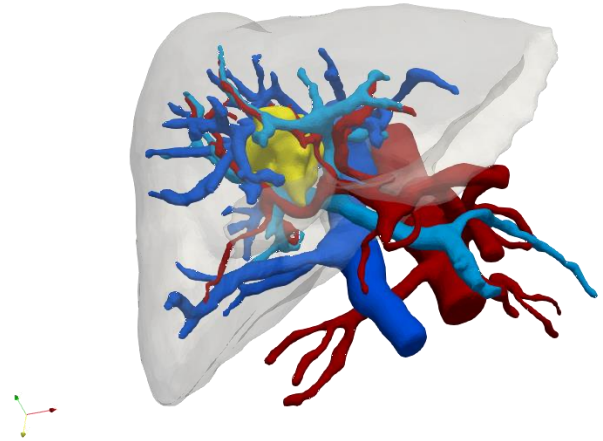
Augmented Reality Visualization

Preoperative









Pfeiffer,..., Speidel IJCARS (IPCAI) 2019 : Learning soft tissue behavior of organs for surgical navigation with convolutional neural networks
Pfeiffer, …, Speidel MICCAI 2020: Non-Rigid Volume to Surface Registration using a Data-Driven Biomechanical Model

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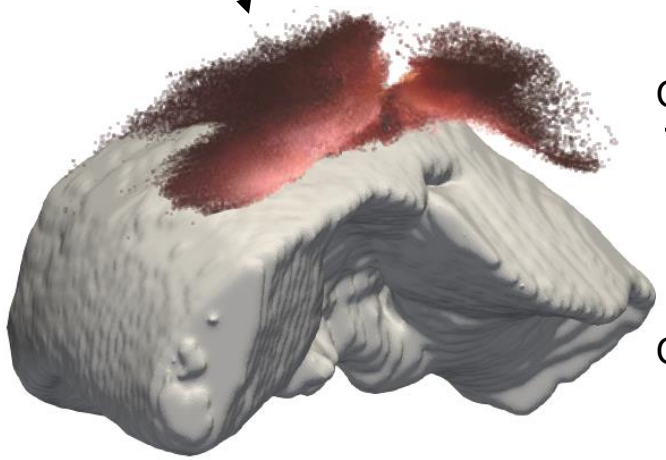
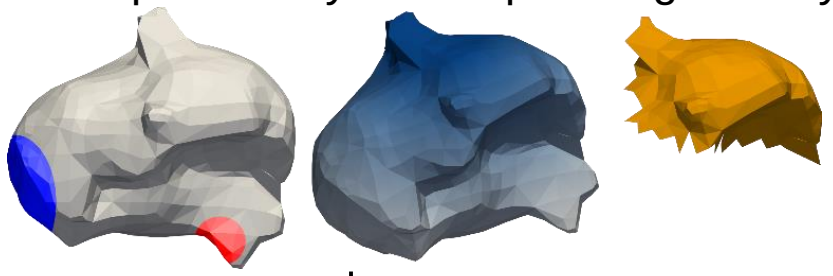
CNN based registration



Trains on random simulations:
Adapts directly to new patient geometry

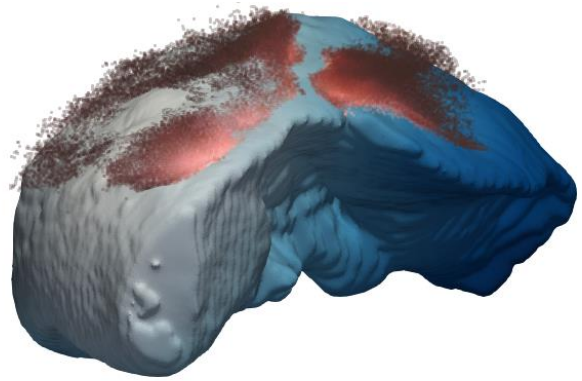


Geometry

Geometry

V2S-Net
Volume to Surface
Registration Network

Displacement
Field



Works directly on geometry:
No known correspondences

Pfeiffer,..., Speidel IJCARS (IPCAI) 2019 : Learning soft tissue behavior of organs for surgical navigation with convolutional neural networks
Pfeiffer, …, Speidel MICCAI 2020: Non-Rigid Volume to Surface Registration using a Data-Driven Biomechanical Model
Tagliabue…Speidel… IEEE Robotics and Automation Letters 2021: Data-driven intra-operative estimation of anatomical attachments for …
Tagliabue,…, Speidel, …. MICCAI 2021 Intra-operative Update of Boundary Conditions for Patient-specific Surgical Simulation

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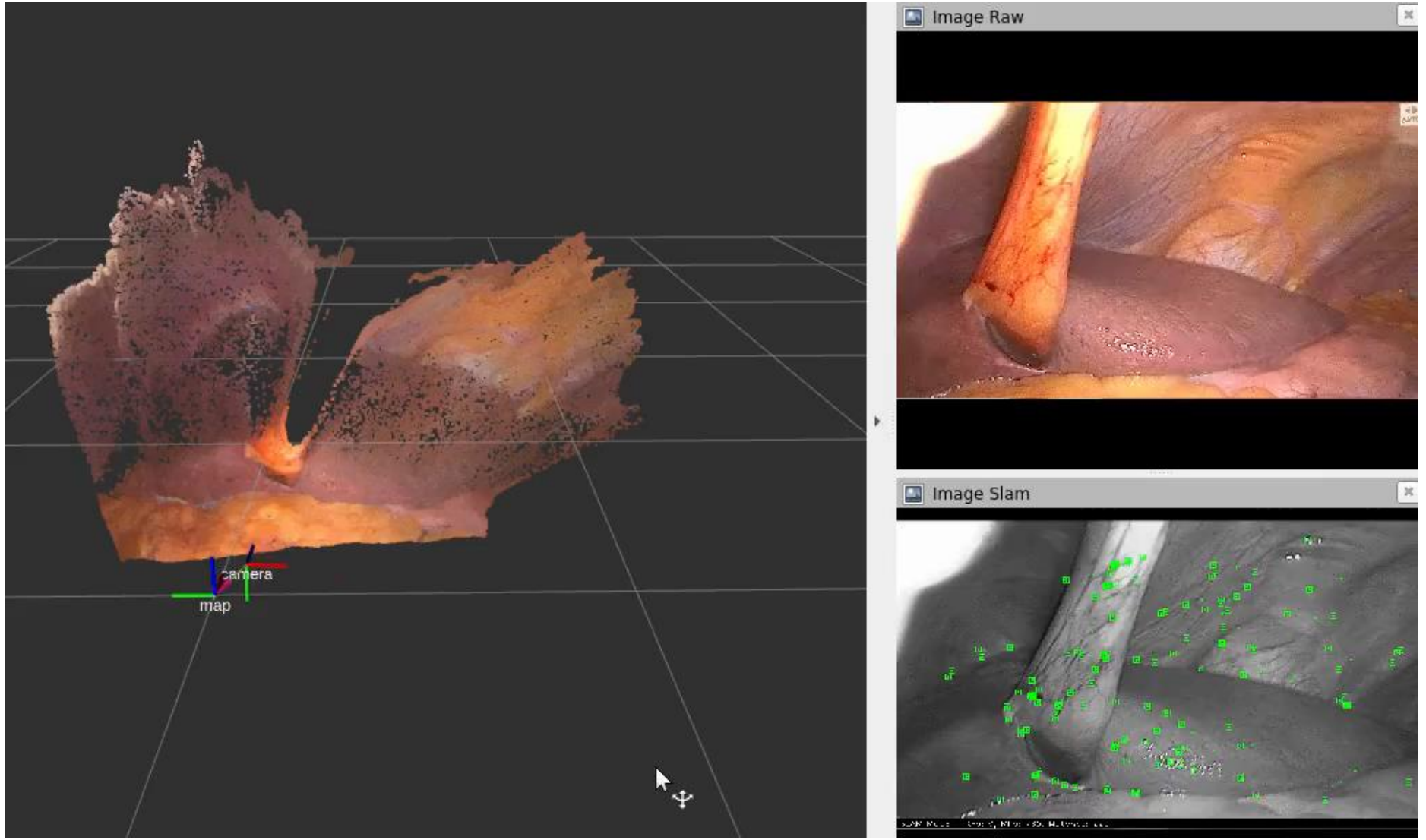
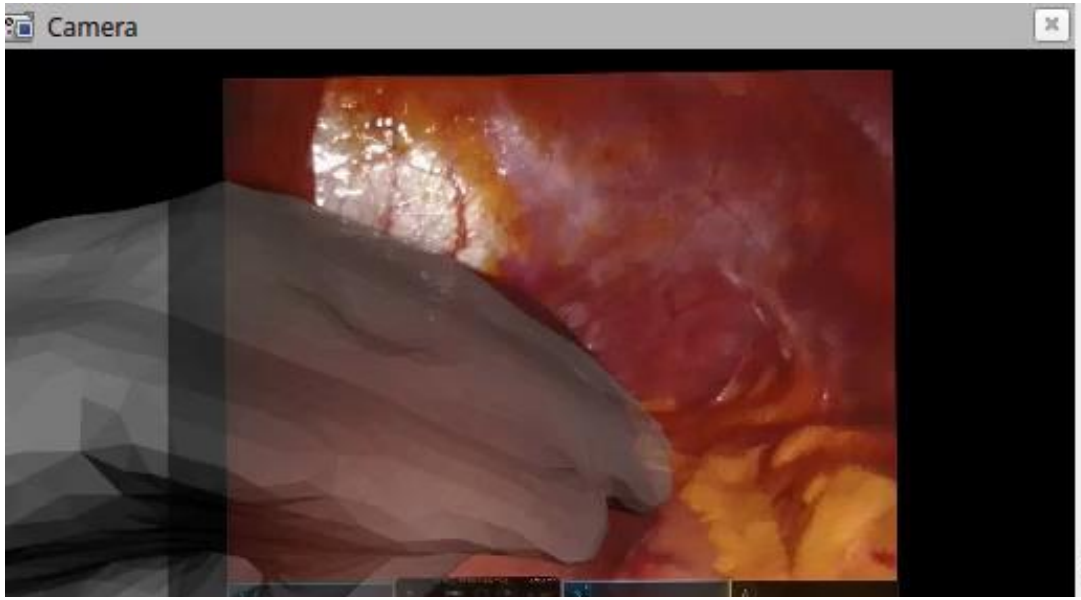
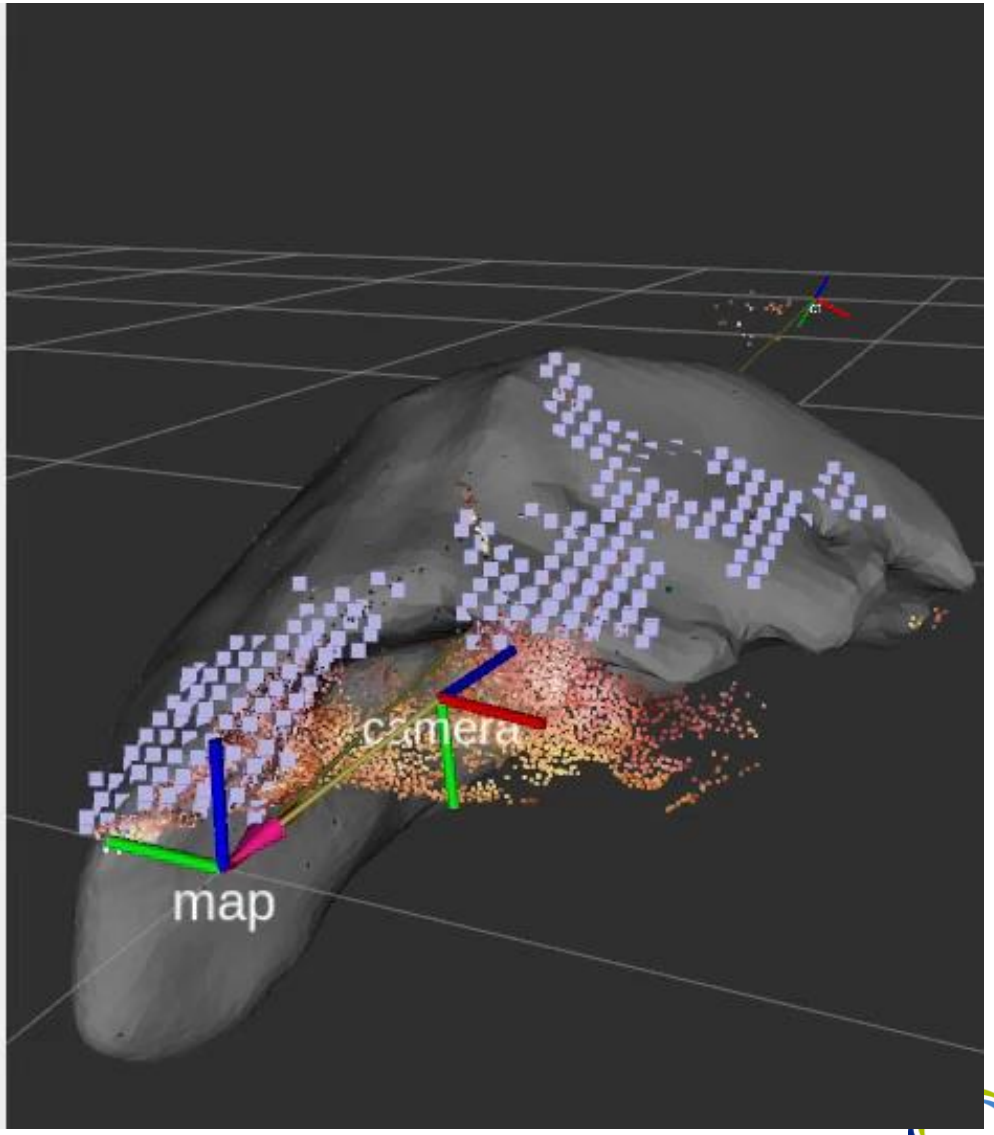
Intraoperative Model: Localisation and Mapping



R. Docea …Weitz, Speidel SPIE Medical Imaging 2021 „Simultaneous localisation and mapping for laparoscopic liver navigation : a comparative evaluation study"

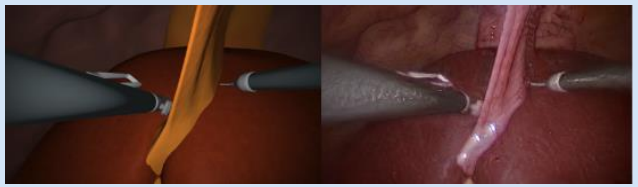
Soft-tissue navigation





Key areas

Data



HMC

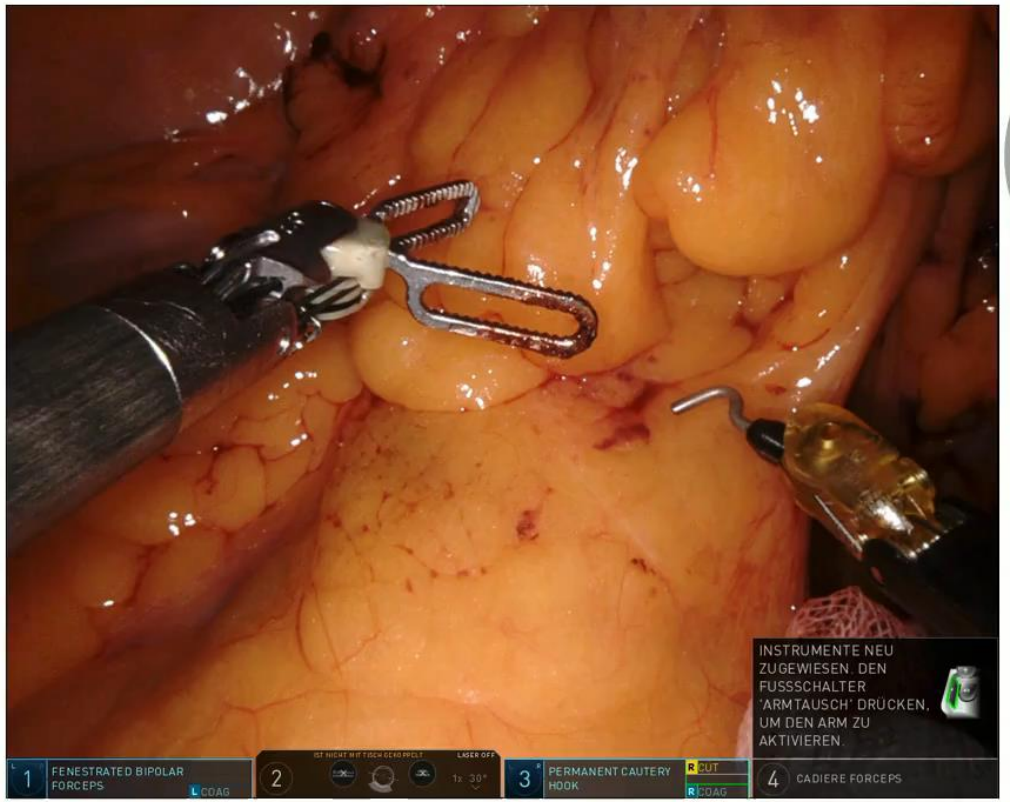
Guidance

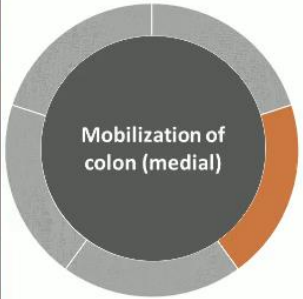
Context-awareness

AI-assisted rectal resection (CoBot)

Context-aware guidance

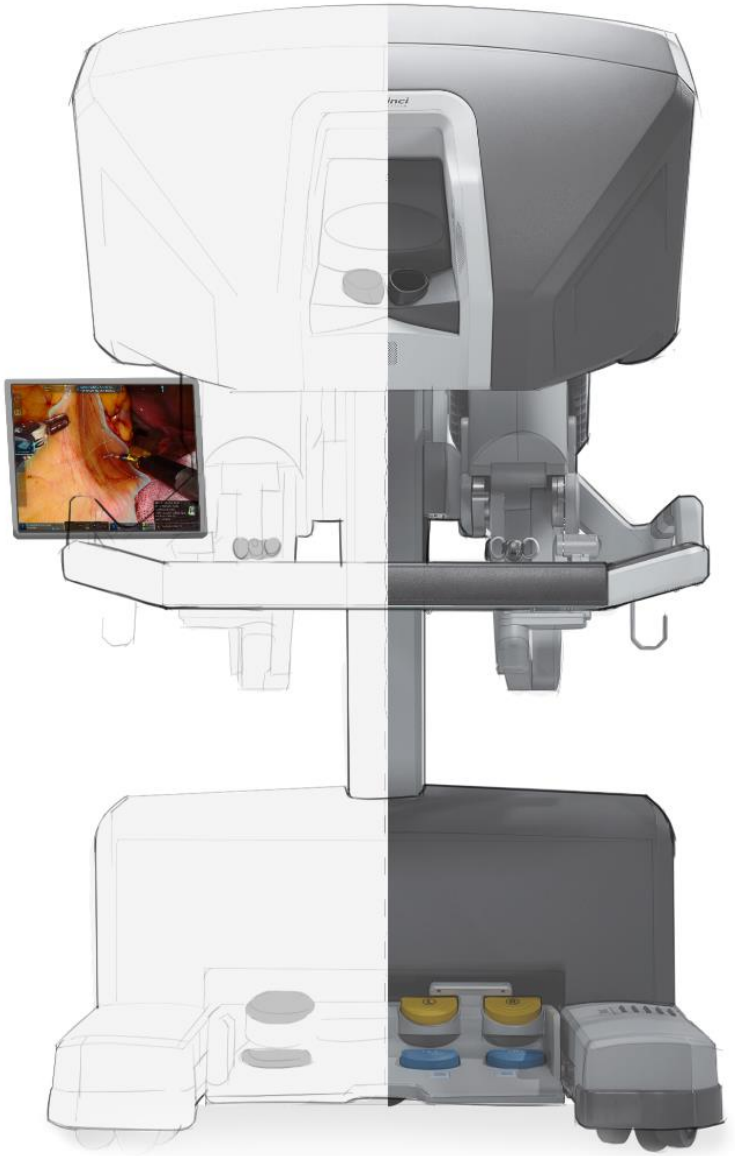
How can we guide surgery based on intraoperative sensor data?





EKFZ Digital Health

CeTI



Kolbinger, …Speidel: medRxiv 2022: Artificial Intelligence for context-aware surgical guidance in complex robot-assisted oncological procedures: an exploratory […]
Rivoir, …Weitz…Speidel. **MICCAI 2020** Rethinking Anticipation Tasks: Uncertainty-aware Anticipation […].
Bodenstedt..Müller-Stich..Weitz,Speidel. IJCARS (IPCAI) 2019 Prediction of laparoscopic procedure duration using unlabeled, multimodal sensor data.

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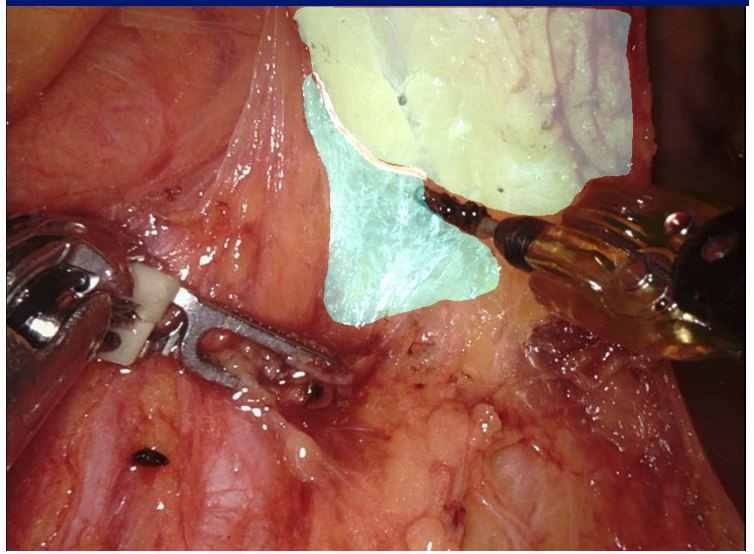
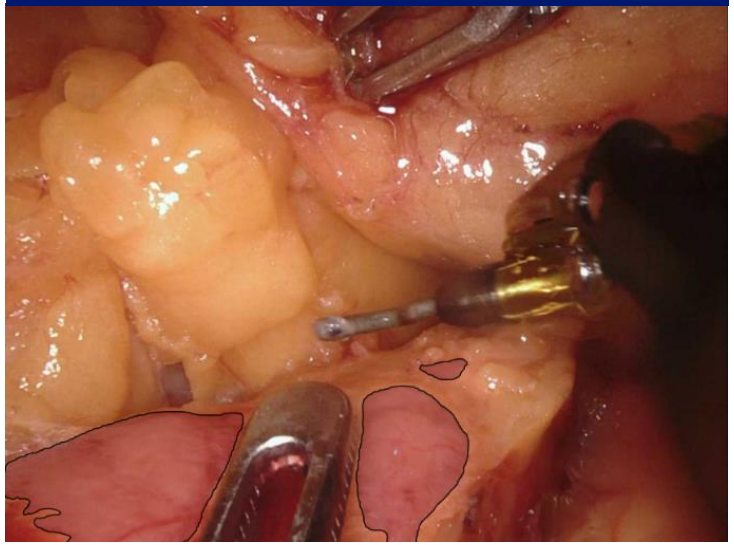
Context-aware guidance

How can we guide surgery based on intraoperative sensor data?

DISSECTION PLANE PREDICTION



DETECTION OF (RISK) STRUCTURES



Kolbinger, …Speidel: medRxiv 2022: Artificial Intelligence for context-aware surgical guidance in complex robot-assisted oncological procedures: an exploratory […]
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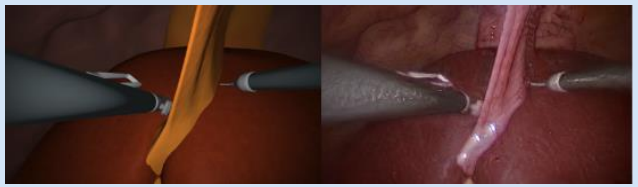
Bodenstedt..Müller-Stich..Weitz,Speidel. IJCARS (IPCAI) 2019 Prediction of laparoscopic procedure duration using unlabeled, multimodal sensor data.

Key areas

Data

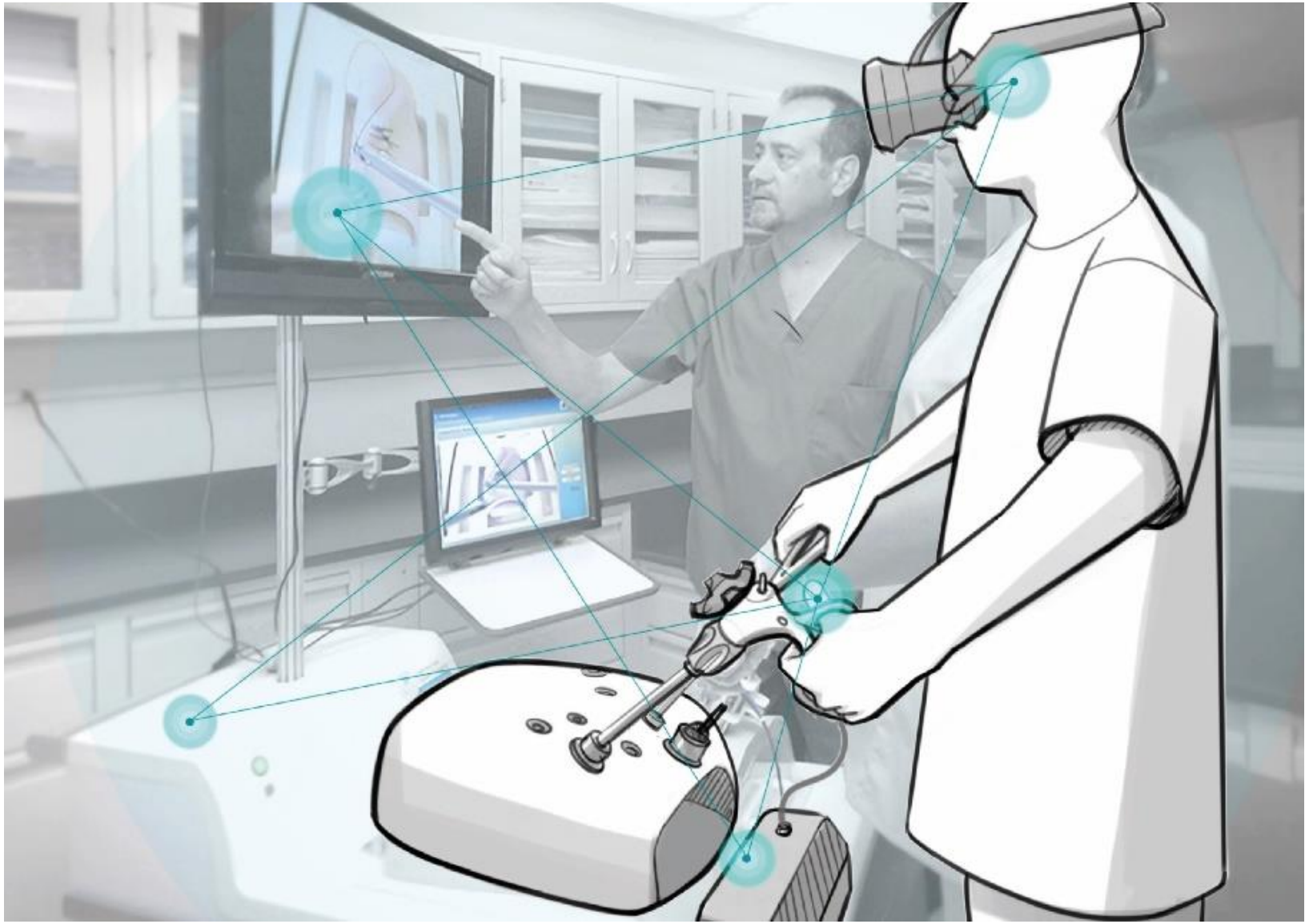


HMC

Guidance

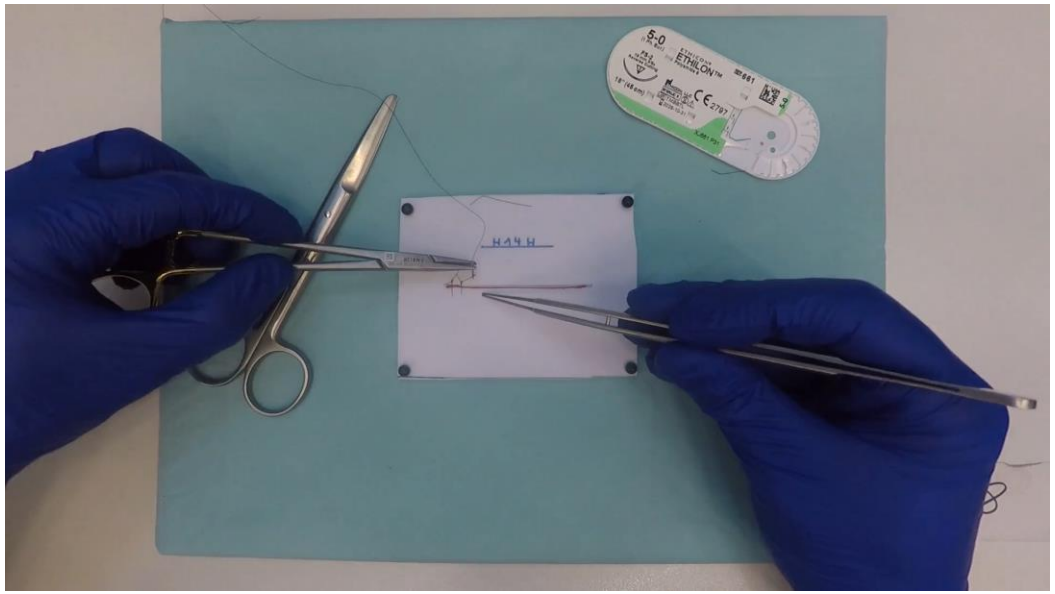
Context-awareness

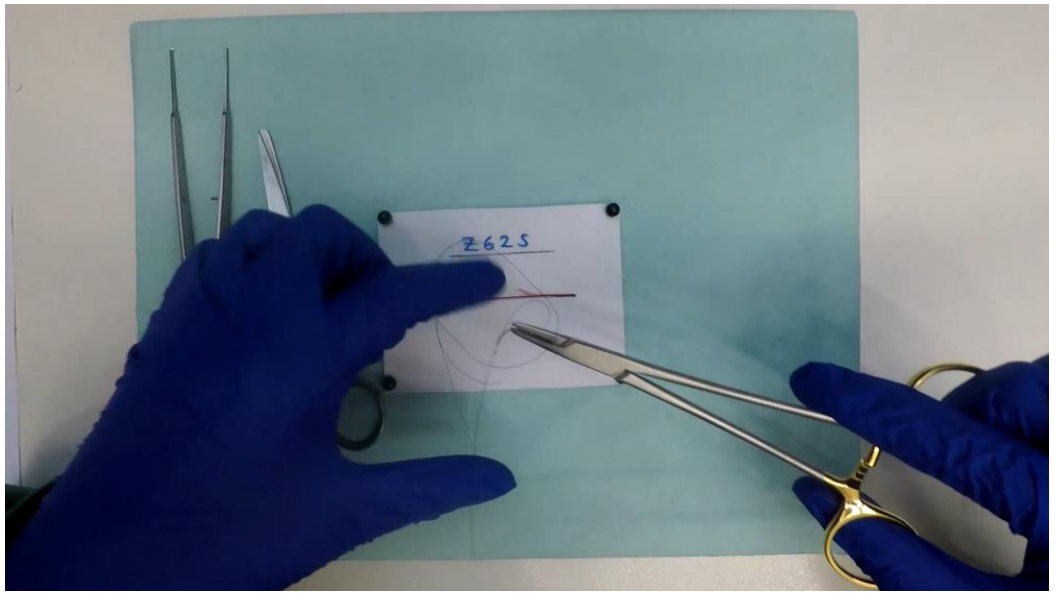
HMC: Sensor-based surgical training



(Copyright Technical Design, TU Dresden, CeTI

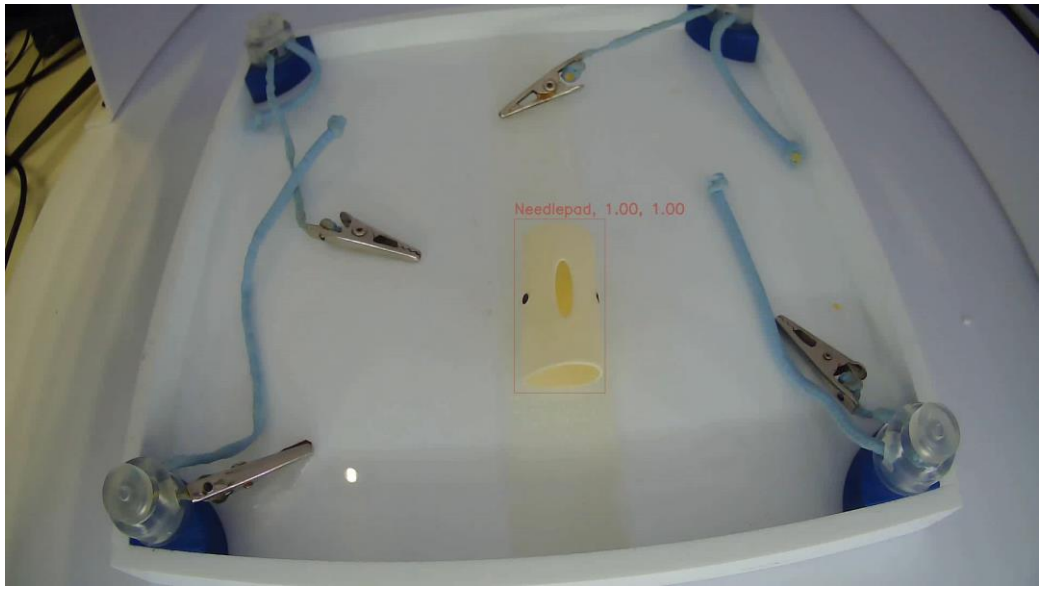
Skill assesment

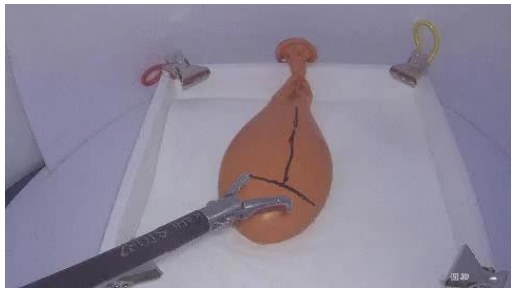




HMC: Data-driven skill assessment and targeted feedback

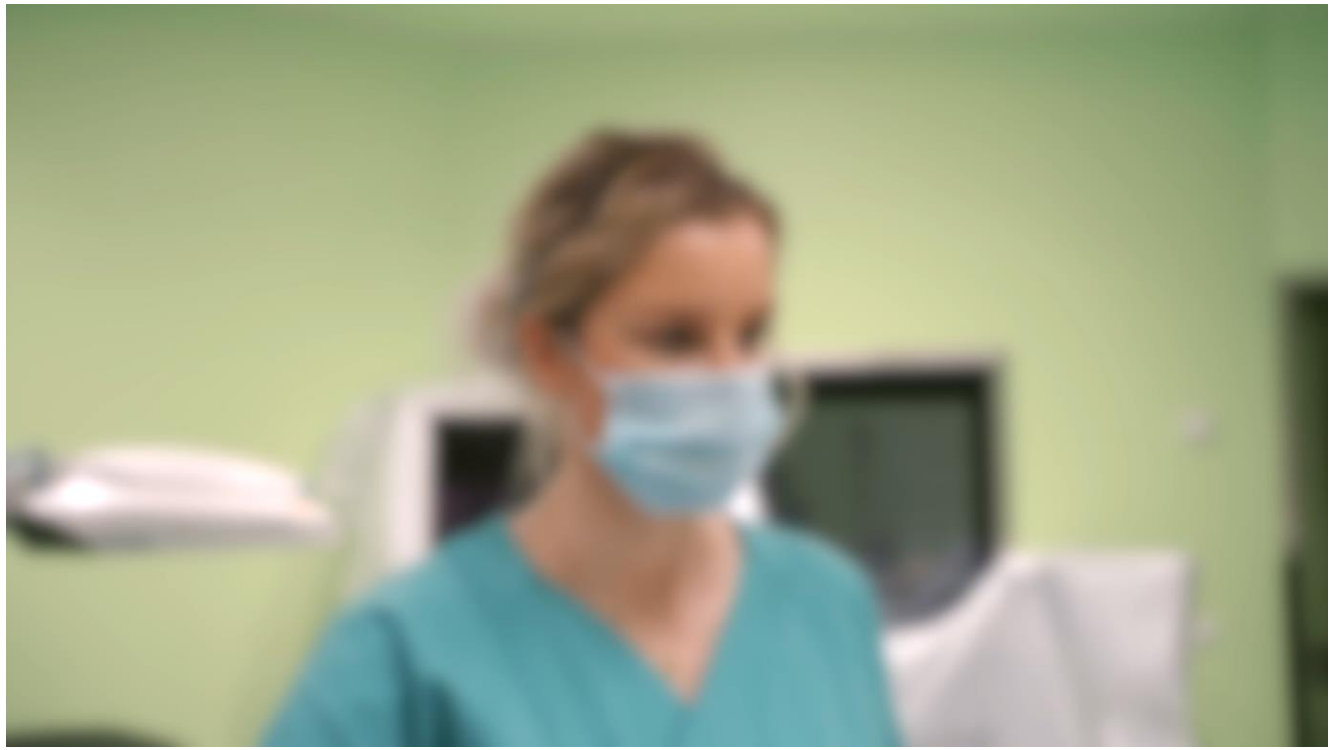
Predict assessment scores
from 1(poor) to 5 (very good)





2.3 **3.2**

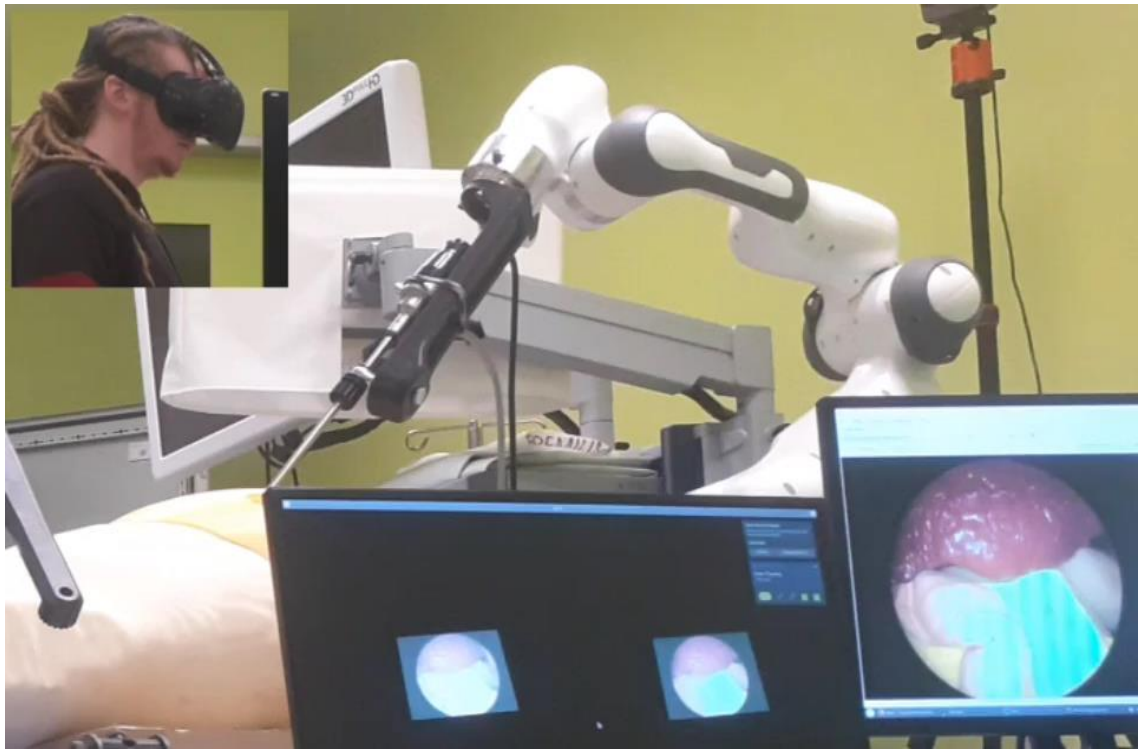
Targeted haptic feedback



Funke,…Weitz, Speidel IJCARS (IPCAI) 2019 „Video-based surgical skill assessment using 3D convolutional neural networks”
Funke, Bodenstedt, Bechtolsheim, Weitz, Speidel (MICCAI) 2019: Using 3d convolutional neural networks to learn spatiotemporal features for automatic surgical gesture recognition in video

HMC: Semi-automatic camera guidance

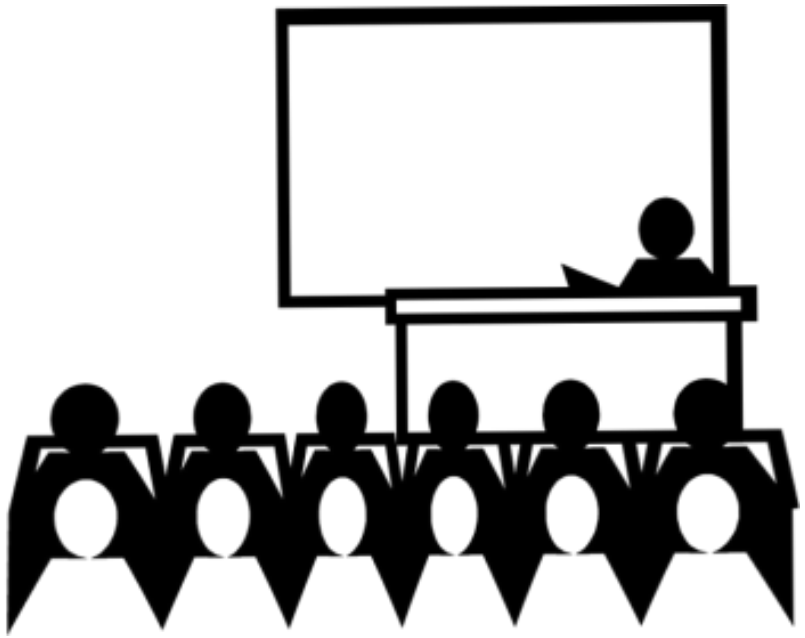
Semi-automatic laparoscope control



Immersive laparoscope control

Further courses

- Tutorial to the lecture



- Komplexpraktikum
  „Computer- and robot-assisted surgery“

- Team project

Participate in research

- Machine Learning, Surgical Computer Vision
- Virtual/Augmented Reality in Surgery
- Analysis of sensor data in the OR

https://www.nct-dresden.de/tso.html

Not all topics can be found online!

Ausschreibung Bachelor-/Master-/Diplomarbeit

Quantitative Laparoskopie

Rahmen

Die Abteilung „Translationale Chirurgisch Onkologie“ am Nationalen Centrum für Tumorerkrankungen (NCT) erforscht computer- und robotergestützte Assistenzsysteme für die Chirurgie an der Schnittstelle zwischen Informatik und Medizin. Ein Forschungsgebiet ist die Quantitative Laparoskopie, die es ermöglicht Metriken wie Distanzen, Volumen und Geschwindigkeiten aus laparoskopischen Bilddaten abzuleiten.

Aufgabe

Ziel der Arbeit ist es aus stereoendoskopischen Bilddaten durch Methoden des maschinellen Sehens quantitative Messwerte abzuleiten und diese für die Chirurgen während der Operation zugänglich zu machen.

Gesucht

- Motivierte Studierende mit Interesse an einer interdisziplinären Arbeit in der computer- und robotergestützte Chirurgie
- Kenntnisse in C++
- Engagement, Teamfähigkeit und Freude am Einbringen eigener Ideen

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PARTNERSTANDORT DRESDEN
UNIVERSITÄTS KREBSCENTRUM UCC

Weitere Details
Sebastian Bodenstedt
sebastian.bodenstedt@nct-dresden.de
https://www.nct-dresden.de/tso.html

NCT

Looking for SHKs

Hiwis gesucht

Computer- und robotergestützte Chirurgie

Die Abteilung „Translationale Chirurgisch Onkologie“ am Nationalen Centrum für Tumorerkrankungen (NCT) erforscht computer- und robotergestützte Assistenzsysteme für die Chirurgie. In Zusammenarbeit mit unseren klinischen Partnern entwickeln wir Systeme an der Schnittstelle zwischen Informatik und Medizin.

https://www.nct-dresden.de/tso.html

Aufgabe

Im Bereich der computer- und robotergestützten Chirurgie suchen wir studentische Hilfskräfte für die Entwicklung von Assistenzsystemen im Operationssaal der Zukunft. Die Aufgaben umfassen die Themenbereiche Bildverarbeitung, Computer Vision, maschinelles Lernen sowie Virtuelle Realität im medizininformatischen Kontext.

Gesucht

- Motivierte Studierende mit Interesse an einer interdisziplinären Arbeit in der computer- und robotergestützte Chirurgie
- Studierende im Studiengang Informatik bzw. ähnliche Fachrichtung
- Kenntnisse in C++ oder Python, Linux
- Engagement, Teamfähigkeit und Freude am Einbringen eigener Ideen

NCT NATIONALES CENTRUM FÜR TUMORERKRANKUNGEN PARTNERSTANDORT DRESDEN UNIVERSITÄTS KREBSCENTRUM UCC

getragen von: Deutsches Krebsforschungszentrum, Universitätsklinikum Carl Gustav Carus Dresden, Medizinische Fakultät Carl Gustav Carus, TU Dresden, Helmholtz-Zentrum Dresden-Rossendorf

Weitere Details

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NCT

Goals and topics of the lecture

Basics that are necessary for understanding and designing an assistance-system for computer-assisted surgery

- What data is necessary and how is it processed?
- Which components are required and how are they interconnected?
- Which methods can be used?
- What are the pros and cons of each method?
- Which clinical requirements have to be considered?
- How can the learned material be applied to concrete use-cases?

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Process chain computer-assisted surgery

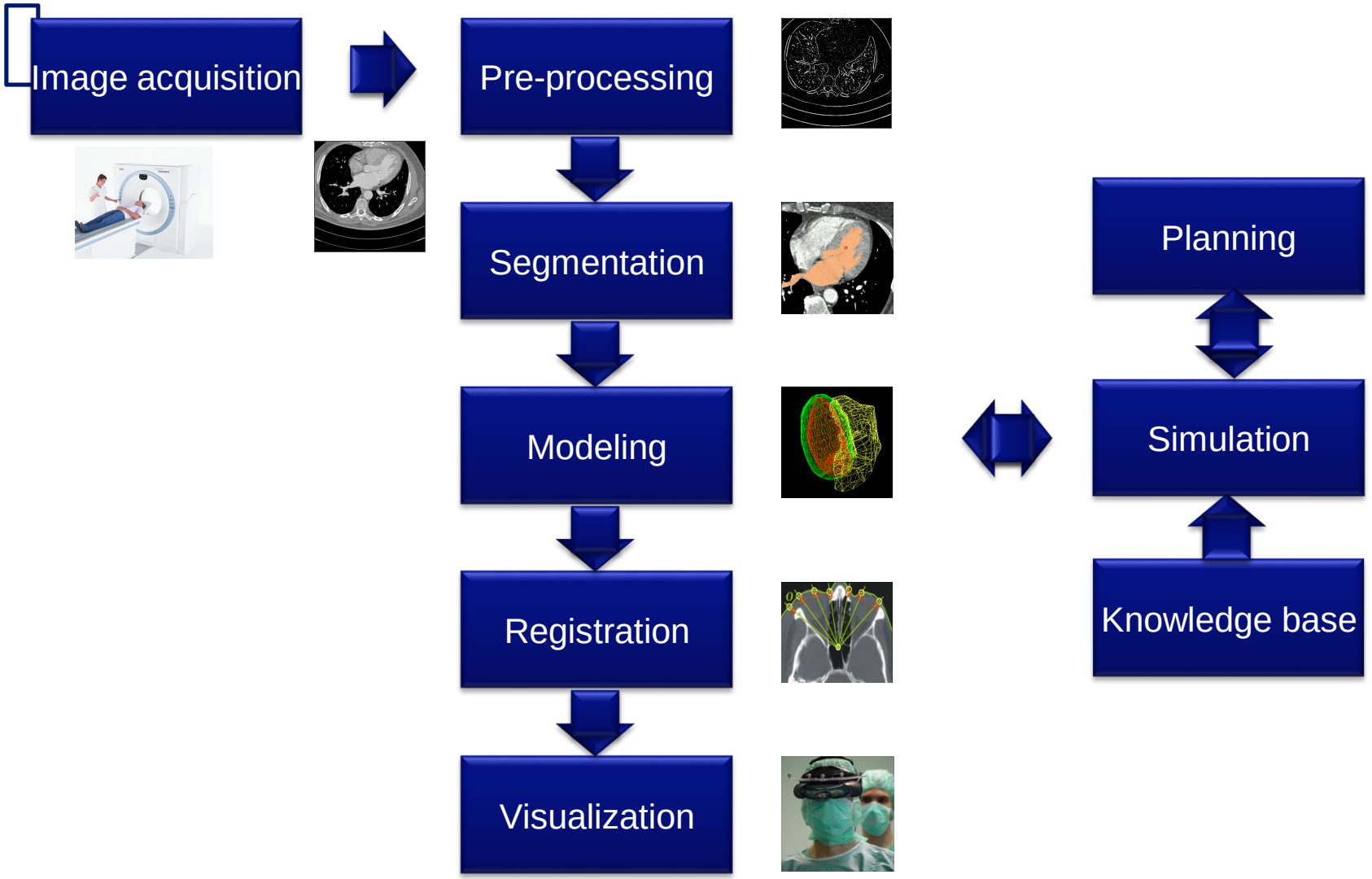
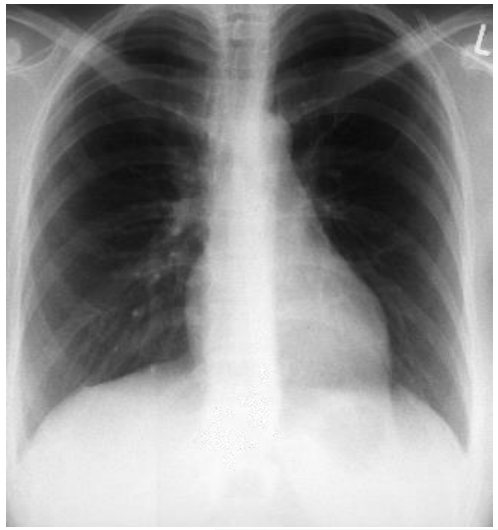


Image acquisition

- X-Ray
- Computed tomography scan



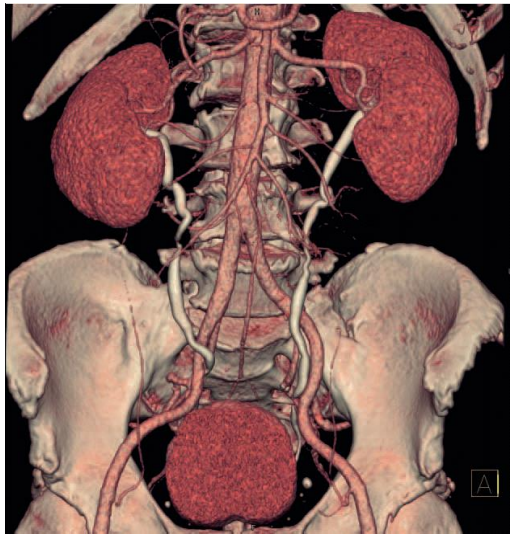


Image acquisition

- Magnetic resonance imaging
- Medical ultrasound

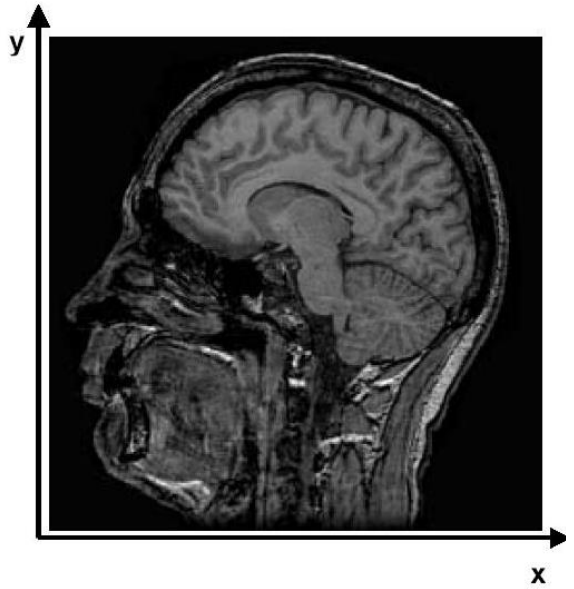
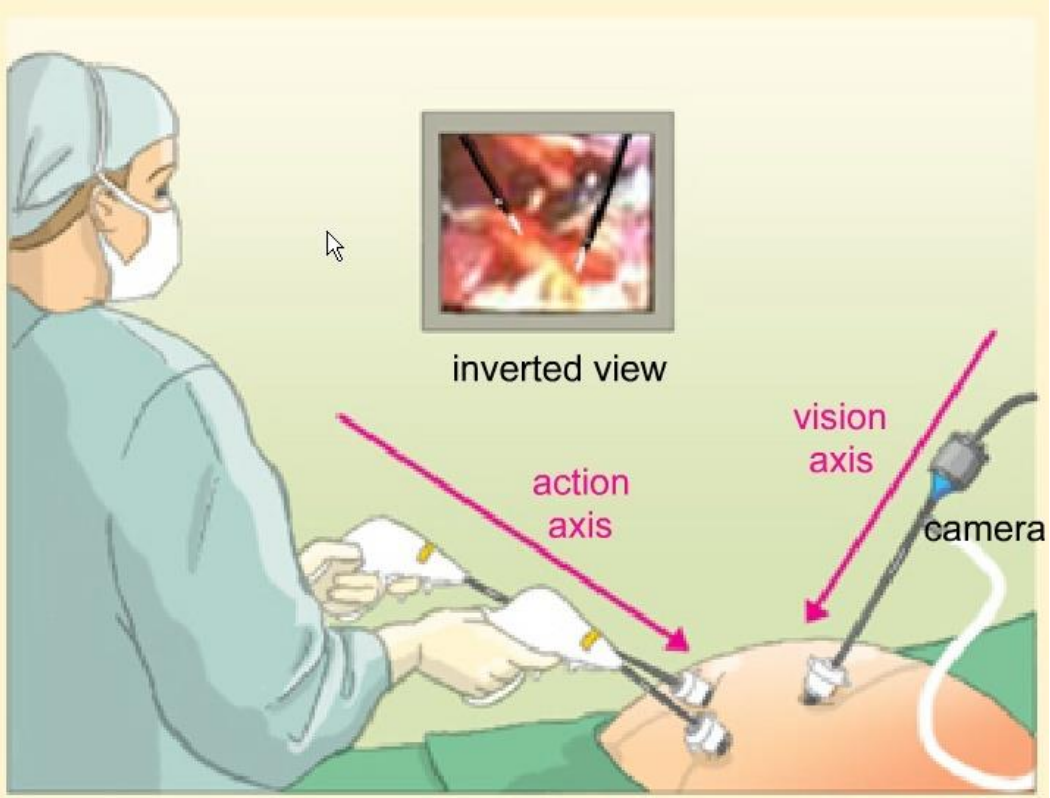
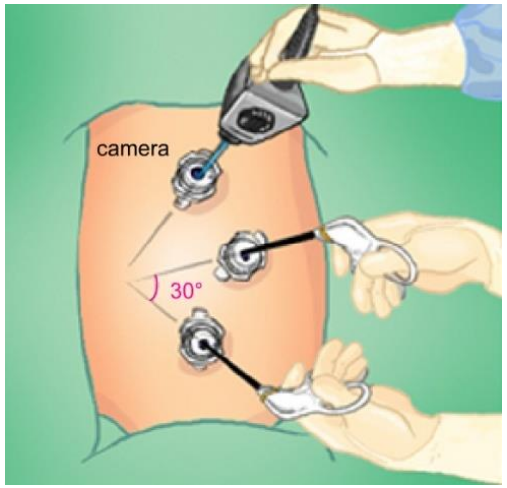


Image acquisition

- Endoscopy





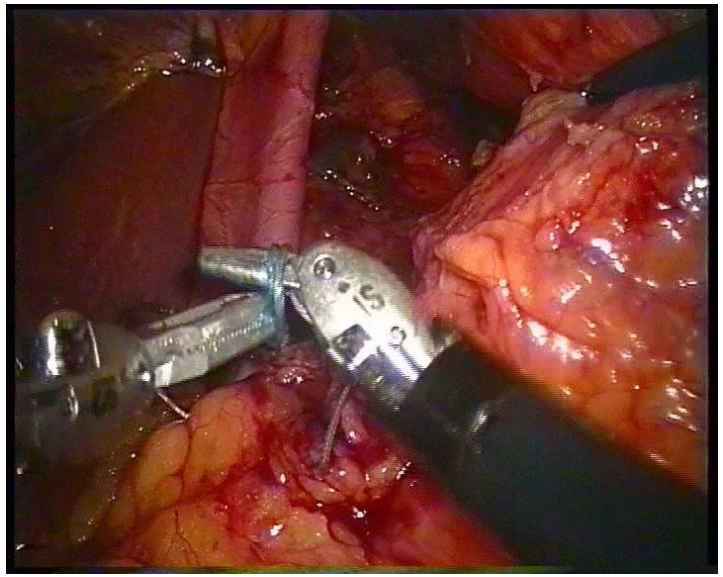
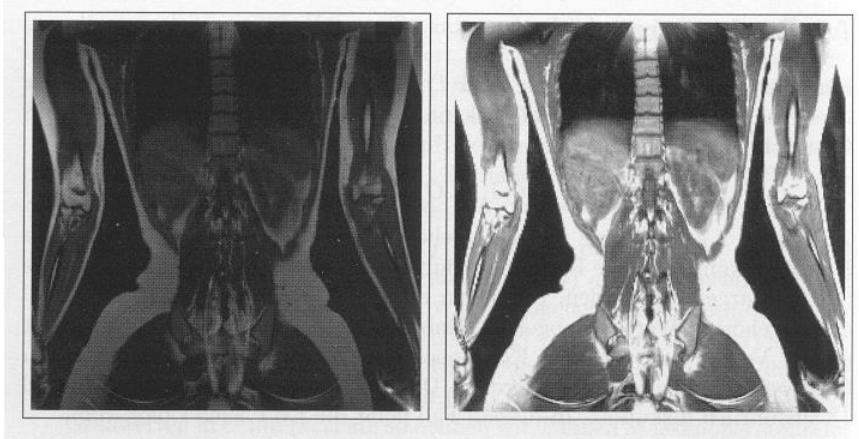
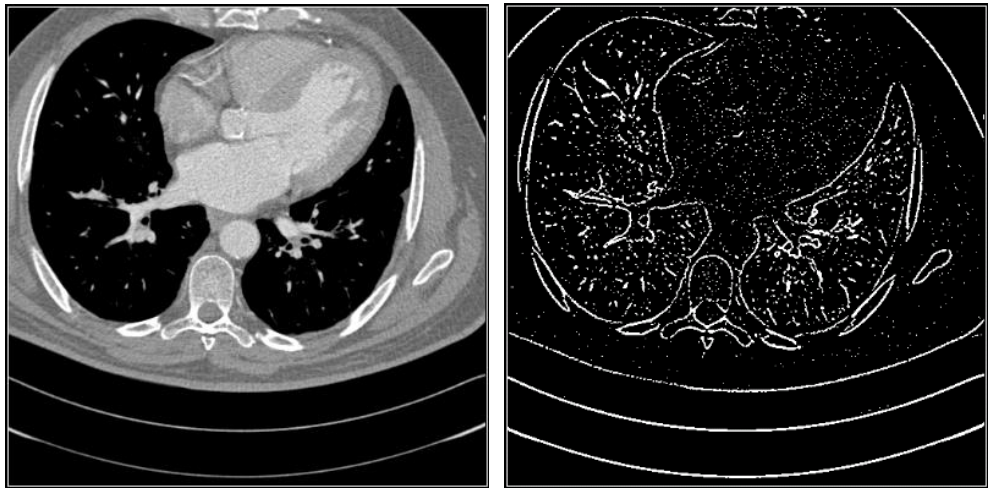


Image pre-processing

- How can image data be “improved”?

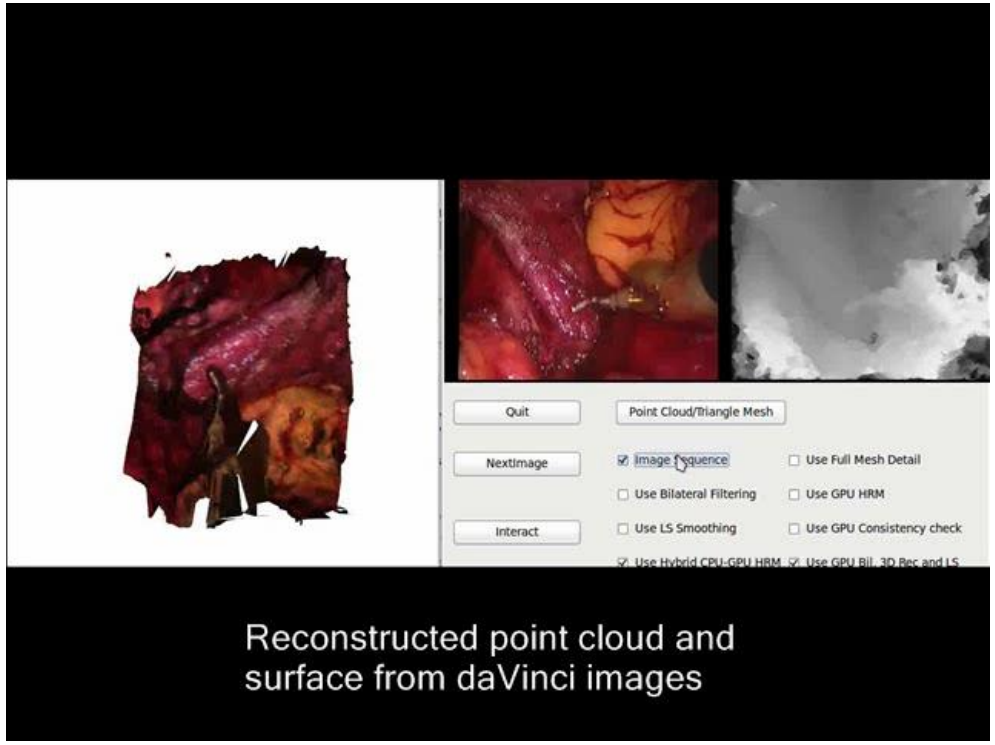


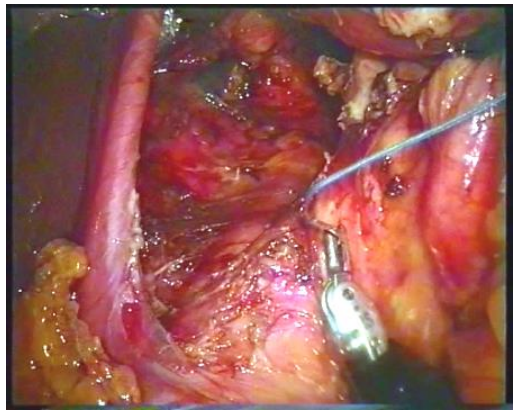
- What processing steps have to be taken to make images usable in further steps?

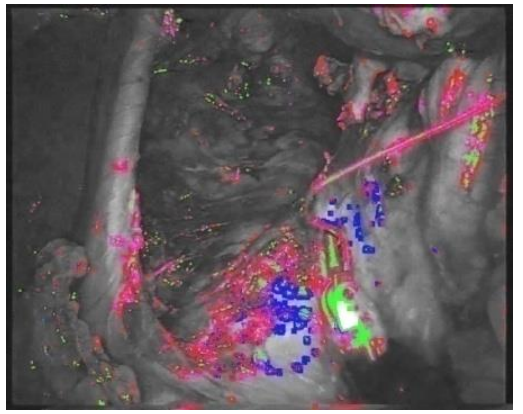


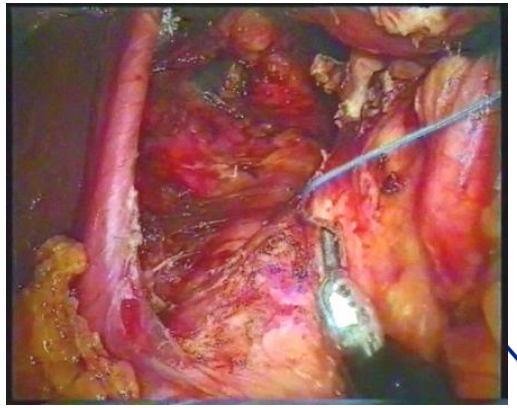
Computer vision basics

- Processing of surgical images
- 3D reconstruction
- Tracking of objects
- …







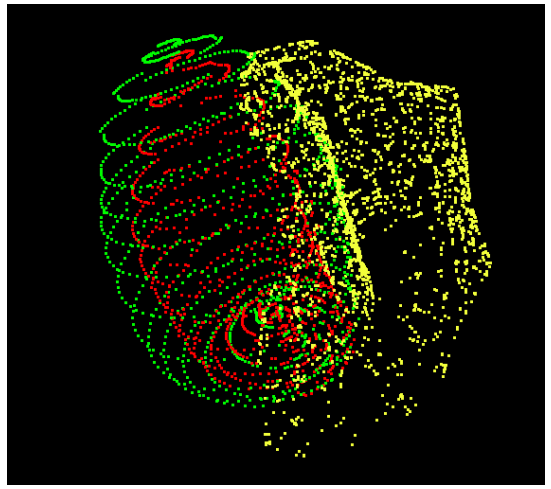


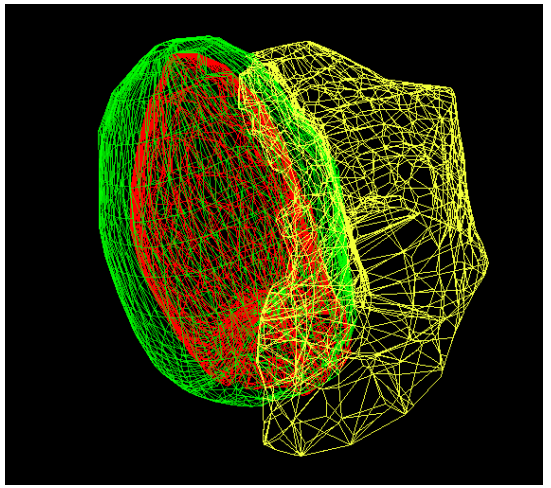
Segmentation

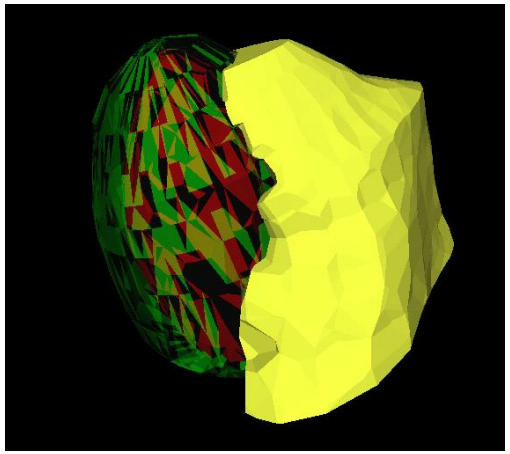
- What does segmentation mean?
- Methods
- Difficulties

Geometric Modeling

- Generate 3-dimensional Models

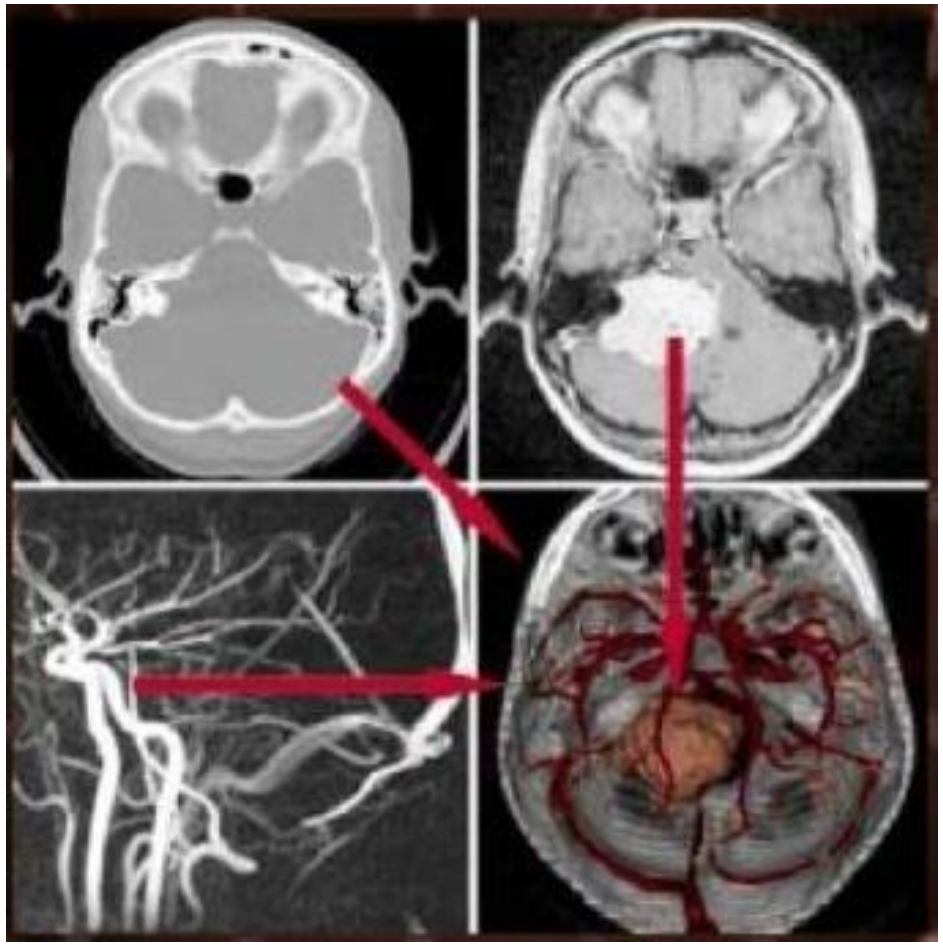






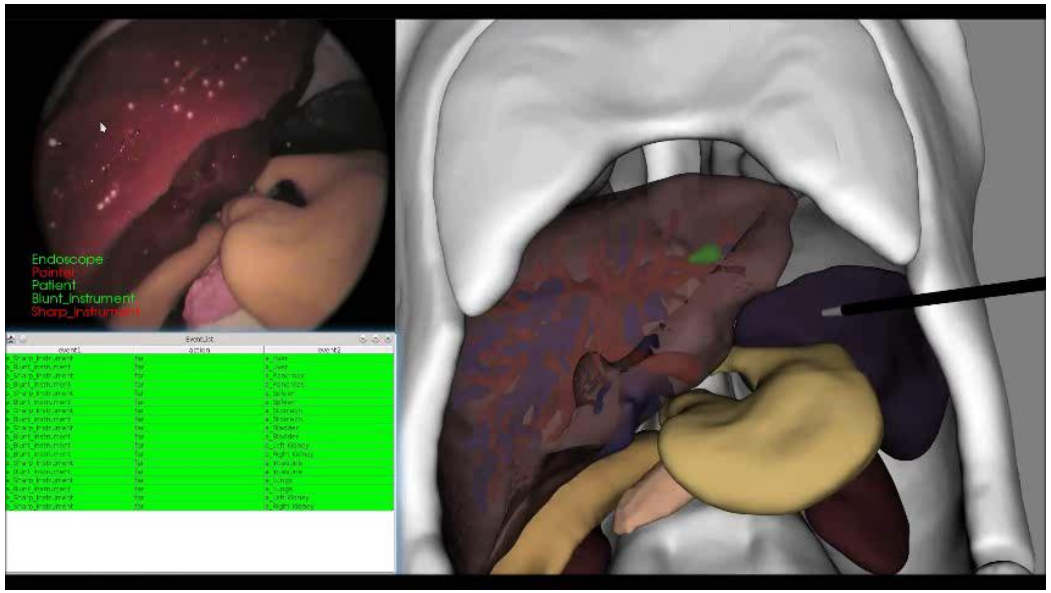
Registration

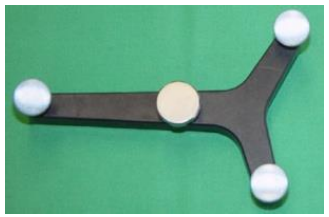
- What exactly is registration?
- Methods
- Combination of different modalities



Navigation

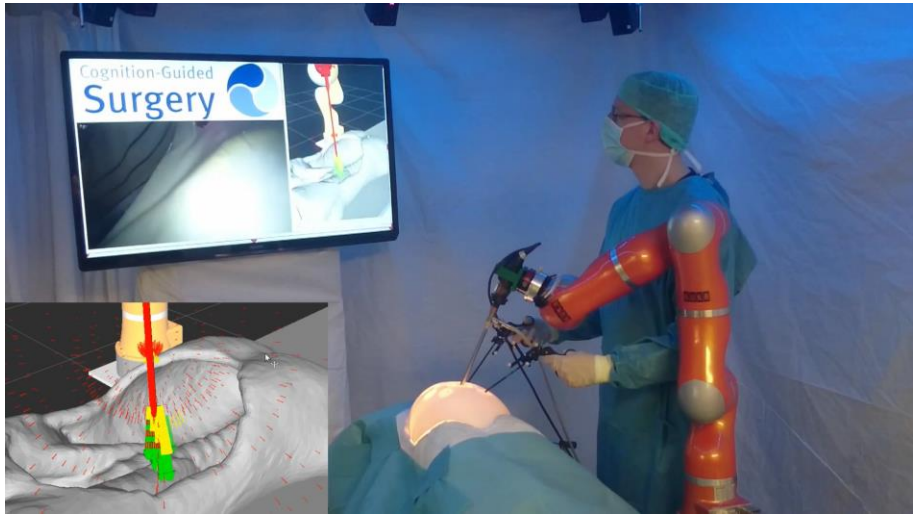
- Optical
- Electromagnetic
- Mechanical
- …





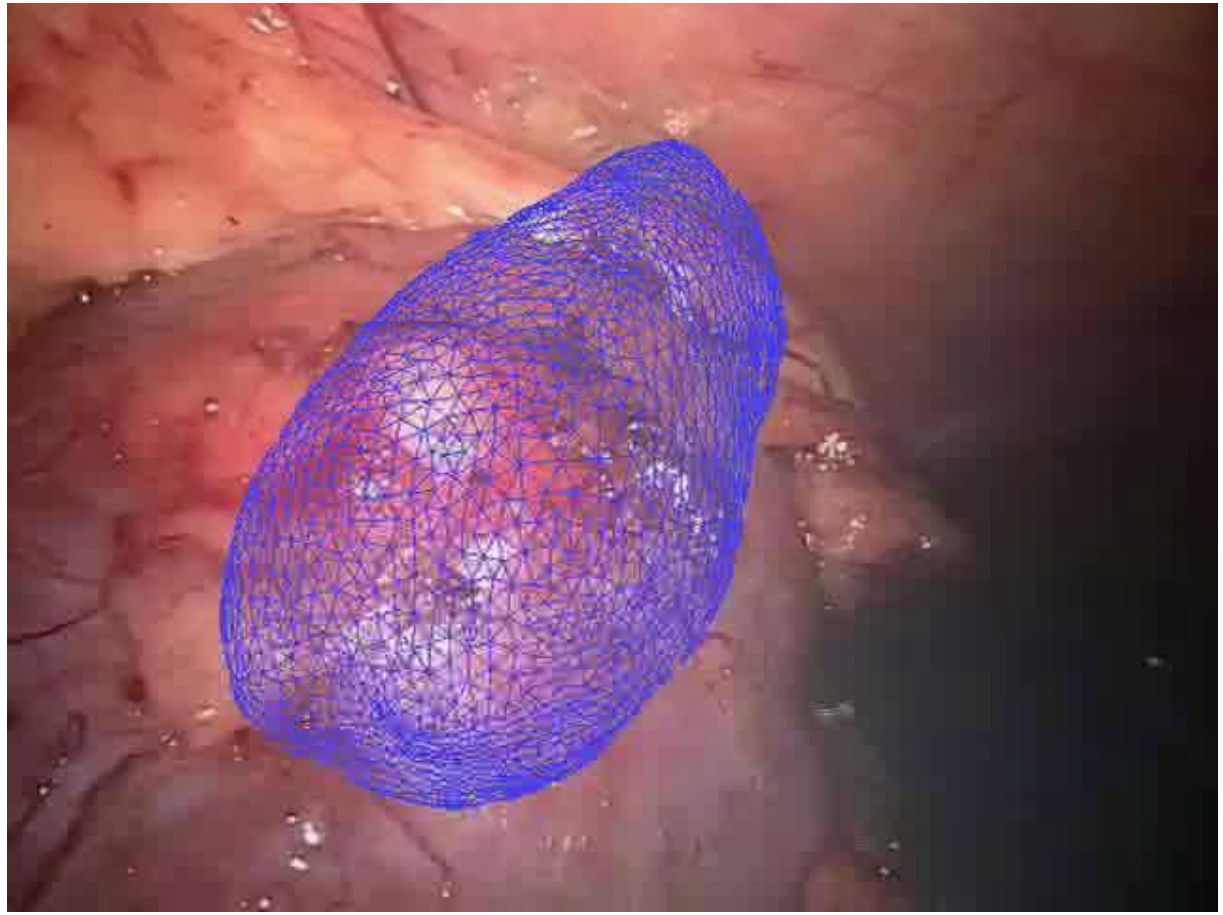
Robotics

- Definition robot
- Kinematics
- How are robots controlled?
- …



Augmented reality

- Assisting the surgeon during surgery

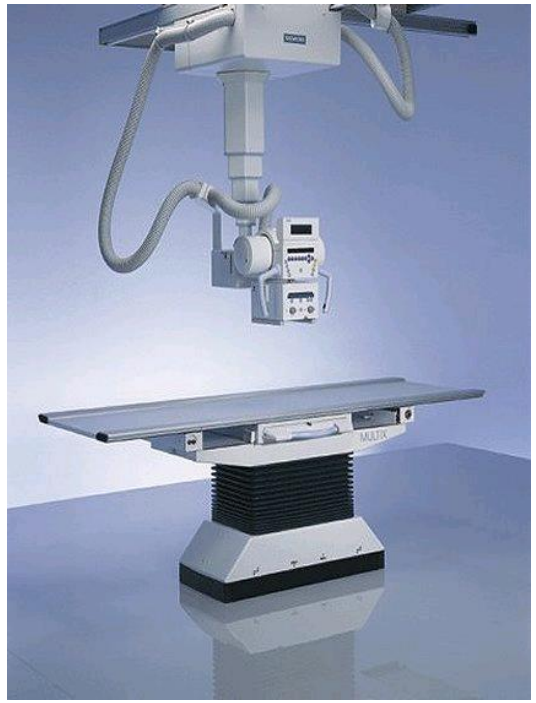


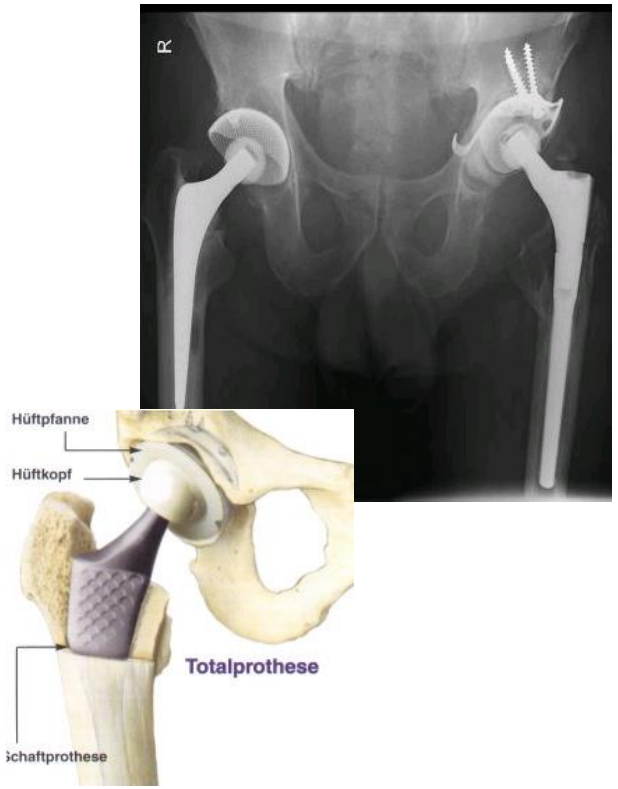
Break

IMAGE ACQUISITION – X-RAYS

Medical X-Rays/Projectional radiography

- Widely used, cheap

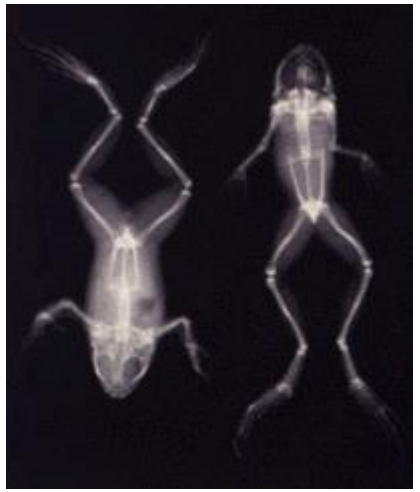




Quelle: Wikipedia

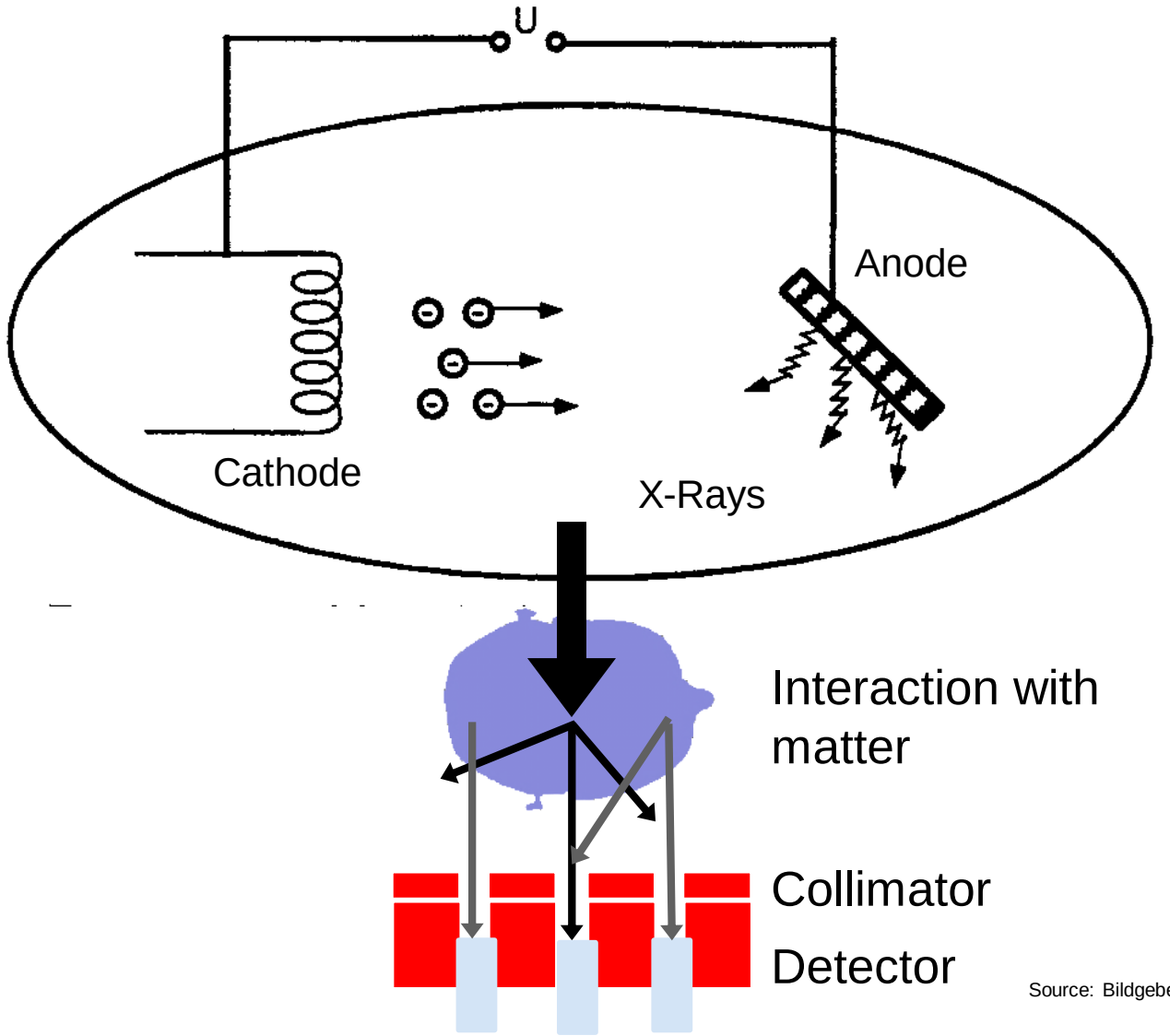
X-Rays - History

- 08.11.1895 *Wilhelm Conrad Röntgen* discovers X-Ray radiation in Würzburg
- 28.12.1895 first diagnostic usage of X-Rays by *Gustav Kaiser* in Vienna
- January 1896 Images of hands, arms, foreign materials, …



Quelle: Wikipedia

Physical principles



Source: Bildgebende Verfahren in der Medizin

Physical principles

- Attenuation (weakening) of X-Rays increases with
  - Wavelength
  - Atomic number of the material
  - Density of the material
  - Thickness of the material

→ Lead(Atomic number 82) high absorption, Water low
→ Bone (Calcium 20) higher than soft-tissue (H 1, C 6, O 8)

- The different attenuations can be used for imaging

$$N = N_0 \cdot e^{-\mu \cdot d}$$

N_0: Initial intensity
d : Thickness of material
μ : Attenuation coefficient

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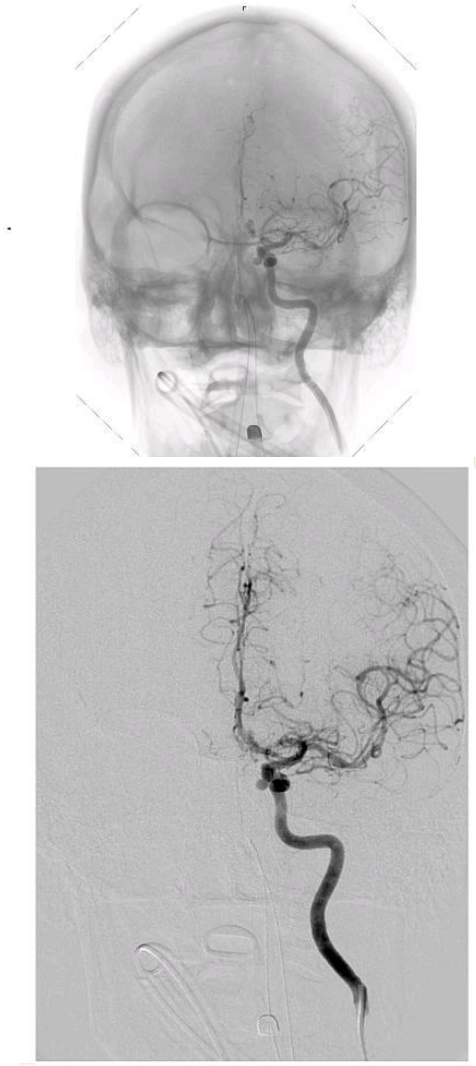
Contrast agent

- Classical X-Ray imaging only highlights bones well
  - Contrast agent increases (or decreases) the absorption of X-Rays.
  - Typical Application: Imaging of blood vessels or hollow organs such as the large intestine
- Digital subtraction angiography:

  Differential image with and without contrast agent

  → Only vessel tree visible



Quelle: Siemens

Summary

- Cheap and prevalent imaging method
- Differences in X-Ray absorption are used for imaging
- Very good depiction of bones

- Exposure of patients with ionizing radiation
- Lower contrast with soft-tissue, bones occlude structures
- No 3D information

SONOGRAPHY / MEDICAL ULTRASOUND (US)

US - History

- 1793 Spallazani discovers during experiments with bats that their collision avoidance stops working when their ear canal is obstructed
- 1883 Discovery of the piezoelectric effect by the Curie brothers
- 1927 the physical und biological effects of ultrasound are examined by Wood und Loomis
- 1952 Howry and Bliss create the first 2D ultrasound images of human organs
- 1954 Edler and Hertz present echocardiography
- 1958 Donald introduces ultrasound diagnostics in midwifery and gynecology

US – Physical principles

Overview ultrasound waves

- Tissue is compressed in direction of propagation
  → Longitudinal waves
- Only propagate through matter, are reflected/scattered at boundaries
- Frequency: 1MHz – 40 MHz (X-Rays 10^{17} – 10^{19} Hz)
- Velocity of propagation < 350 m/s (X-Rays speed of light)
  → Measurement of runtime (Echo)
- No biological damage

US - Physical principles

Production und receiving of ultrasound wave

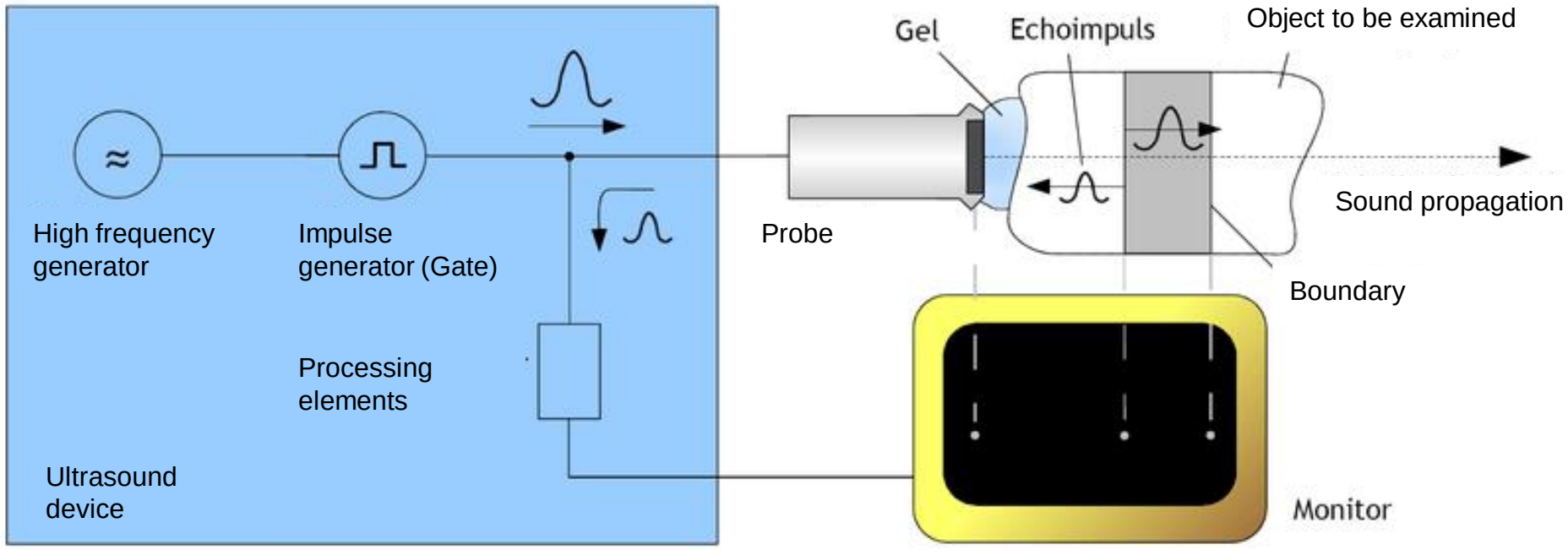
- Production ultrasound wave

  Using piezoelectric components (Deformation of a crystal through electric impulses)

- Receiving the reflected ultrasound wave

  using the same piezoelectric components (Crystal is deformed through sound waves and generates a measureable electric impulse)

US – Physical principles



Source:Wikipedia

US – Physical principles: Impedance

Impedance

- Tissue-specific resistance, which hinders the propagation of ultrasound waves

- Boundaries between areas of different impedance are visible in Sonograms

- Important: Not the impedance is being measured

⇔ X-Rays attenuation coefficient

US – Physical principles: Reflection

Reflection

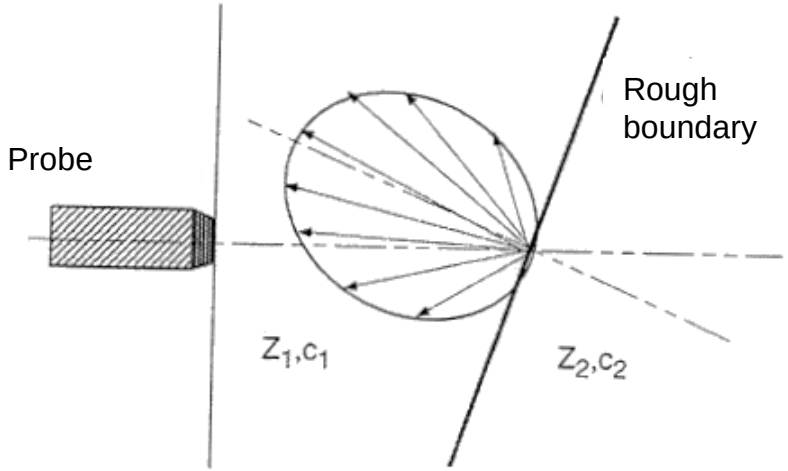
- Ultrasound waves are reflected at the boundaries between areas of differing impedance (contour echo)
- The larger the difference in impedance, the larger the rate of reflection (Compare to refractive index in optics)

$$R = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1} \right)^2$$

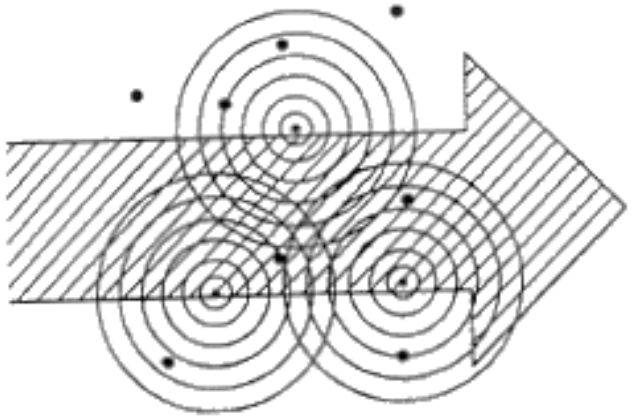
→ Gel is necessary for introducing ultrasound waves into the body (impedance matching)

US – Physical principles: Structural echo

- Structural echo
  results due to areas of inhomogeneity inside the Organ



Contour echo



Structural echo

Source: Bildgebende Verfahren in der Medizin

US - Frequencies

With what frequencies are waves emitted?

- High frequency -> high spatial resolution and low penetration
- Low frequency -> low spatial resolution und high penetration

→ Select highest frequency that can still reach the required penetration

Frequency	2-15 MHz
Wavelength (in muscle tissue)	0,78-0,1mm
Penetration	12-1,6 cm
Resolution lateral	3,0-0,4 mm
Resolution axial	0,8-0,15 mm

US – Measurement parameters

Measured Parameters

- Runtime of the reflected signal

  Allows determining the depth of reflected structures.
- Strength of the reflected signals (echogenicity)

  Color-coding: typically high echogenicity -> white

Numbers

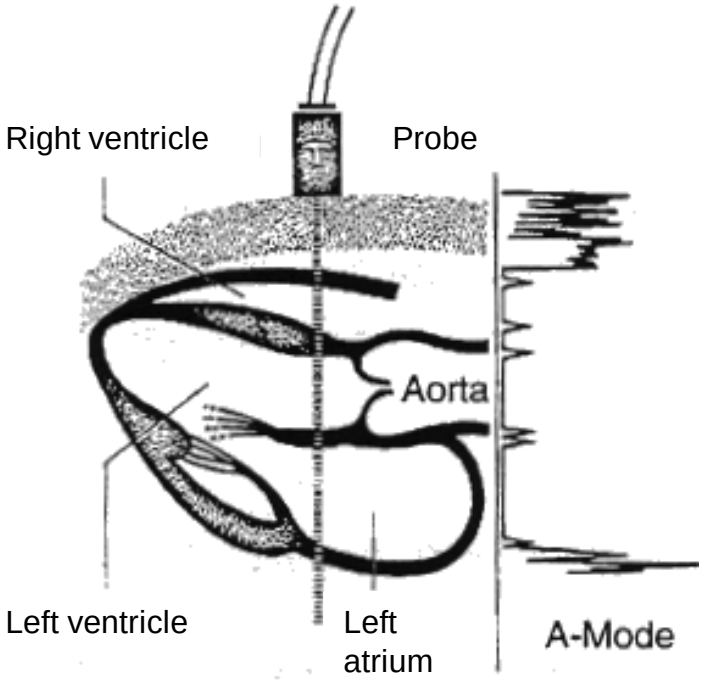
- Duration emission: ca. 1μs
- Duration measurement: ca 300μs

1D-Ultrasound (A-Mode)

A-Mode (Amplitude modulation)

- Reflection of a signal ray is examined
- Penetration depth is plotted against the amplitude of the echos
- Returning signals are amplified with a time-dependent amplifier

→ is practically not used anymore!



Source: Bildgebende Verfahren in der Medizin

2D-Ultrasound (B-Mode)

B-Mode (Brightness Modulation)

- The ultrasound ray is evenly passed over a plane
- Echo amplitude is translated into grayscale
- Image consists of a fan of approximately 100 lines

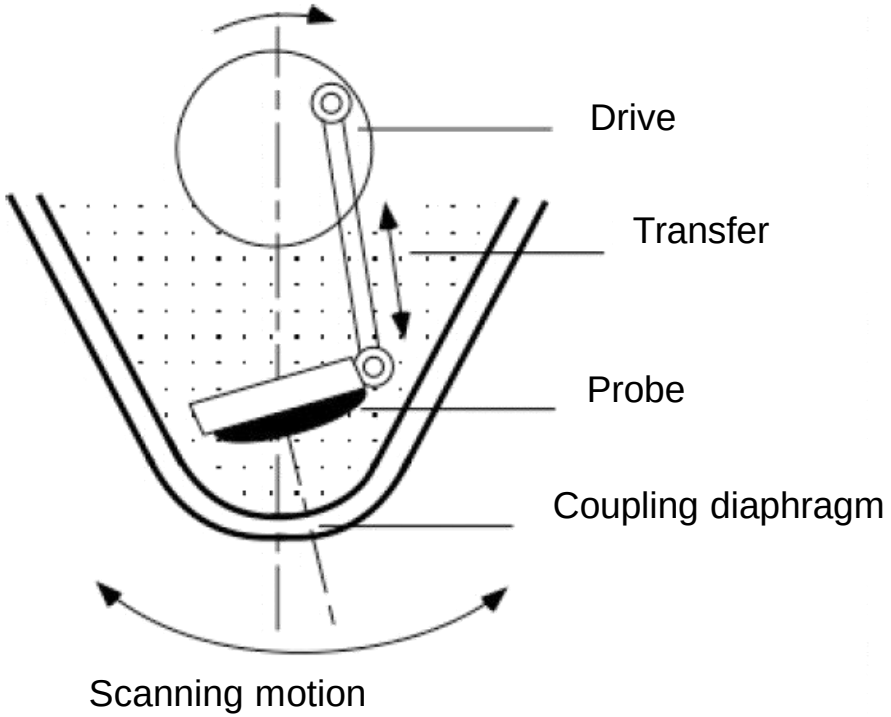
→ 30 Hz framerate

9-week-old Fetus (Source: Wikipedia)

2D Ultrasound (B-Mode)

Mechanical solution

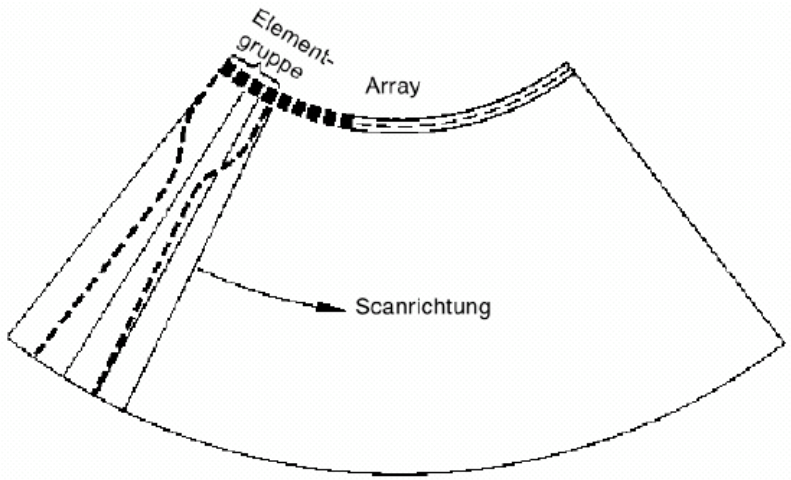
- US-probe oscillates and generates arc-slices



Source: Bildgebende Verfahren in der Medizin

Electrical solution

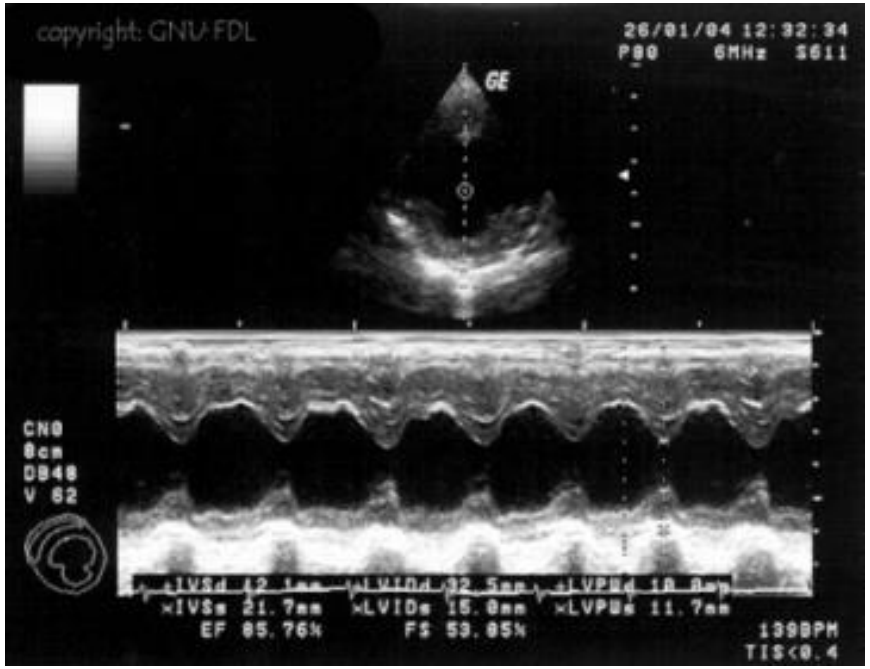
- Many small US-probes in an array
- A few probes are addressed simultaneously
- The active probe-group is moved elementwise



M-Mode

Ray with a high impulsee repetition frequency, Amplitude on vertical axis

Over multiple time points: Analysis of movements



Snap-shot of dog heart

Source:Wikipedia

Application in cardiology

3D-Ultrasound

- Additional scanning plane
- Similar scanning technic as for 2D-US
- Measurement over time = 4D-Ultrasound
- Lower spatial resolution

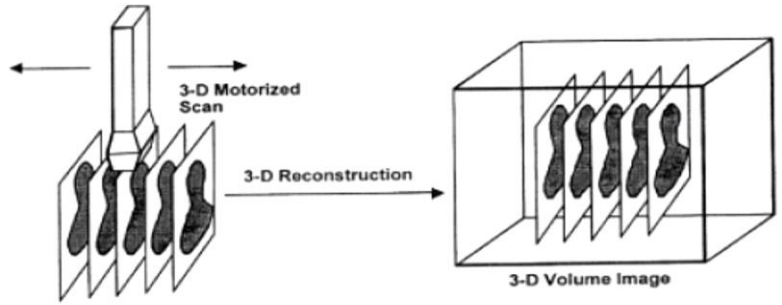


Abb. 3.6: *Linear Array beim 3D-Ultraschall* [3]

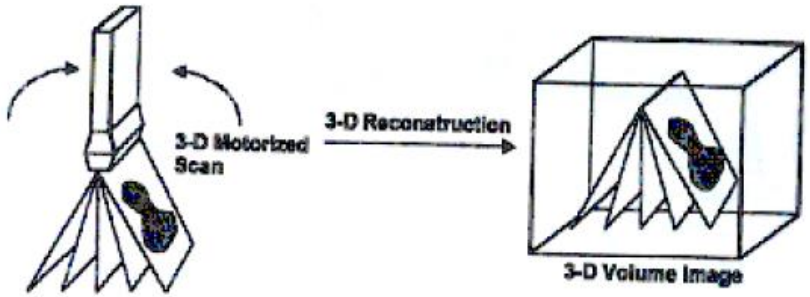


Abb. 3.7: *Sectorscan beim 3D-Ultraschall* [3]

3D demonstration of cranial sutures and fetal structure anatomy

Quelle:Diagnostica

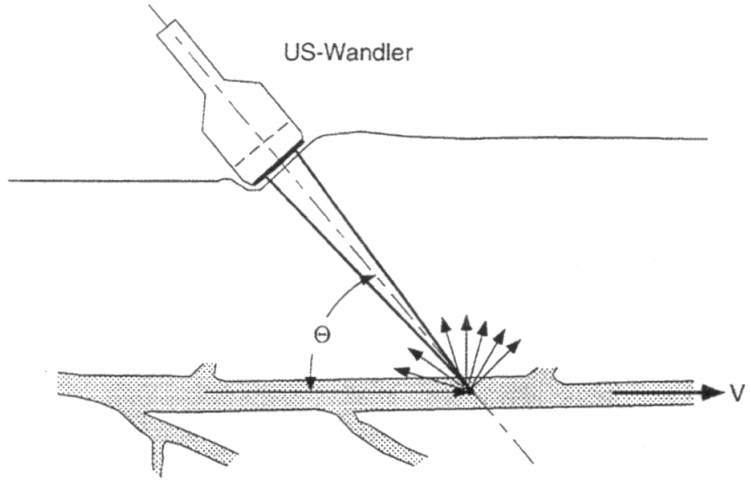
Doppler effect

- Doppler effect = Frequency change of waves, when receiver and/or transmitter change their distance to one another

- Example: Passing ambulance

$$\Delta f = \frac{2f}{c} \cdot v \cdot \cos \Theta$$

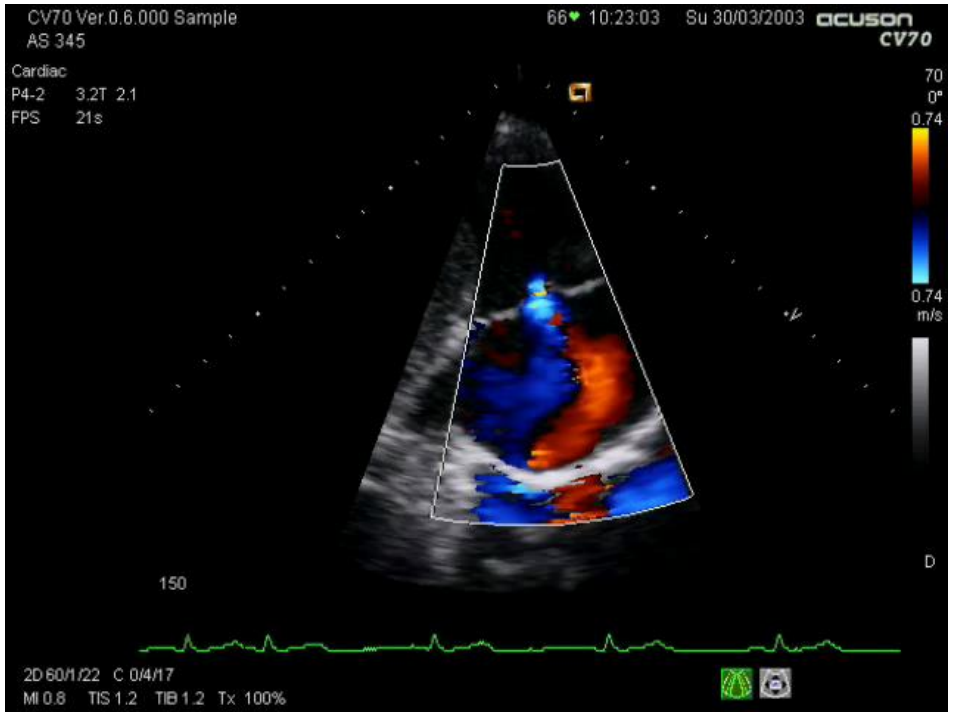
- Application: Measurement of blood flow velocity



Quelle: Bildgebende Verfahren in der Medizin

Color Doppler-Ultrasound

- Determing blood flow velocity via Doppler-Effect.
- Coding the velocity in red/blue pseudo-colors in an overlay.



Quelle: Siemens

US Summary

- Based on the propagation and reflection von sound waves

- Pros:
  - No ionizing radiation, not invasive
  - Cheap (in comparison to CT / MRT)
  - Real-time information

- Cons
  - Low penetration, no examination of air filled spaces
  - Difficult to interprete

Literature

- O. Dössel, Bildgebende Verfahren in der Medizin, Springer
- http://de.wikipedia.org/wiki/Sonografie
- H. Handels, Medizinische Bildverarbeitung, Teubner
- T. Lehmann, Bildverarbeitung für die Medizin, Springer