Cognitive Robotic Surgery: Participation to EUROSURGE

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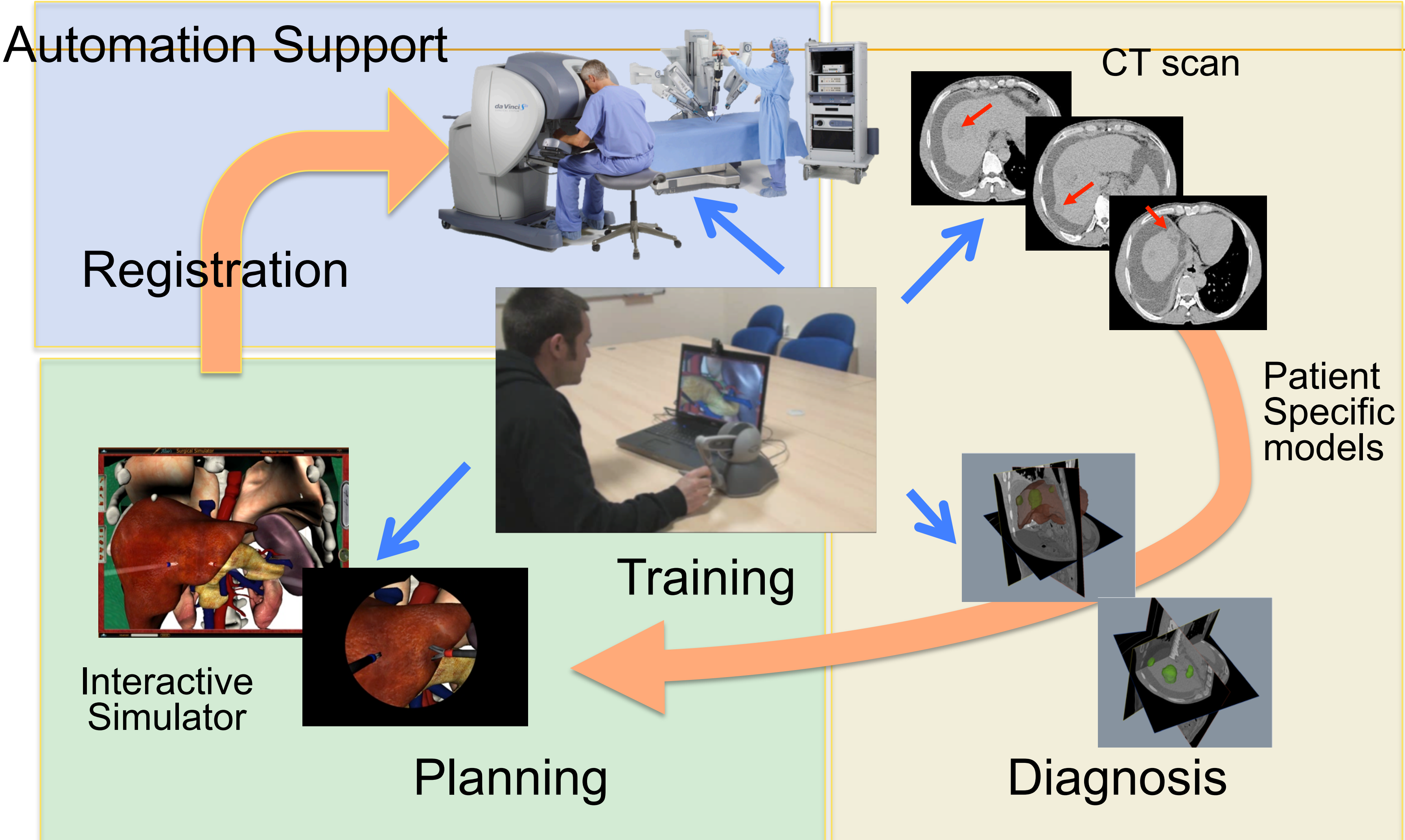
Summary

- My understanding of Cognitive Surgical Robotics
- How the EU has sponsored this area
- Key issues
- Conclusions

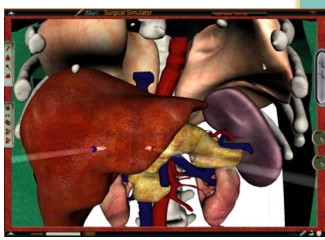
Data-driven Robotic Surgery



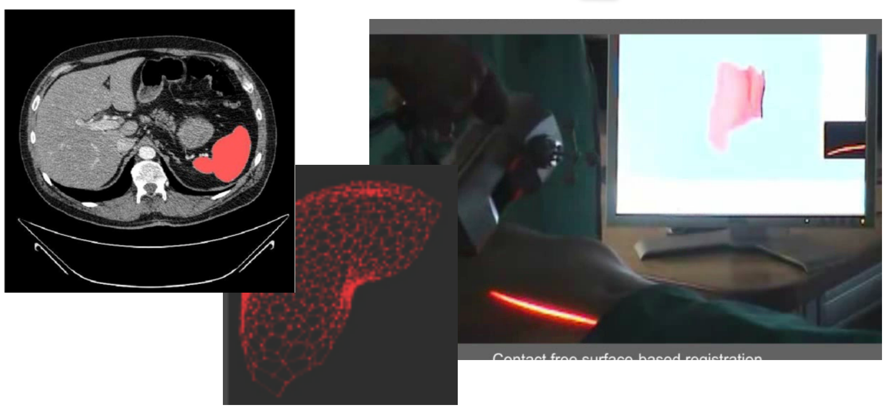
Robotic Hardware

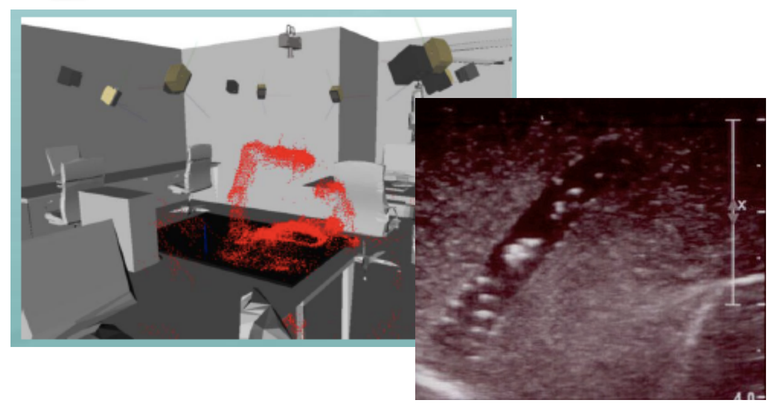
Need new robots and controls to support data flow

Software Applications

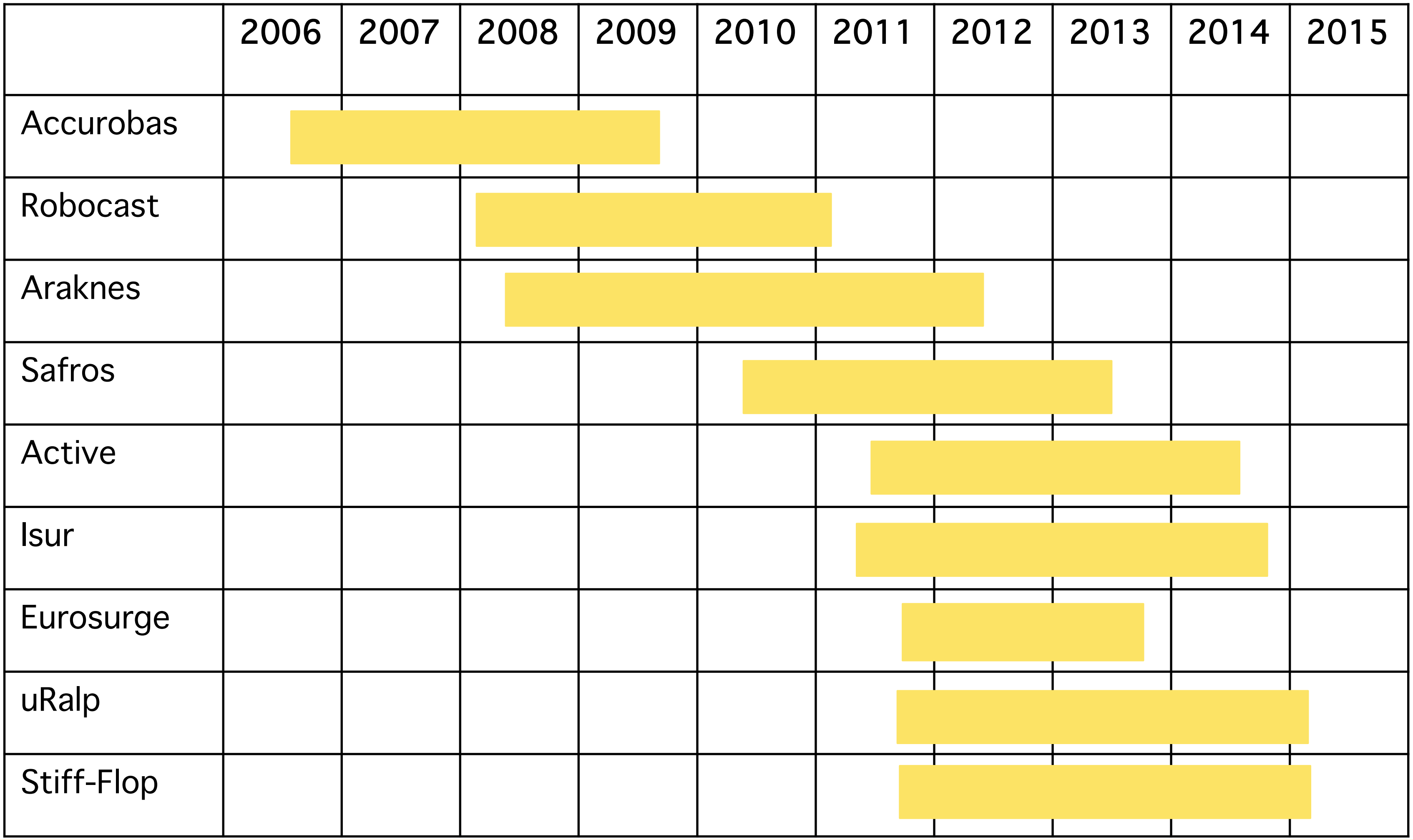


Need modeling and registration software





Schedule of (some) EU Projects on Robotic Surgery



AccuRobAs Project (2006-2009)

Universität Karlsruhe (TH)
Forschungsuniversität • gegründet 1825

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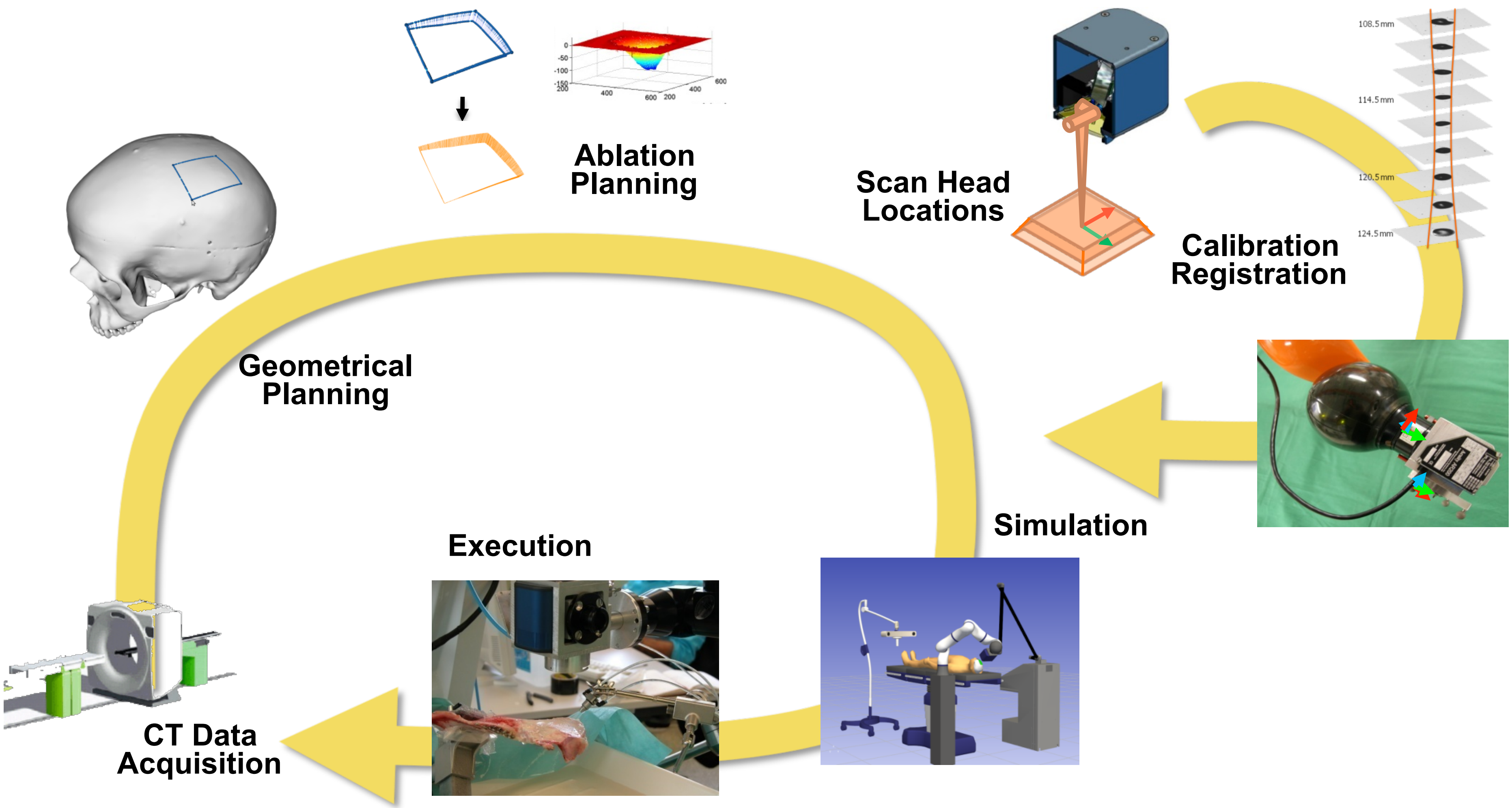
DLR

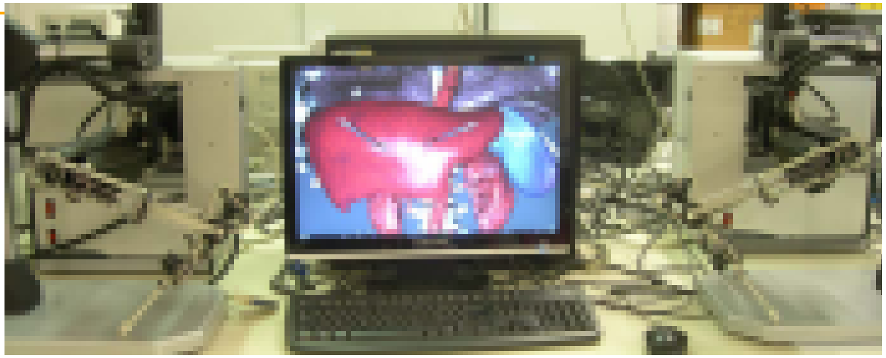
BrainLAB

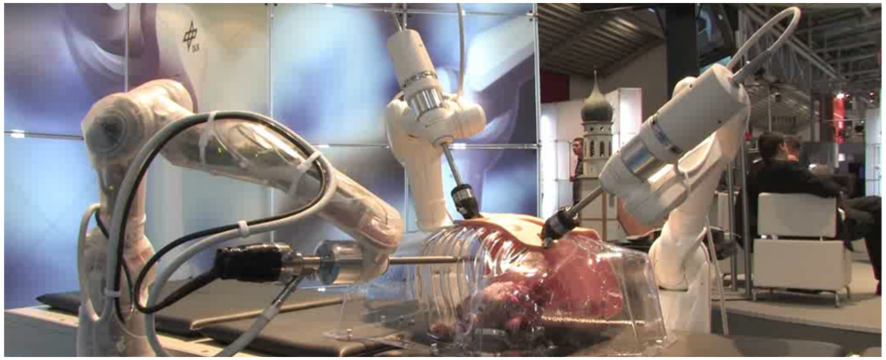
Robot Assisted Laser Osteotomy



Minimally Invasive Robotic Surgery Demonstrator

- Pre-operative Phase
- Peri-operative Phase
- Intra-operative Phase
  - Palpation
  - Motion Compensation





SAFROS: Patient Safety in Robotic Surgery (2010-2013)

EPFL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

center for biorobotics

KIT
Karlsruhe Institute of Technology

HOLOGRAFIKA Holographic display technology

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DLR

HSR
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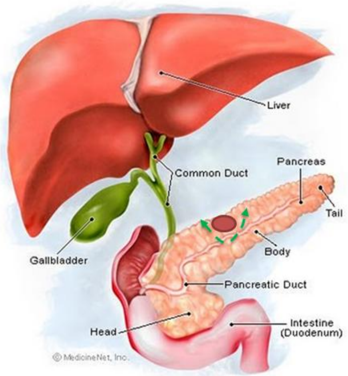
Force Dimension

World Health Organization

SCHOOL OF PEDAGOGICAL AND TECHNOLOGICAL EDUCATION

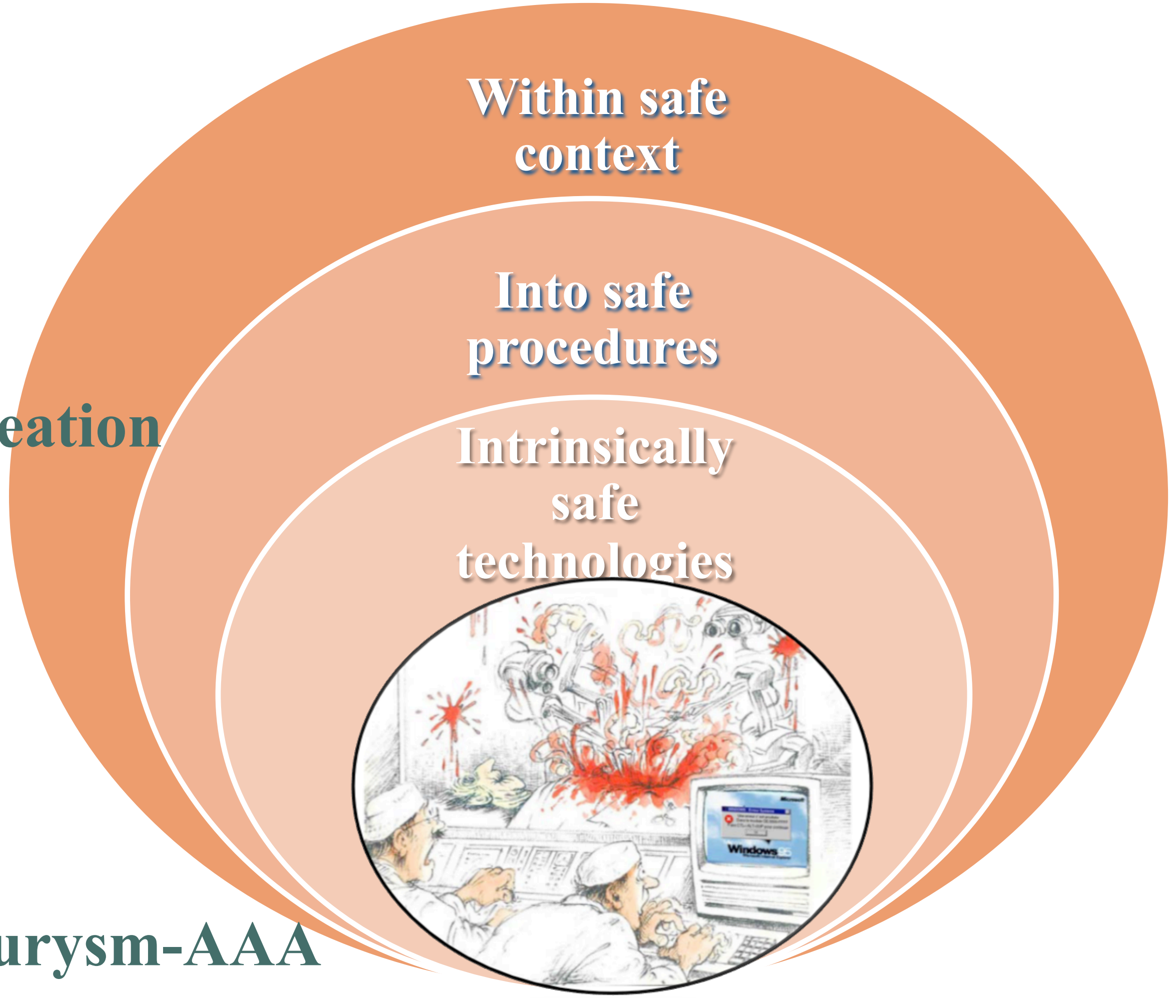
FP7-ICT-2009-4-248960

Analysis of two different procedures

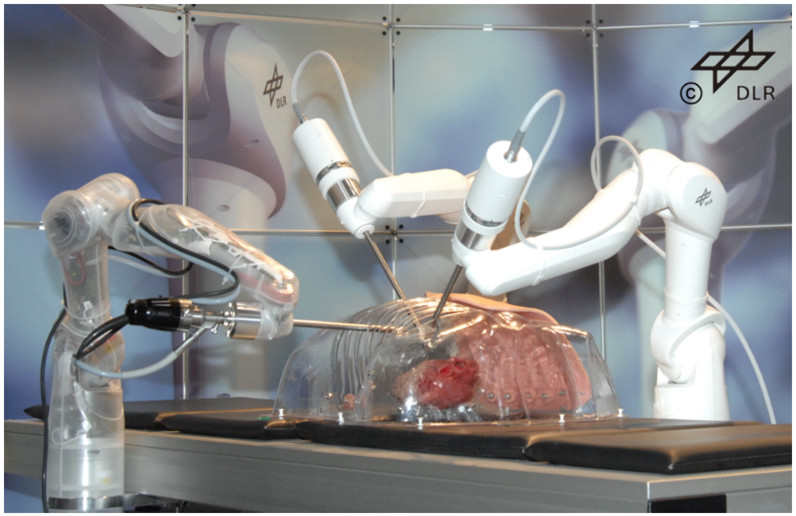


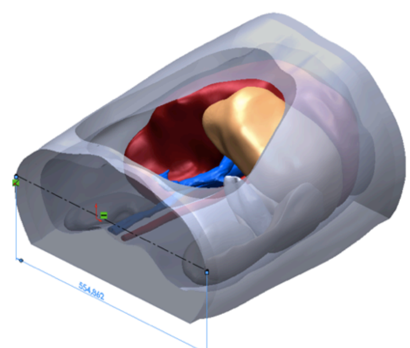
Pancreas Tumor Enucleation

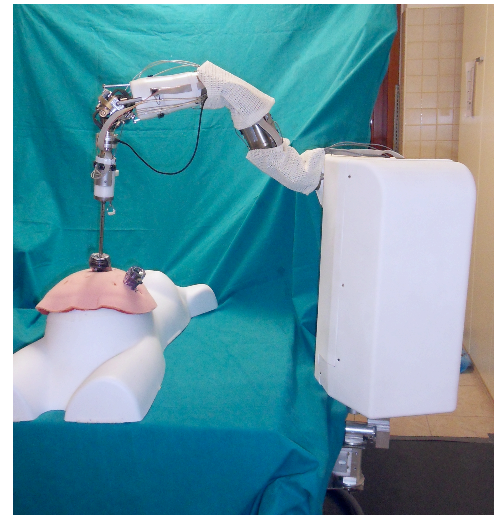
Abdominal Aortic Aneurysm-AAA



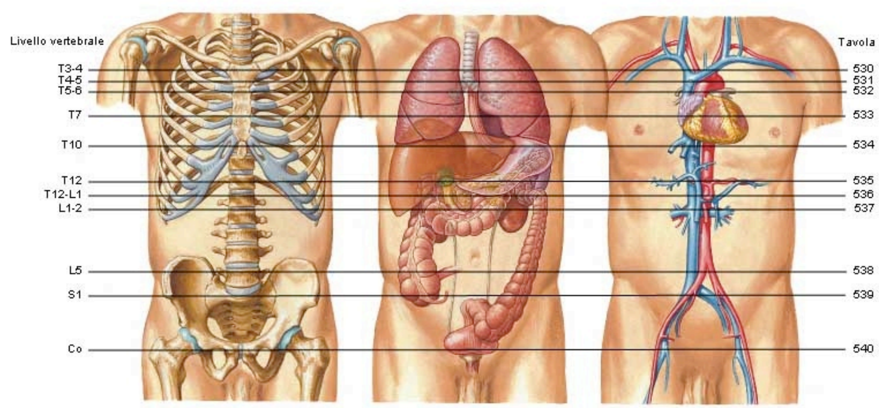
Performed with two different robots







- Define patient safety in the context of robotic surgery
- Measure how technology can improve it



I-SUR: Intelligent Surgical Robotics (2011-2014)

center for biorobotics

Oslo University Hospital
The Intervention Centre

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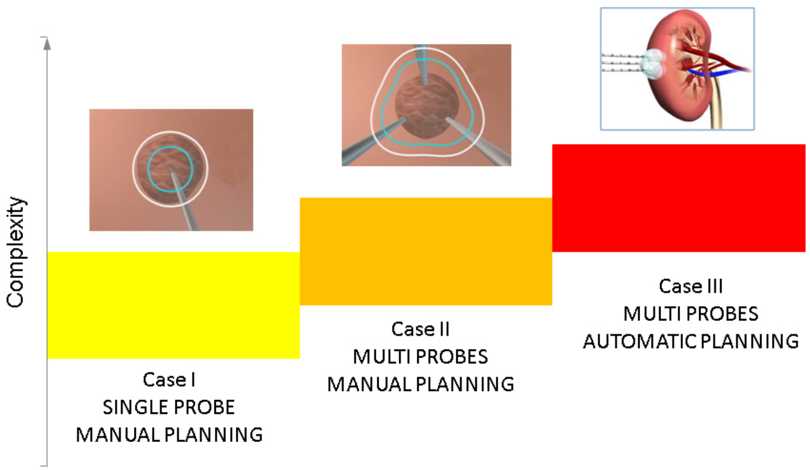
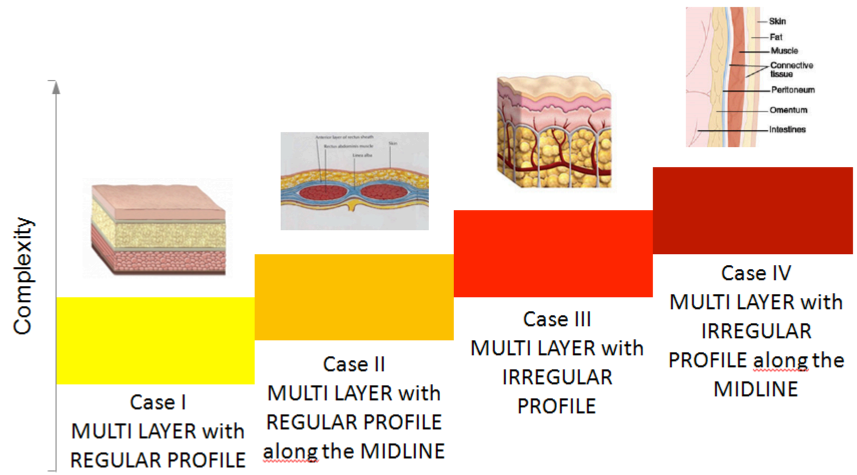
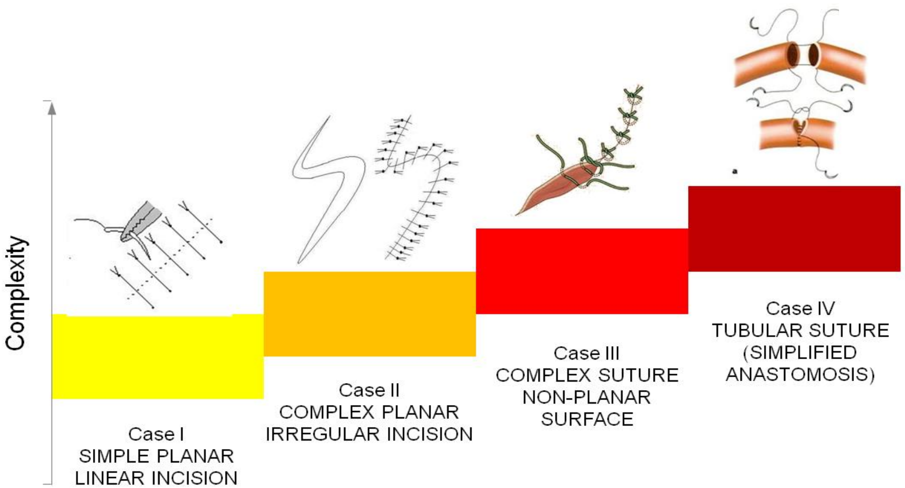
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

FP7-ICT-2009-6-270396

Automating tasks of increasing complexity

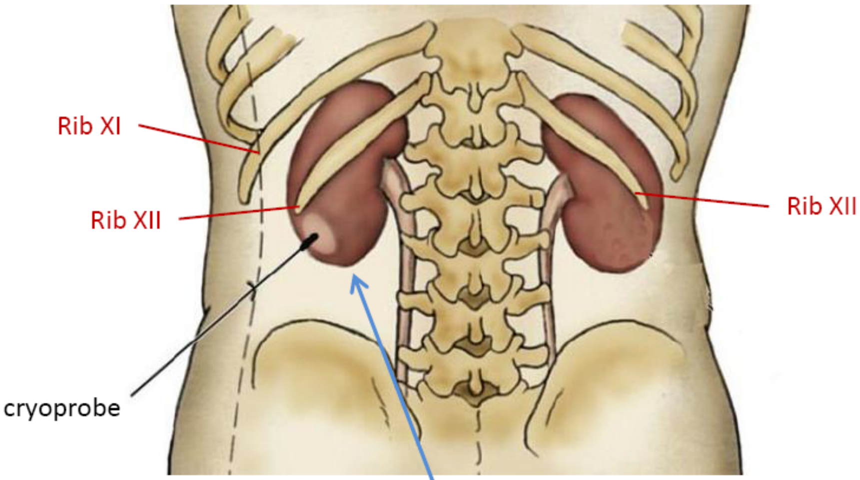




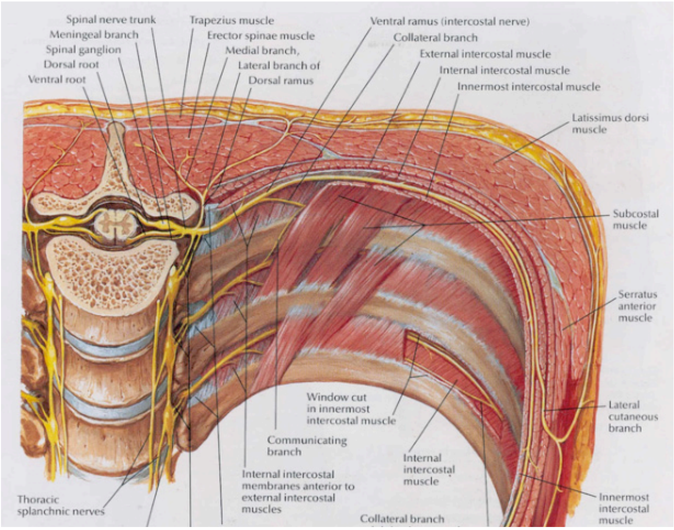


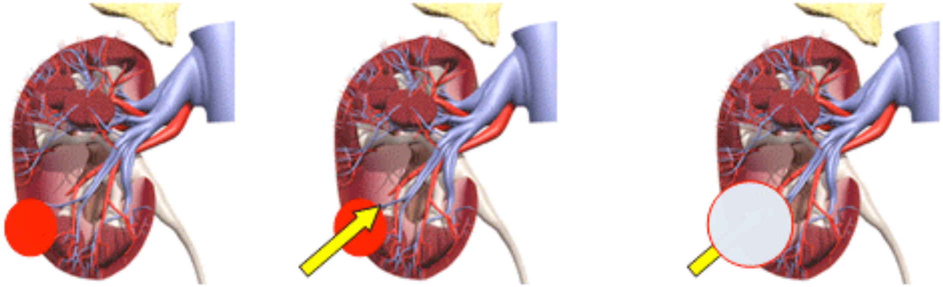
- Surgical action model
- Sequence plan
- Robotic design
- Sensing requirements
- Reasoning requirements
- Control structure

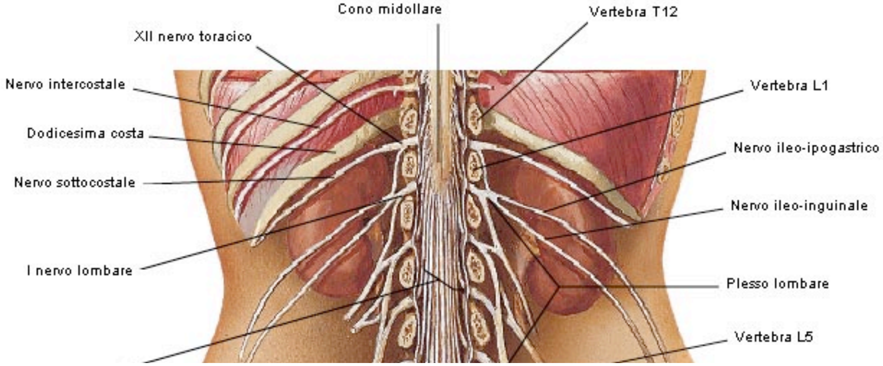
Medical context of puntcturing



Tumor in the posterior side
inferior pole of the kidney







EuRoSurge: European Robotic Surgery (2011-2013)

POLITECNICO DI MILANO

KIT
Karlsruhe Institute of Technology

ibec Institut de bioenginyeria de Catalunya

VE RI TAS

NIPG

Project Objectives

1. Identification of the **key European players** in surgical robotics, (e.g. technological players, skilled end-users and EU funded projects) from which to derive the *applicable device/solutions*;
2. Identification of the **key European players** in cognitive sciences relevant to surgery, from which to derive *the applicable methods*;
3. Creation of a **glossary/ontology** for cognitive surgical robotics to specify the *interconnection among devices and methods*;
4. Specification of a **reference architecture** for cognitive surgical robotics on which *to test the device/method connections*;
5. Formulation of **procedures for validation** of surgical robots, their architectures and composing modules;
6. Identification of **non-technical roadblocks**, e.g. patents, ethical and legal aspects.

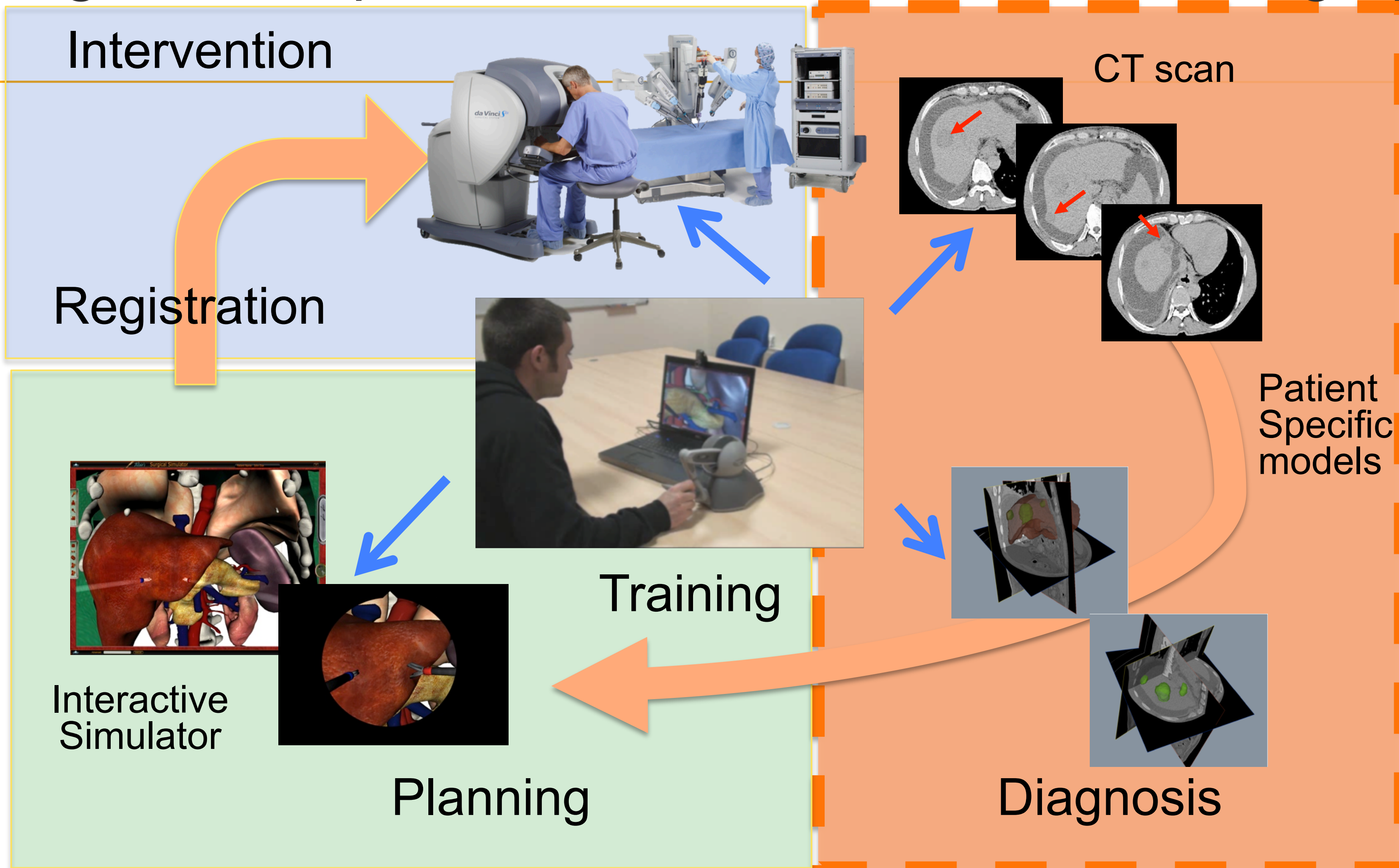
Initial Efforts

1. Census of laboratories involved in robotic surgery
2. Development of a portal for glossary/ontology definition, linked to other similar efforts
3. Development of a ROS/Orocos based architecture for modularity and validation
4. Survey of validation benchmarking methods
5. Cooperation with lawyers to assess regulatory and legislative aspects of new technologies
6. Involvement of extra-European partners as advisors to the project, JPL and Chonnam National University (South Korea)

Cognition should aim at Patient Safety

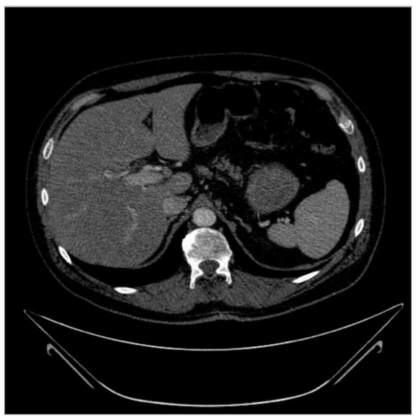
- **Cognition should improve:**
  - **Medical image processing:** segmentation and validation
  - **Model computation:** techniques, calibration, hardware
  - **Simulation and planning:** trajectories and virtual fixtures
  - **Perception:** haptics, 3D vision, acoustic
  - **Execution:** new surgical robots, automation & control
- Training: skills, rules and knowledge for these technologies
- Support through European projects

Cognitive Aspects of Data-driven Robotic Surgery

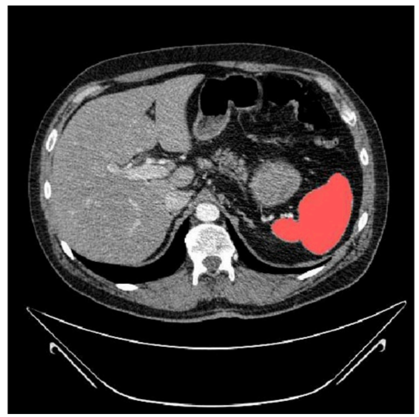


Virtual model creation

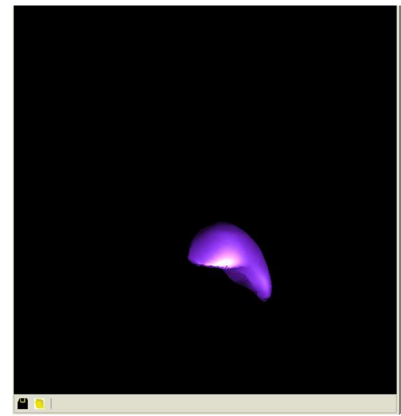
Each step corresponds to a software module



DICOM dataset



Segmented image

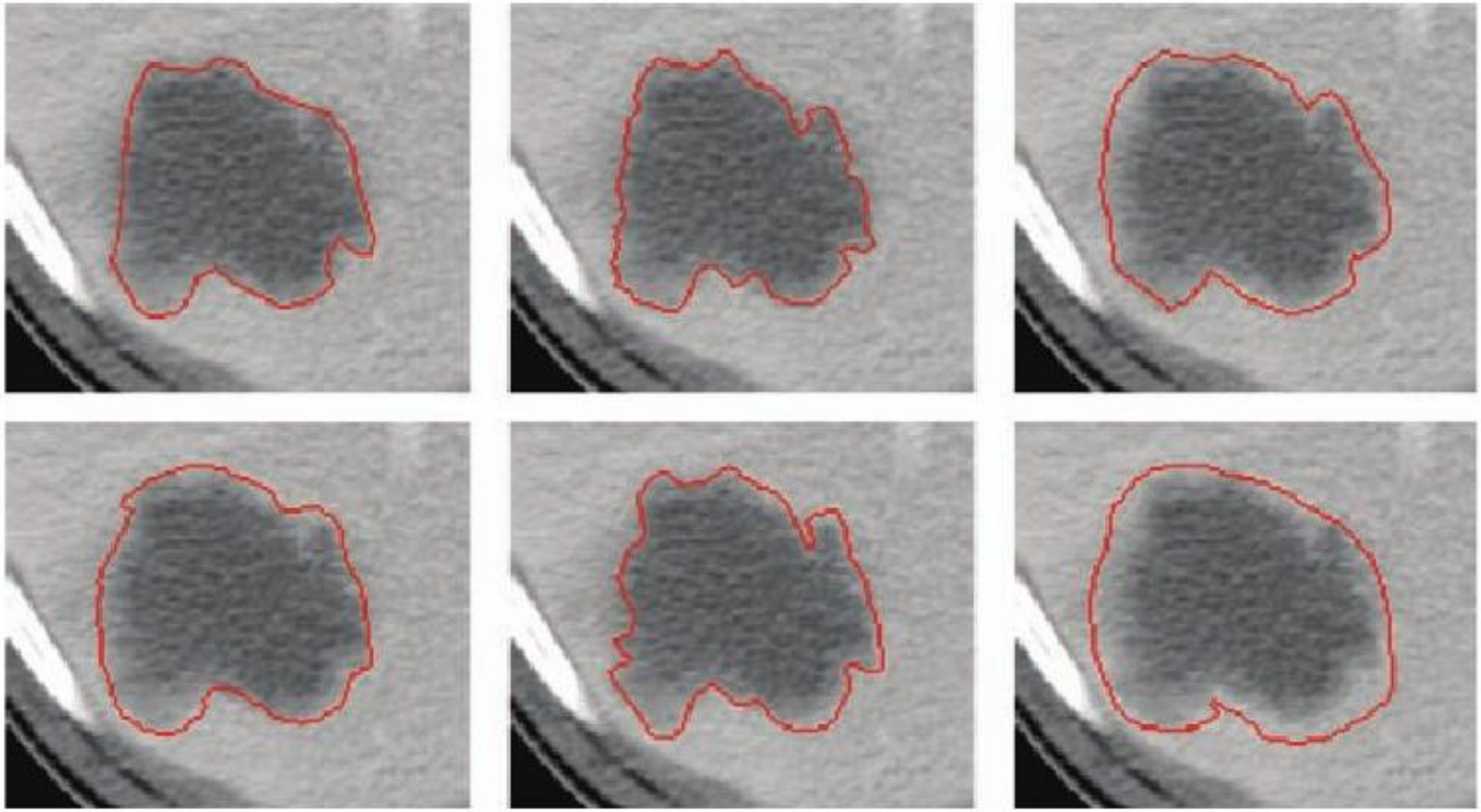


3D model

Repeat for each organ of interest

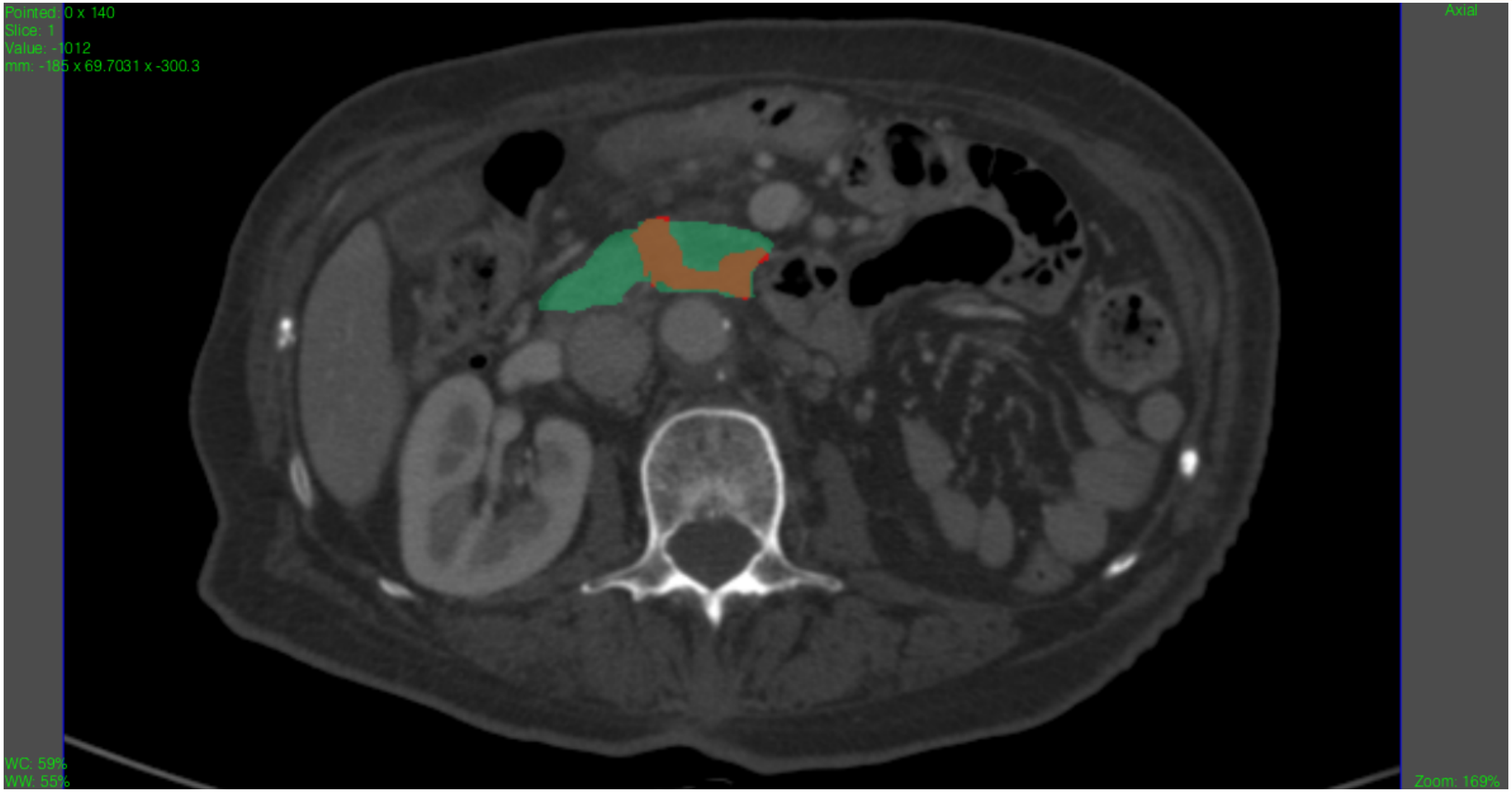
However, how do we validate the segmentation?

Typical performance: easy environments



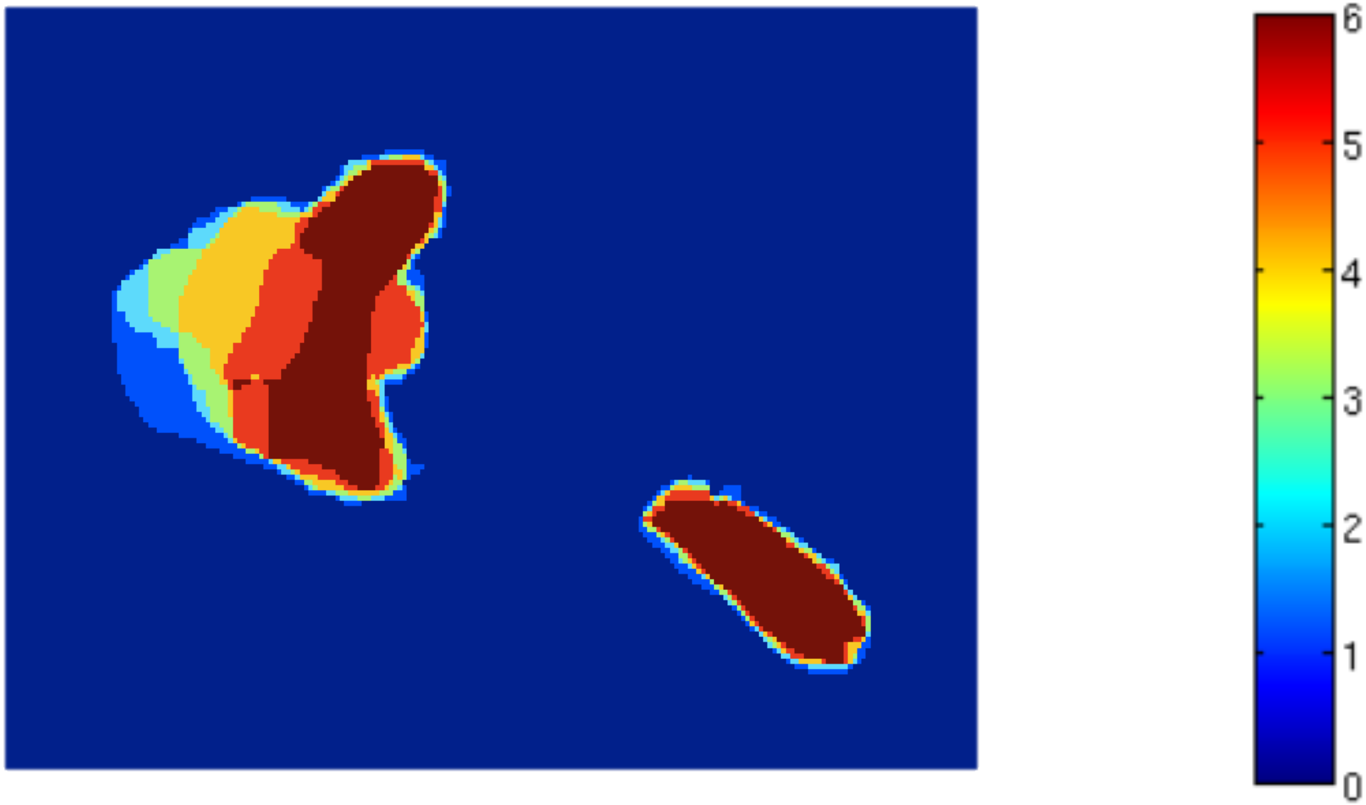
Task: countour an epatic tumor by 6 different radiologists

Typical performance: more complex environments



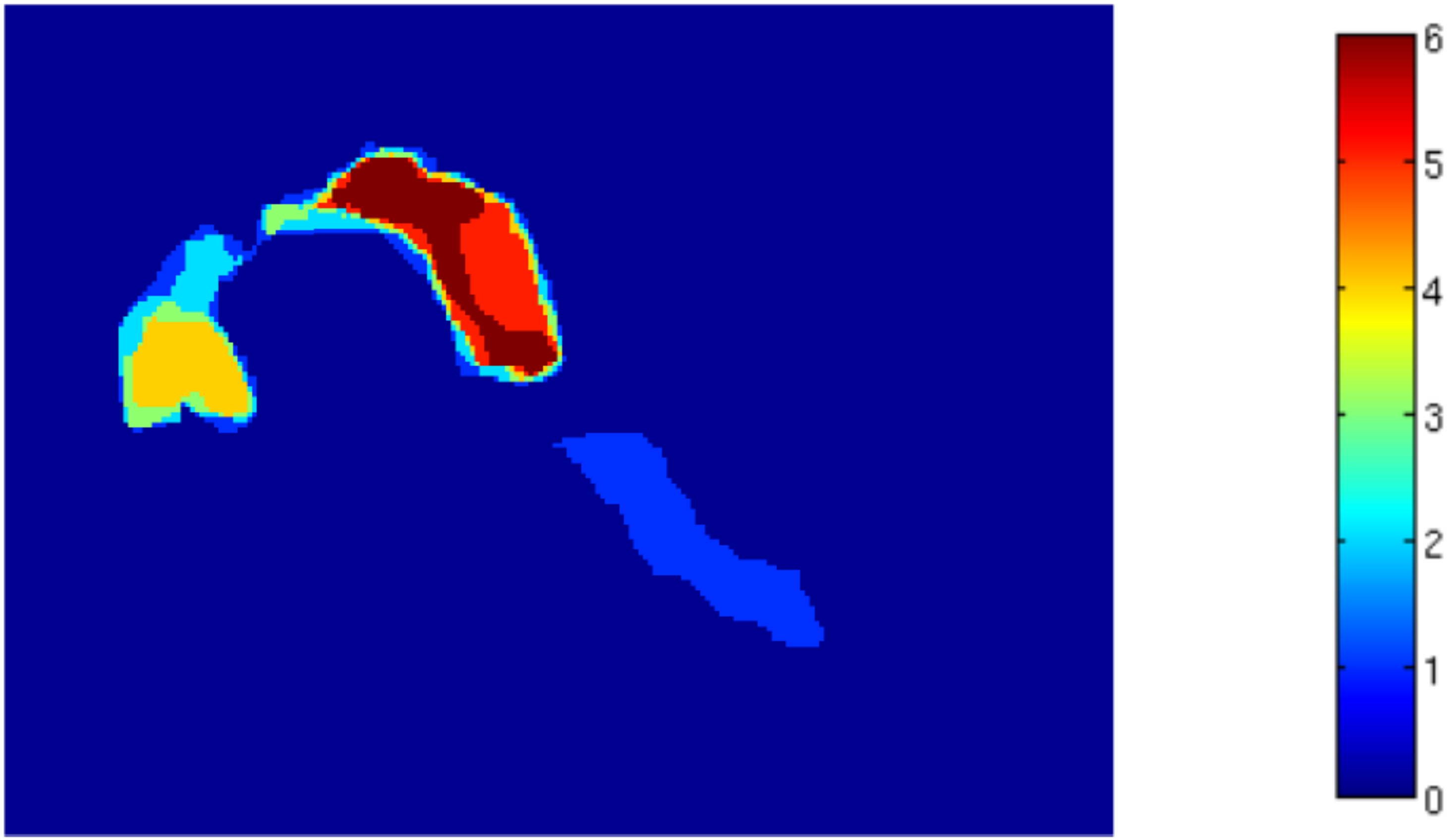
Task: contour pancreatic parenchyma

Consensus on healthy organs



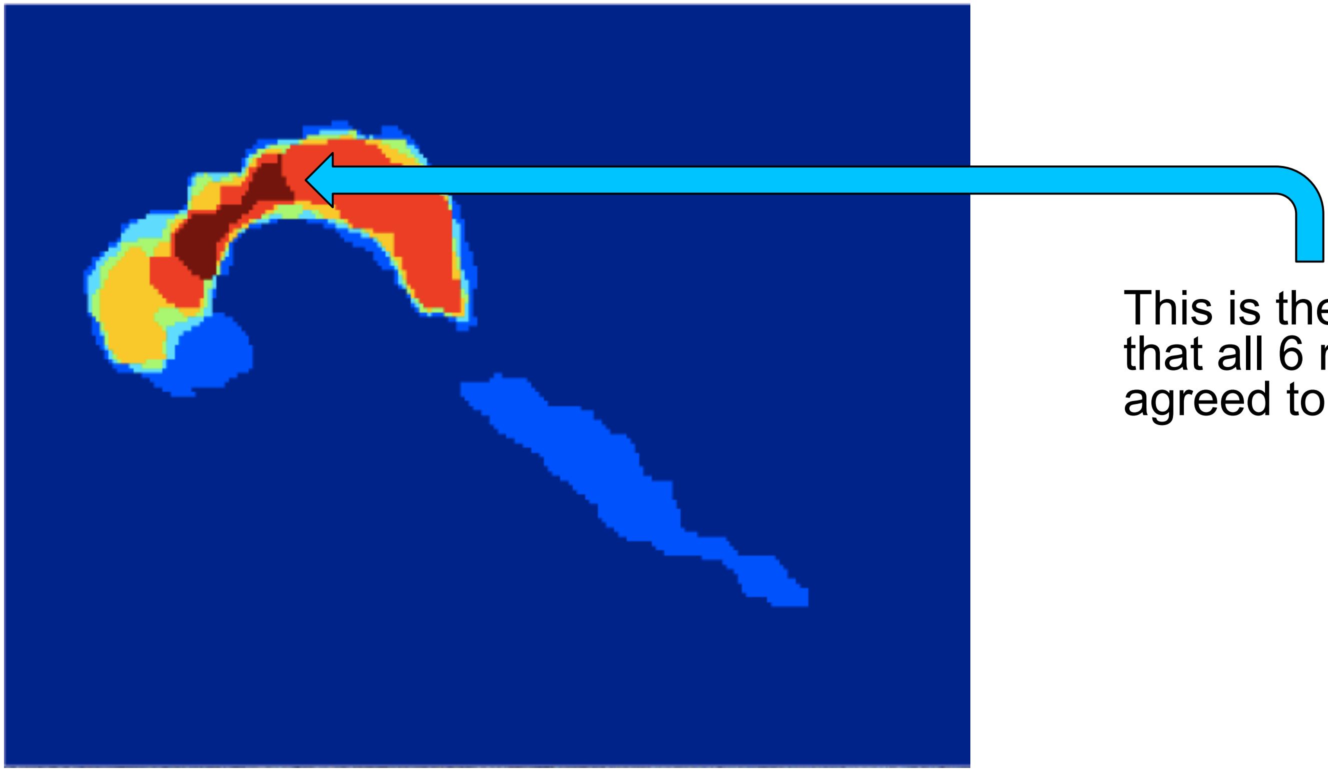
Task: contour healthy pancreatic parenchyma
(6 different radiologists)

Consensus on pathological organs



Task: contour healthy pancreatic parenchyma
(6 different radiologists)

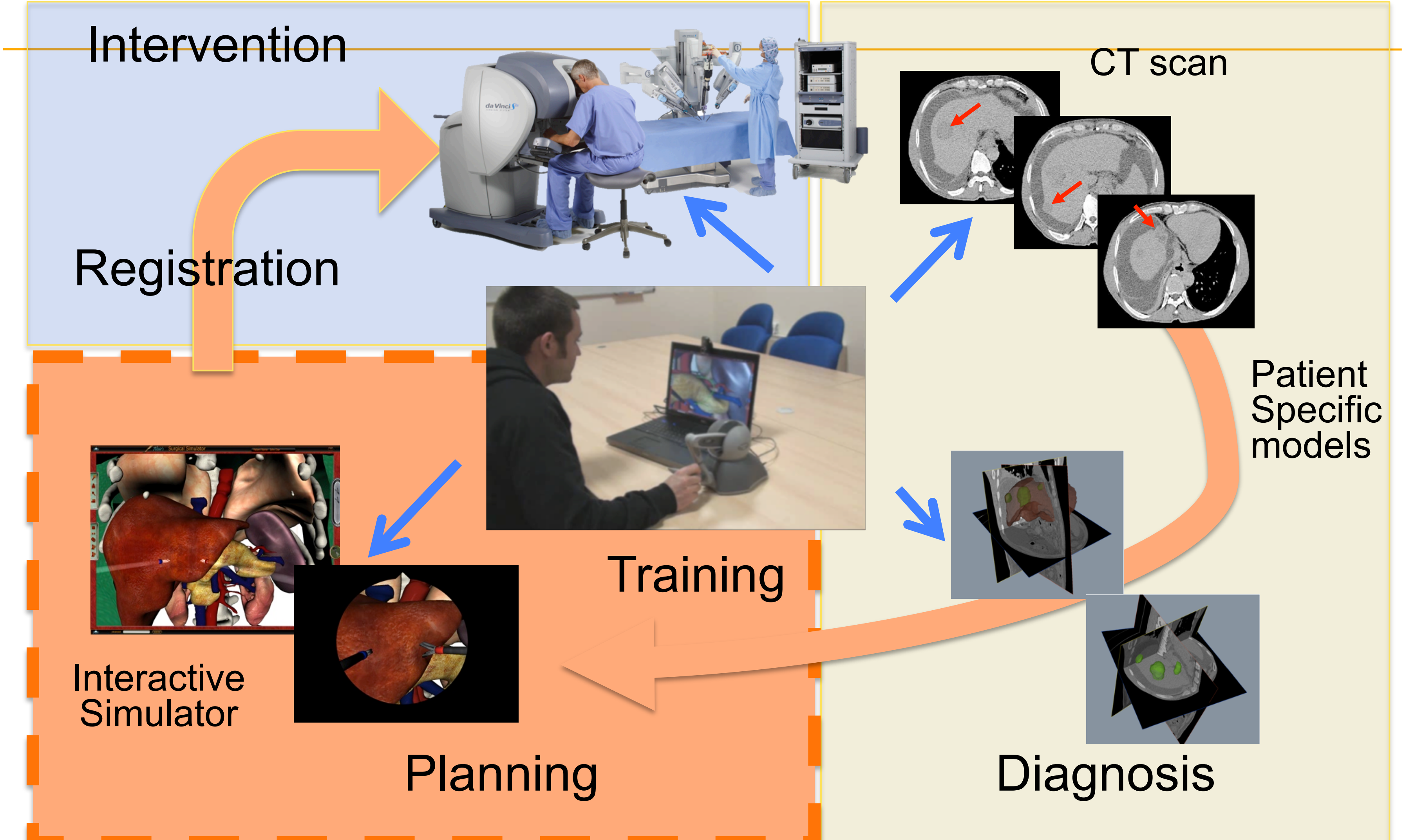
Segmentation Validation of Pathology?



This is the only area that all 6 radiologists agreed to be healthy

Model generation depends on the radiologist: we are investigating what are the factors influencing such largely different diagnosis

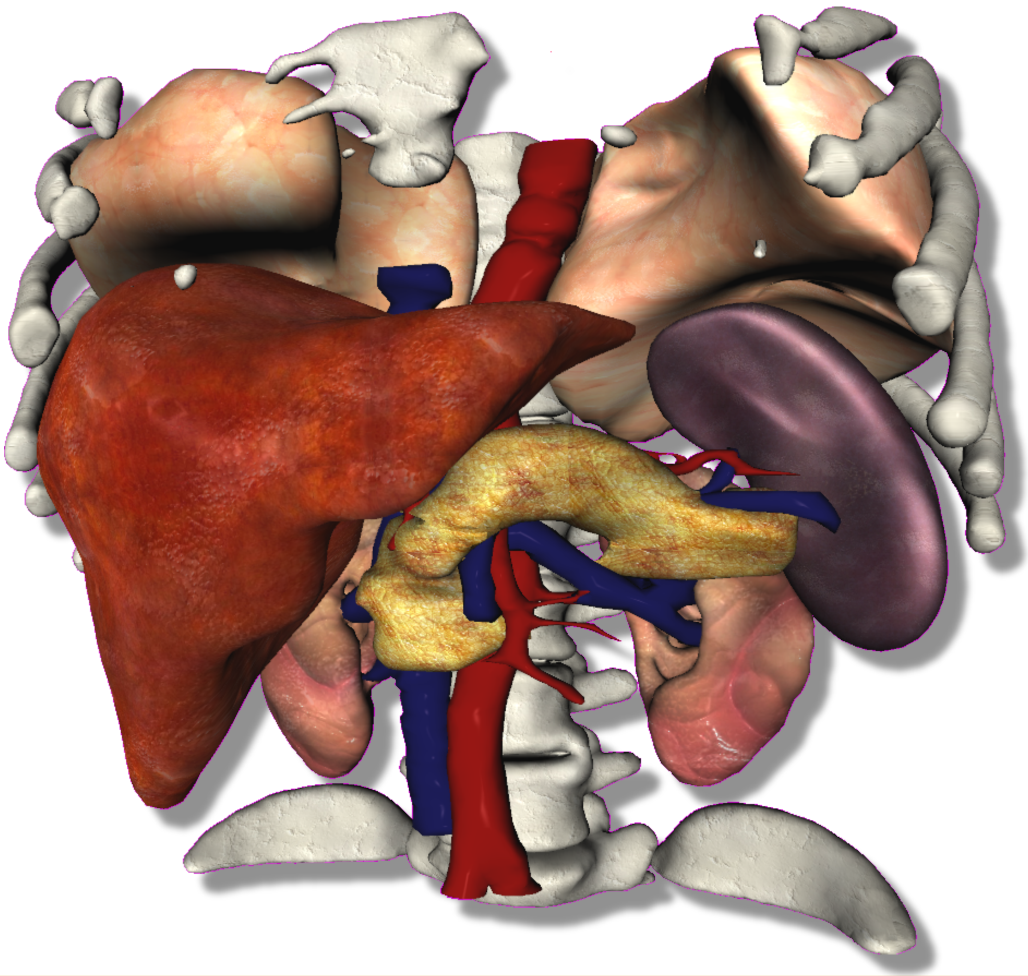
Cognitive Aspects of Data-driven Robotic Surgery



Embedding Cognition in Simulator

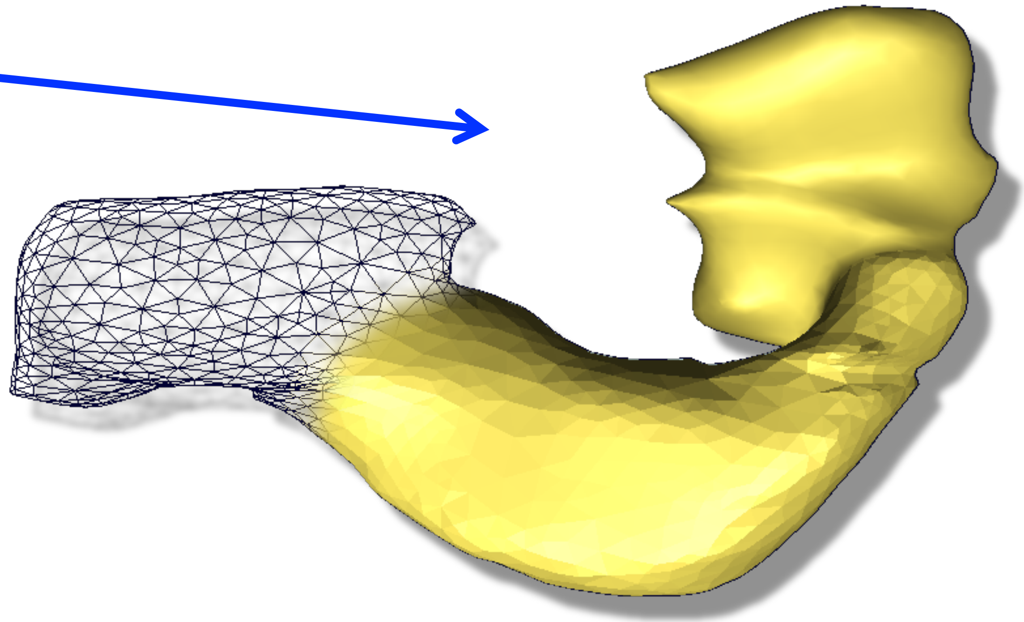
- Should we design for "realism" by achieving:
  - dynamic behaviour of soft tissues,
  - haptic frame-rate
  - **realistic zooming**
  - surgical procedures
- or maintain a "cartoon-like" appearance?

- Is the Uncanny Valley a real problem?



Organ Reconstruction

- Aiming at automatic planning or intra-operative assistance
- Tradeoff between computational complexity and errors
- Two representations:
  - Graphical
  - Physical



Simulation of Cutting Action

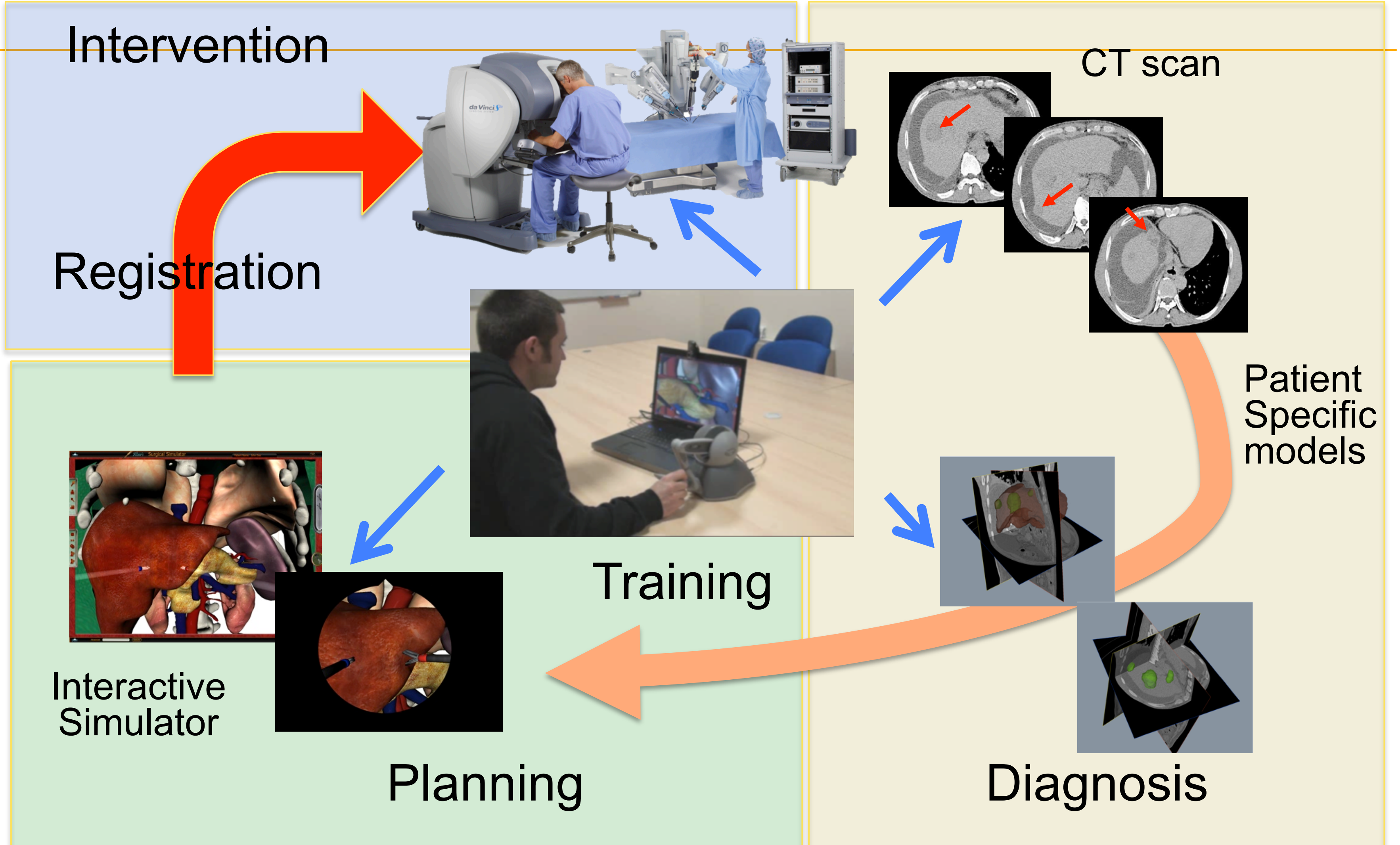
Clamping

Force Feedback: yes or no?

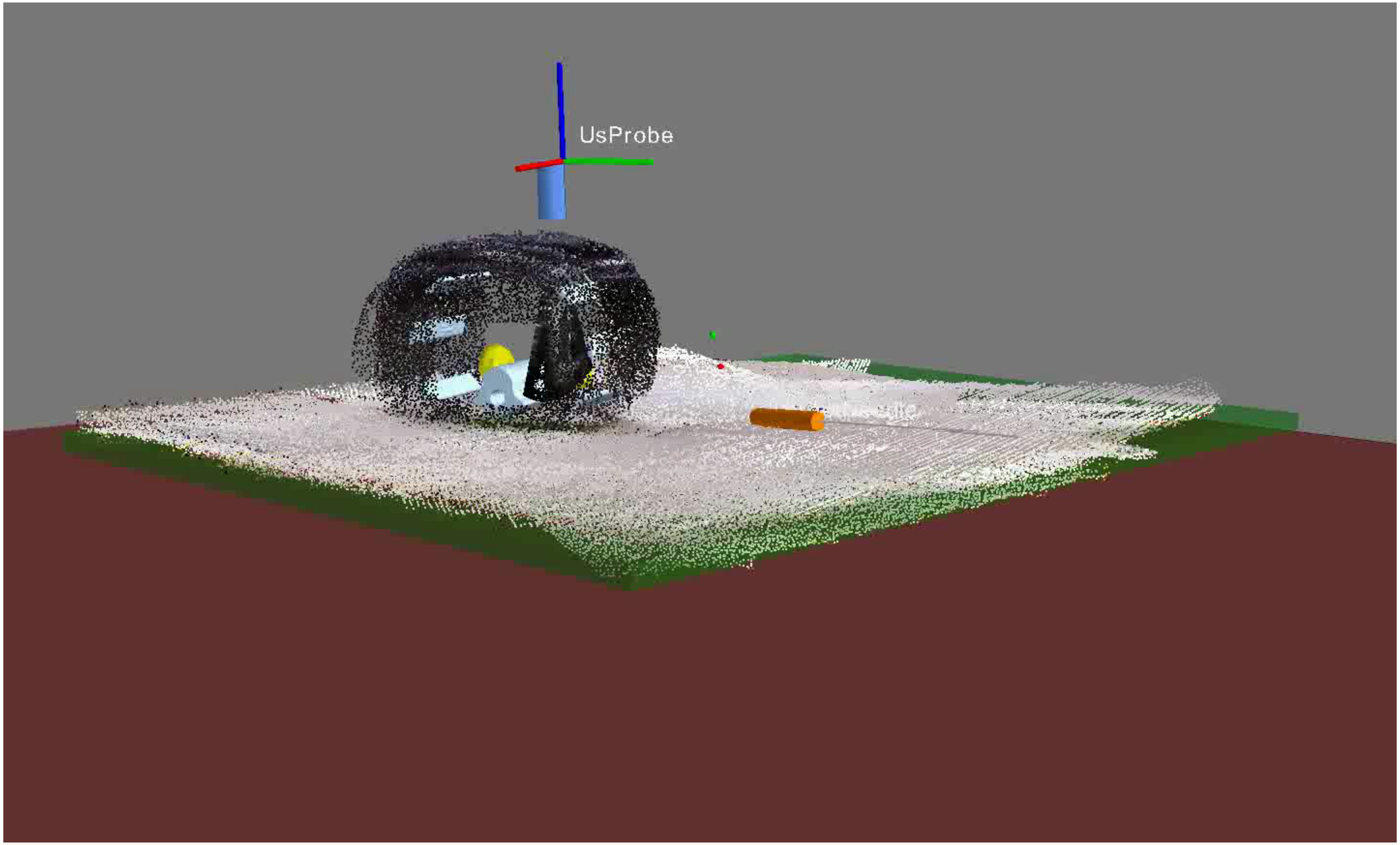
- Current system lacks haptics:
  - Surgeons who use it are happy
  - Surgeons who do not use it would like to have it
  - Robot strong enough to damage tissues
  - Out of sight motion difficult to control (navigator)?

- Research issues:
  - Can FFB be substituted by visual cues?
  - How would synchronization affect perception?
  - How is perception affected by sampling time (1KHz)?
  - How do you satisfy regulatory issues?
    - Autonomous motions
    - Software validation

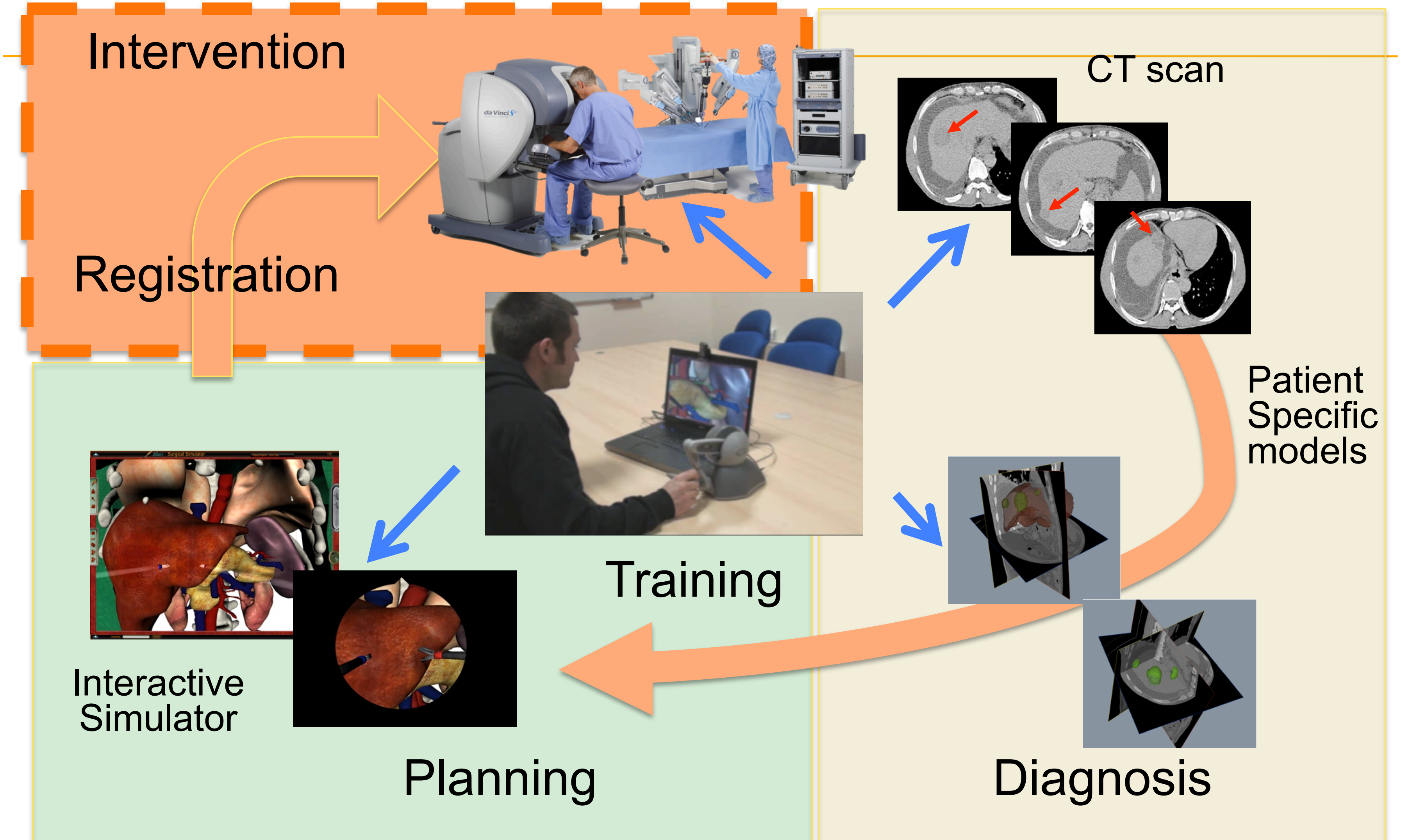
Cognitive Aspects of Data-driven Robotic Surgery



Simplifying Cognition with Sensor Data Fusion

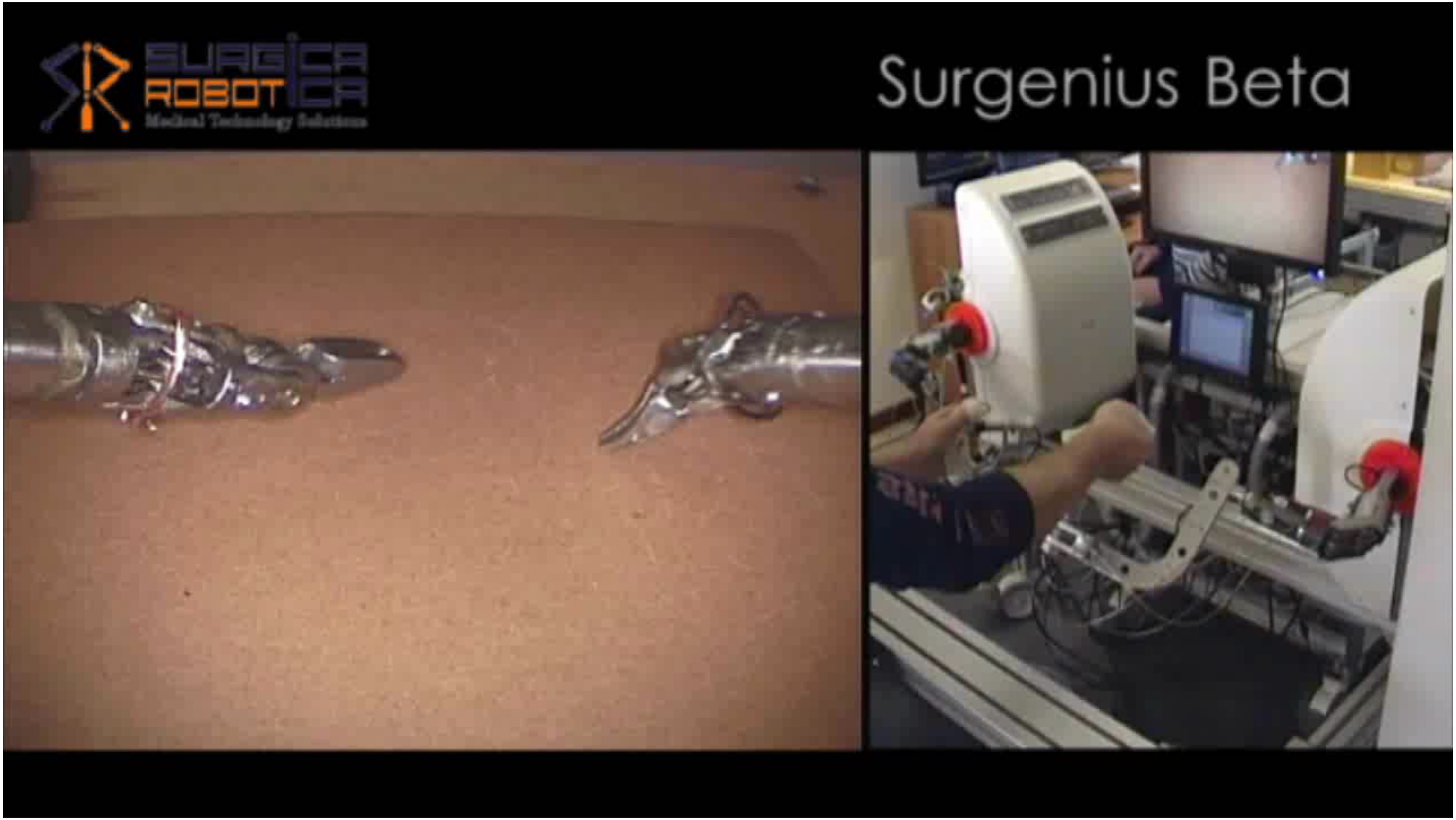


Cognitive Aspects of Data-driven Robotic Surgery

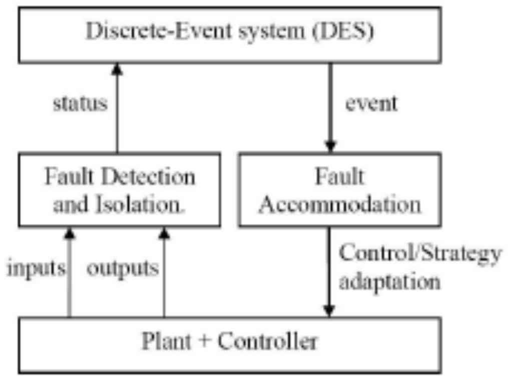


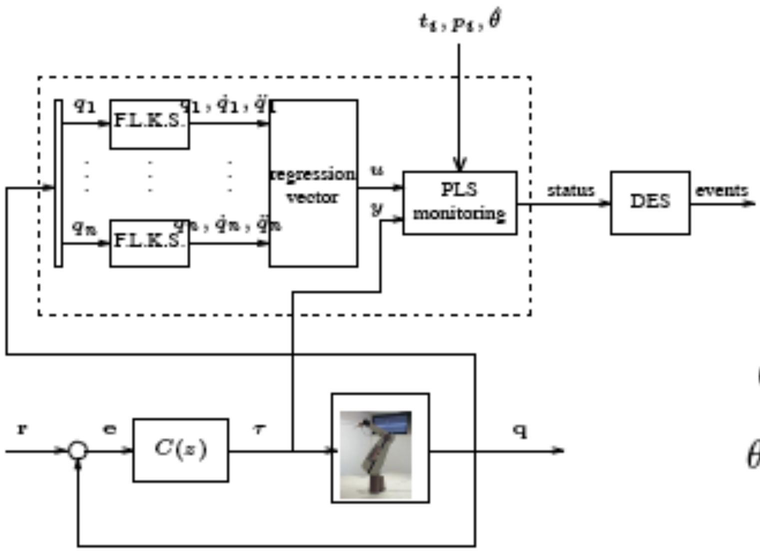
The Surgenius Surgical Robot

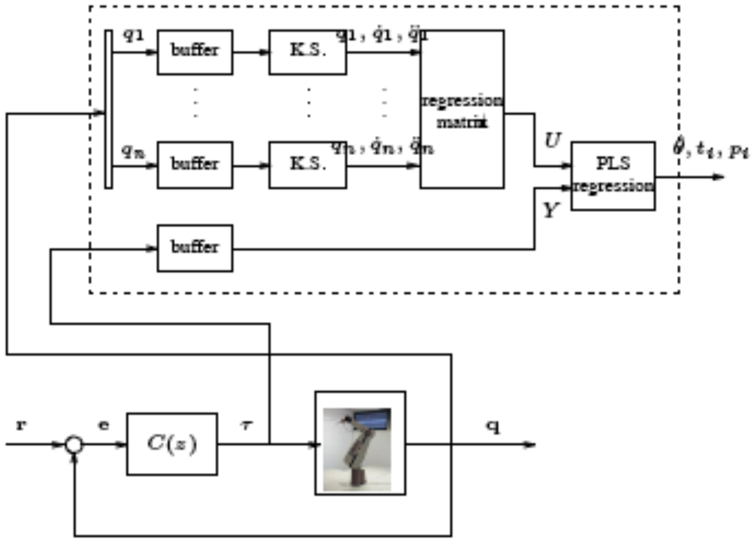
System Dexerity



Robot Modeling and Monitoring







$$\underbrace{F(\mathbf{q}(t), \dot{\mathbf{q}}(t), \ddot{\mathbf{q}}(t))}_{u(t)}\, \theta = y(t)$$

$$\theta = \begin{bmatrix} \theta_1^T & \cdots & \theta_n^T \end{bmatrix}^T$$

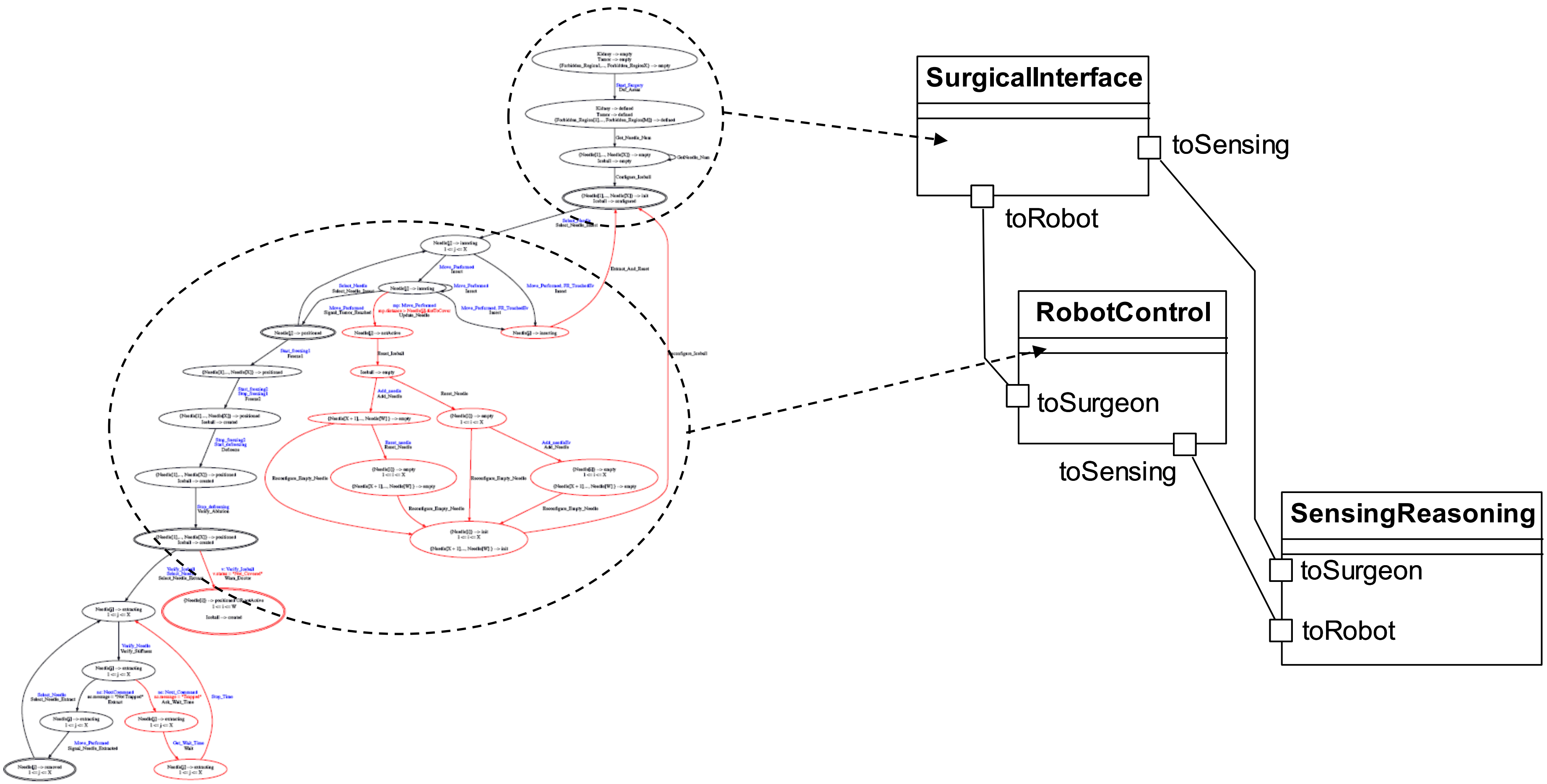
$$\theta_i = \begin{bmatrix} m_i & m_i r_{i,C_i}^T & \hat{I}_i^T & J_i & R_{c_i}^+ & R_{c_i}^- & R_{v_i}^+ & R_{v_i}^- \end{bmatrix}^T \quad (8)$$

Automation of Percutaneous Kidney Cryoablation
(US-CT-MRI Guided)

Goal Model decomposition

Goal Model operationalization

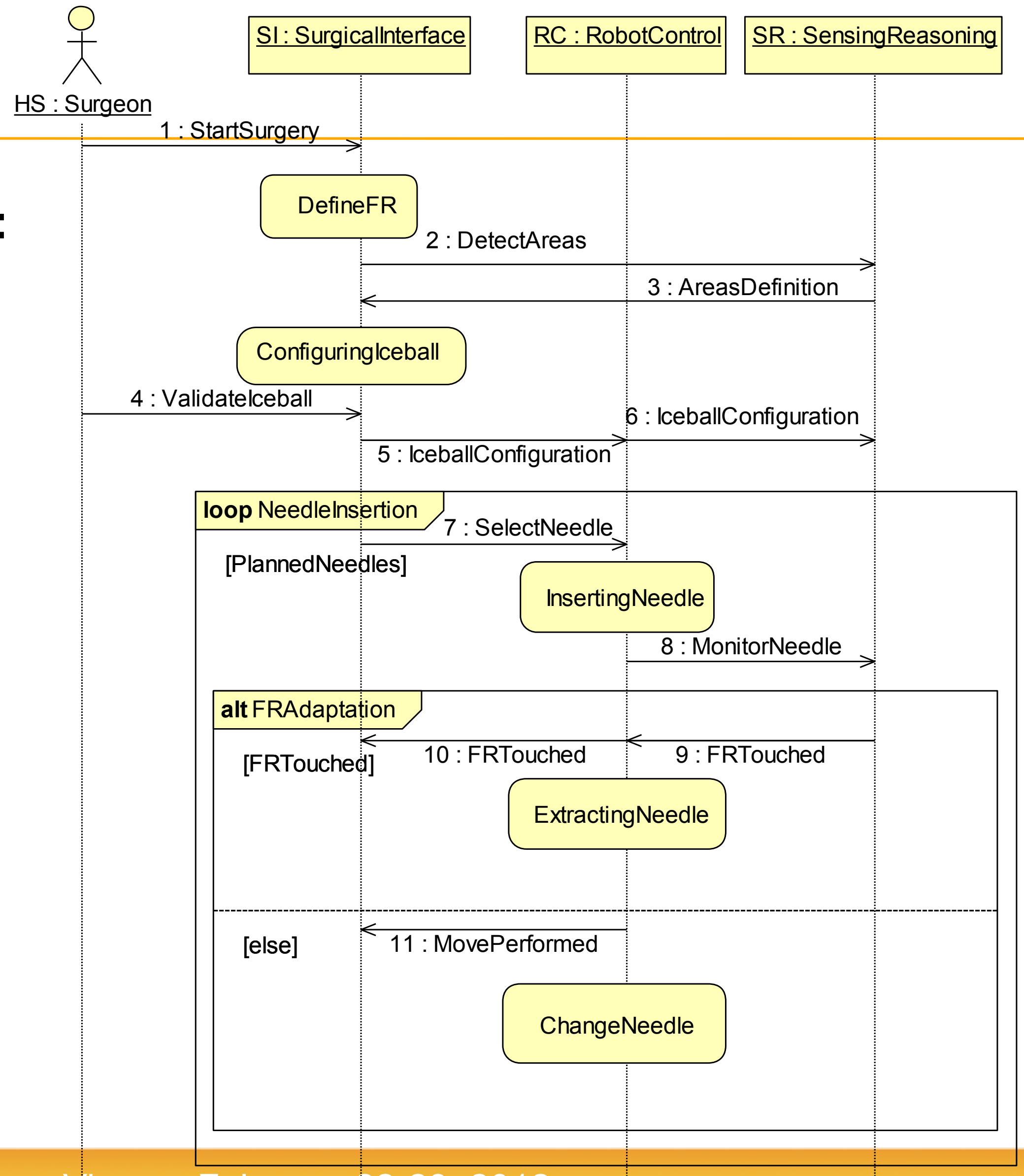
UML Structural Model



Puncturing Task

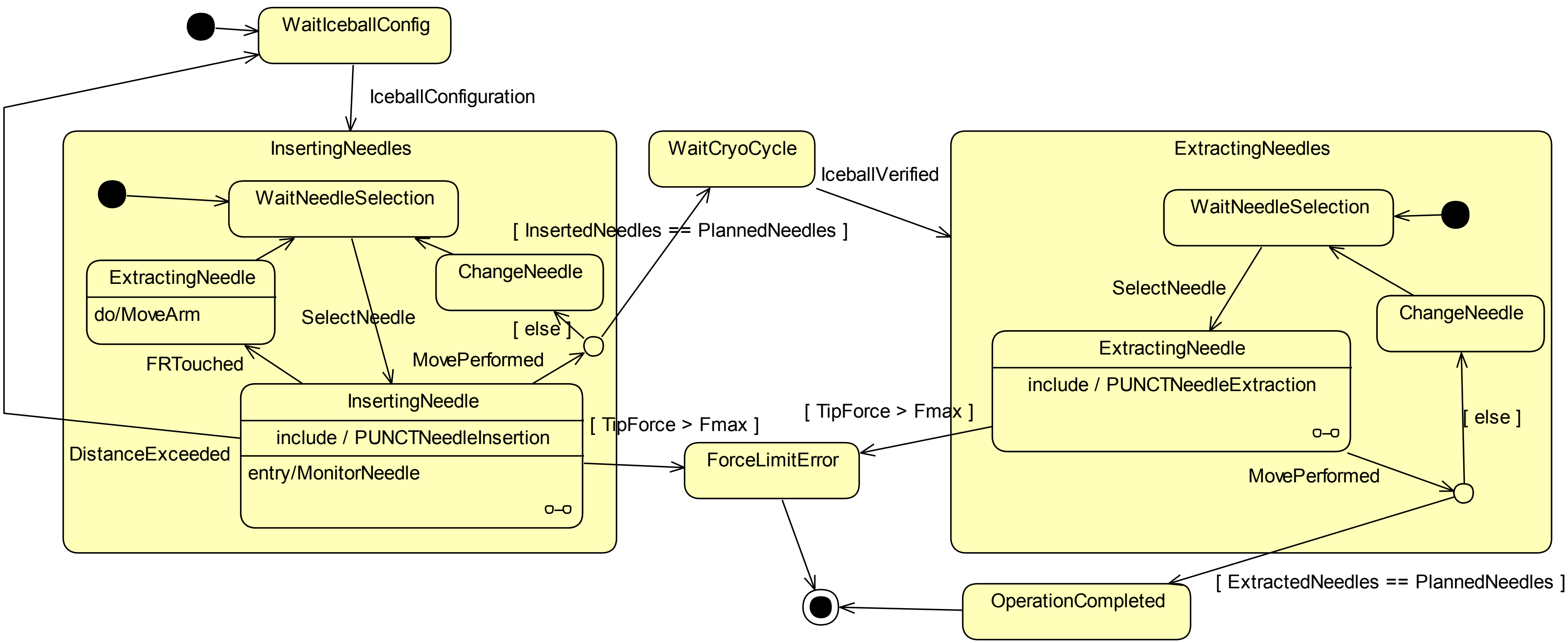
UML Sequence Diagrams: Scenarios of Interactive Behavior

Example:
Needle insertion and Adaptation related to touching Forbidden Region

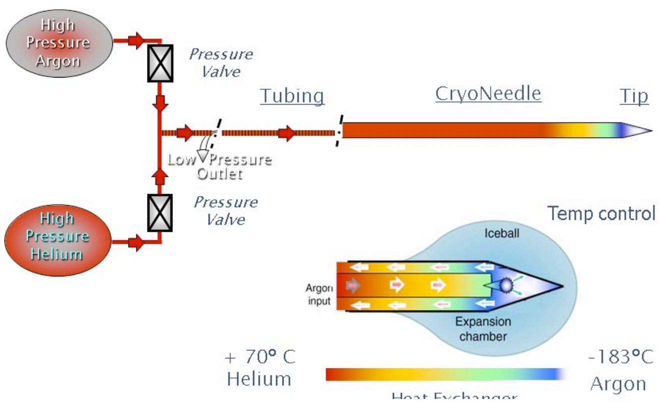


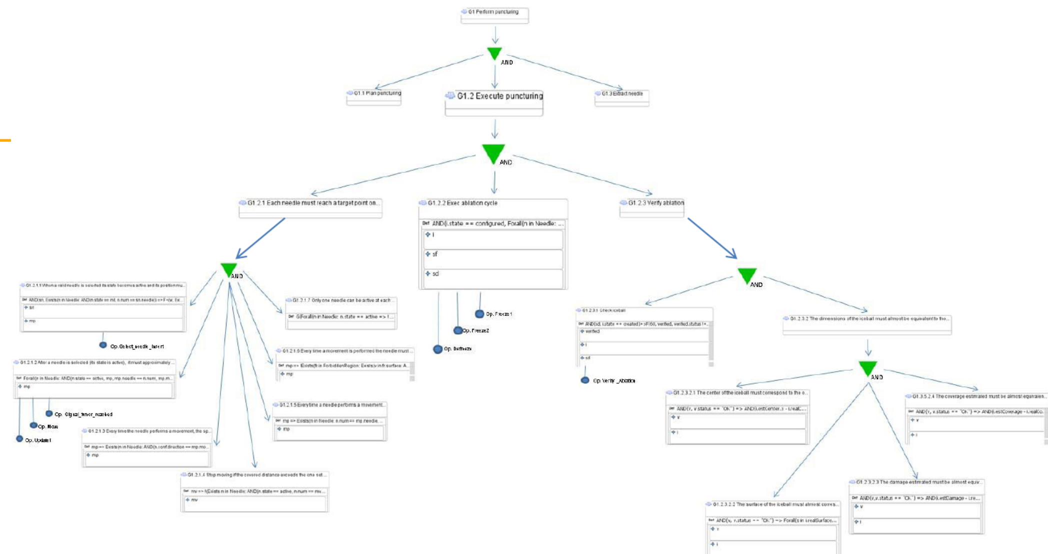
Puncturing Task

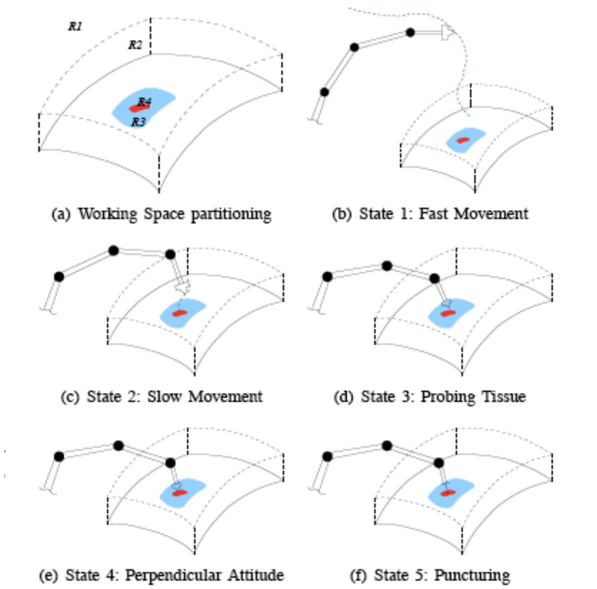
UML State Diagram: hierarchical state machine



Task Planning and Execution



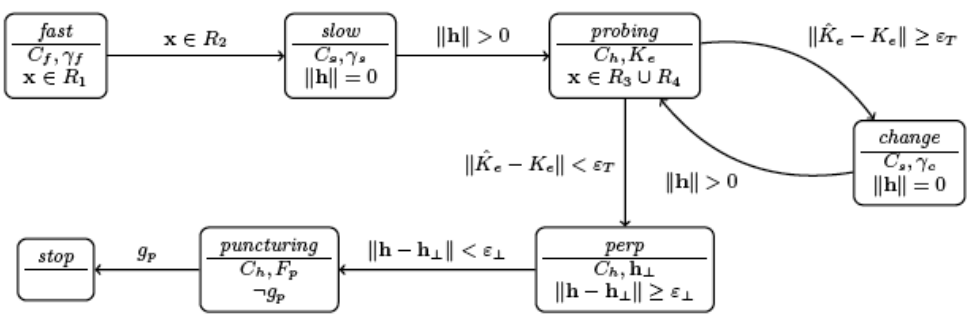




(a) Working Space partitioning (b) State 1: Fast Movement

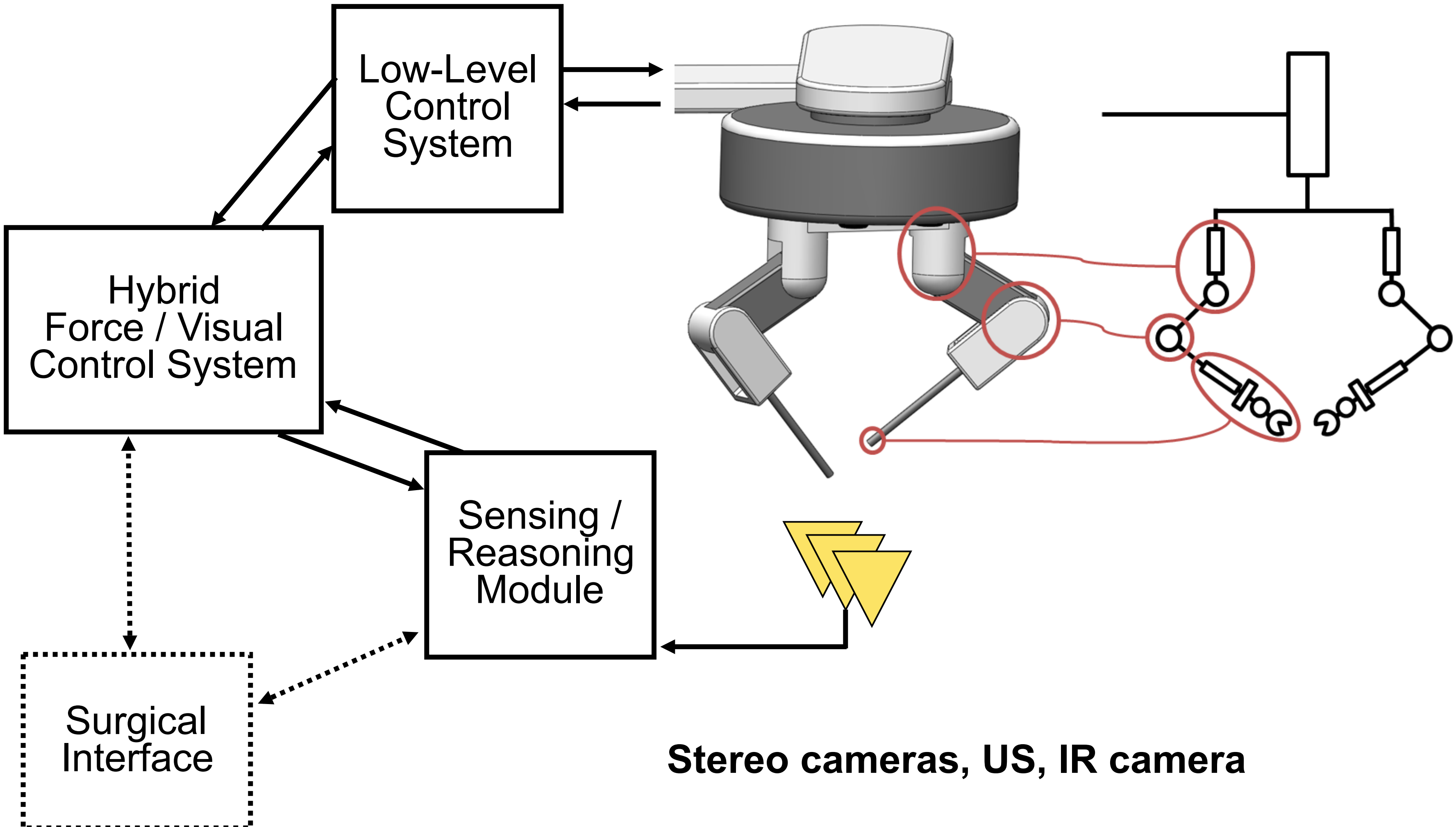
(c) State 2: Slow Movement (d) State 3: Probing Tissue

(e) State 4: Perpendicular Attitude (f) State 5: Puncturing

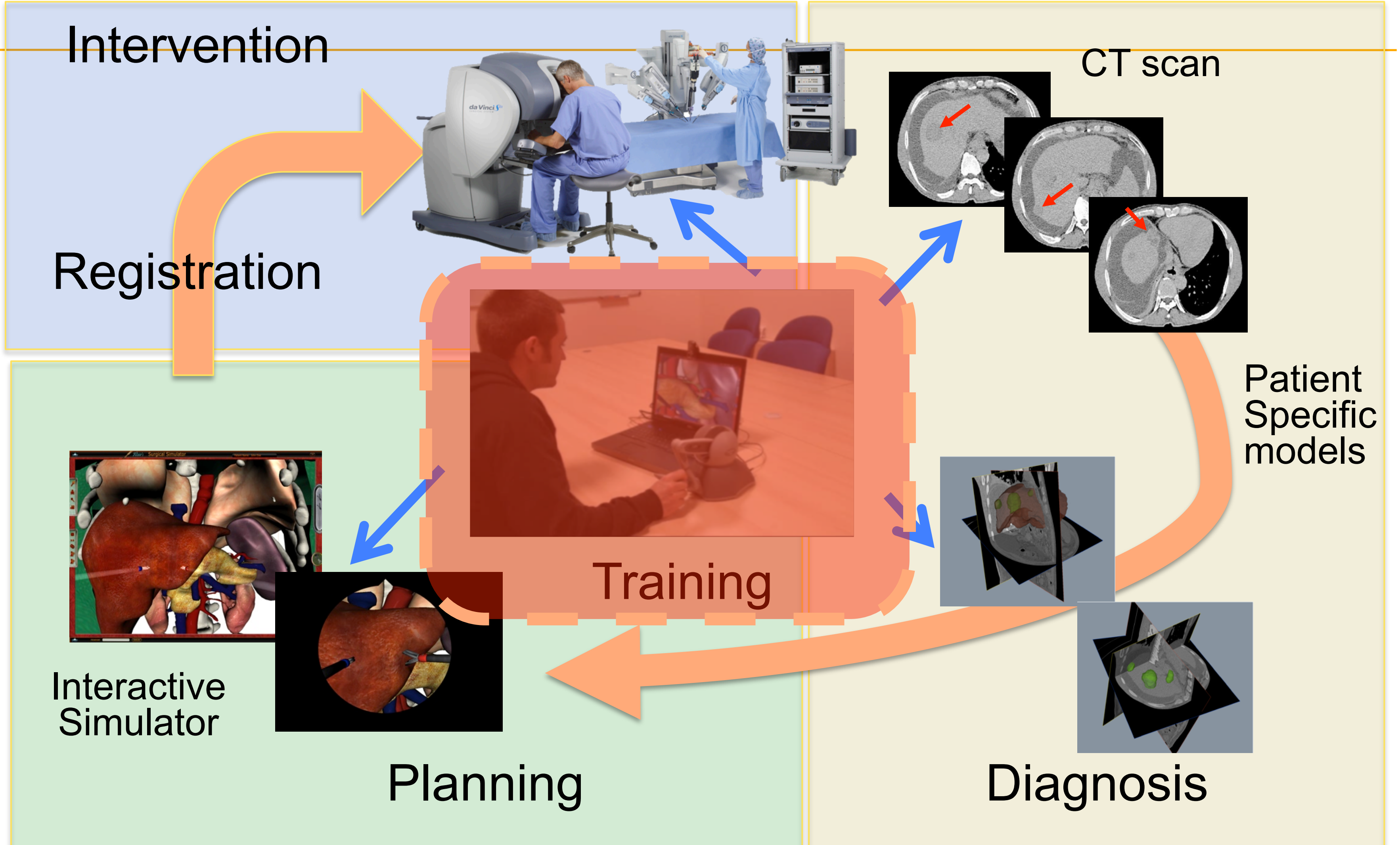


I-SUR setup

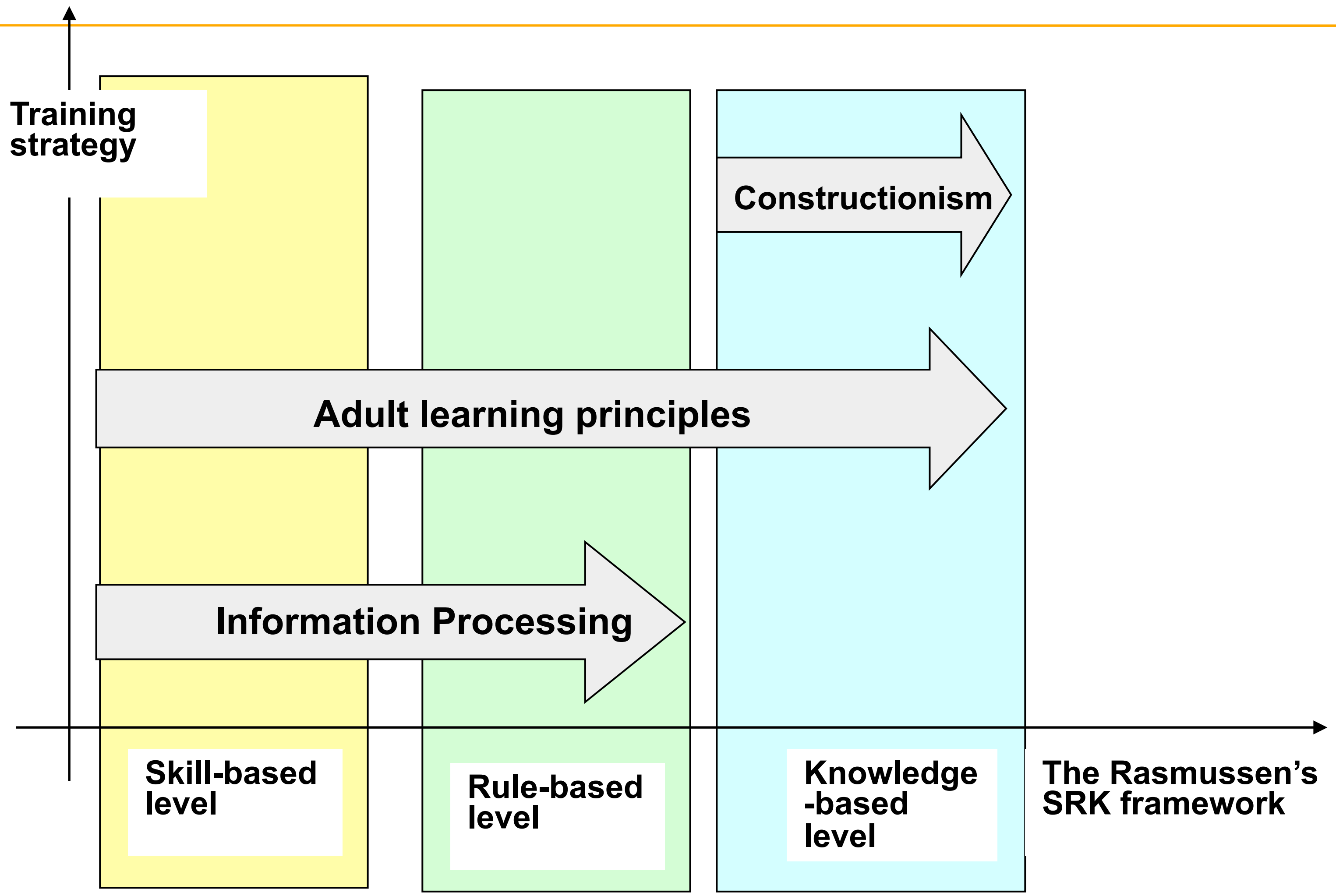
Twin Serial Manipulator (developed by ETH)



Cognitive Aspects of Data-driven Robotic Surgery



Conceptual Evaluation Sequence



Dexterity training

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