PHYSICS-BASED MODELING AND SIMULATIONS IN MEDICINE

PV177 Seminary Group
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OUTLINE

- **Motivation for physics-based simulations**
  - training, planning, navigation
- **Examples of models and simulations**
  - cataract surgery: training ophthalmologists
  - cryoablation planning: pre-operative tool for interventional radiologists
  - augmented reality framework for hepatic laparoscopy
- **Basic concepts of modeling**
  - Images vs. Models: reconstruction of models from images
  - conceptual, mathematical, physics-based models

Motivation

From Training to Navigation

COMPUTER-BASED MEDICAL SIMULATION

- Main areas of interest
  - procedural training: practical and ethical considerations
  - pre-operative planning and rehearsal
  - per-operative guidance
- Different requirements on each level
  - Increasing levels of complexity as we get closer to the operation room

MAIN CHARACTERISTICS

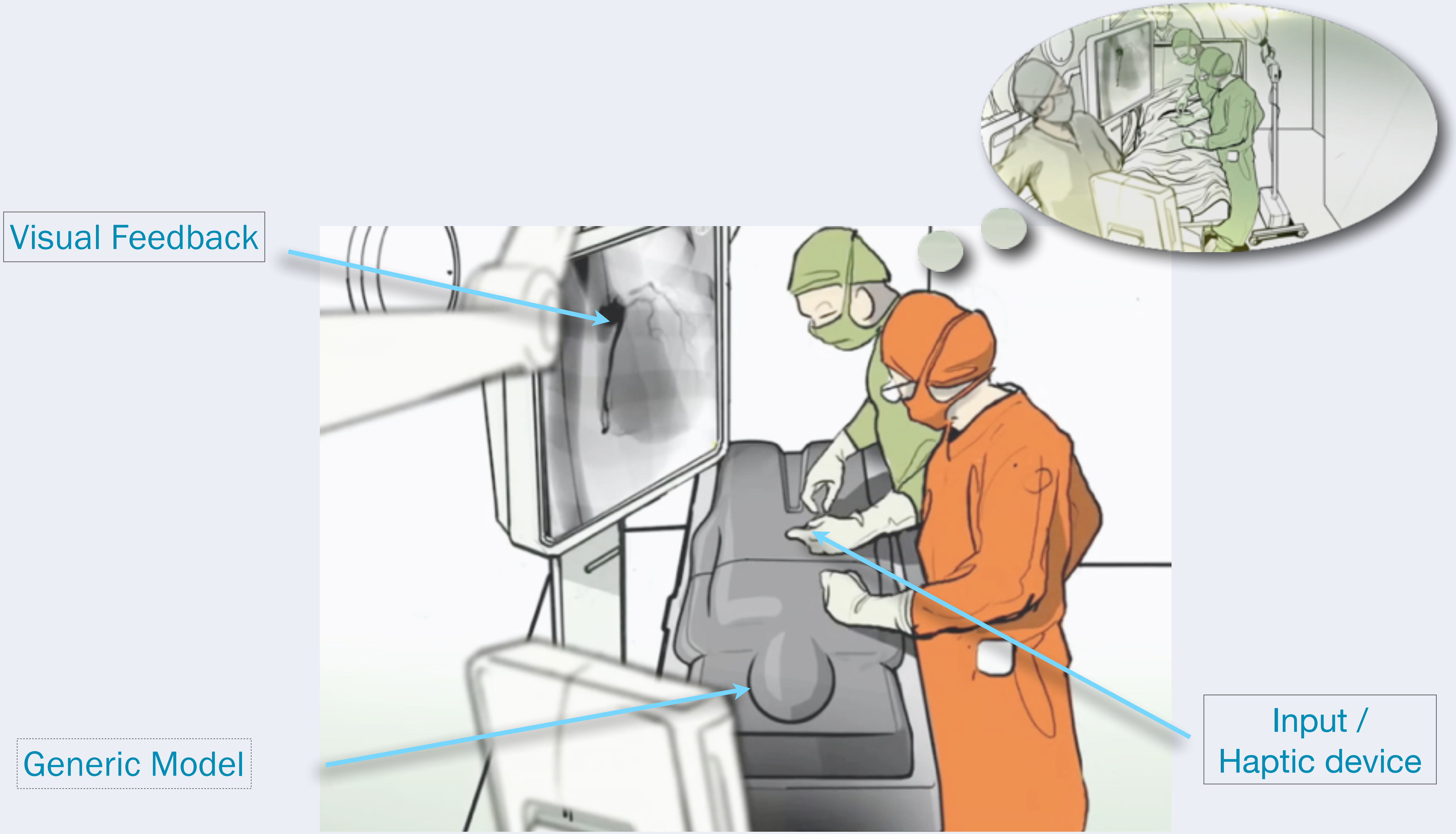
- procedural training
  - interventions in eye surgery, catheter
  - realistic, interactive (visual and haptic rendering), generic models
- pre-operative planning
  - liver, kidney resection, deep-brain surgery
  - realistic, not necessarily interactive, patient-specific models
- intra-operative navigation
  - catheter, needle insertion navigation, laparoscopic augmented reality
  - realistic, interactive, robust, patient-specific

NOTE: HAPTIC DEVICE

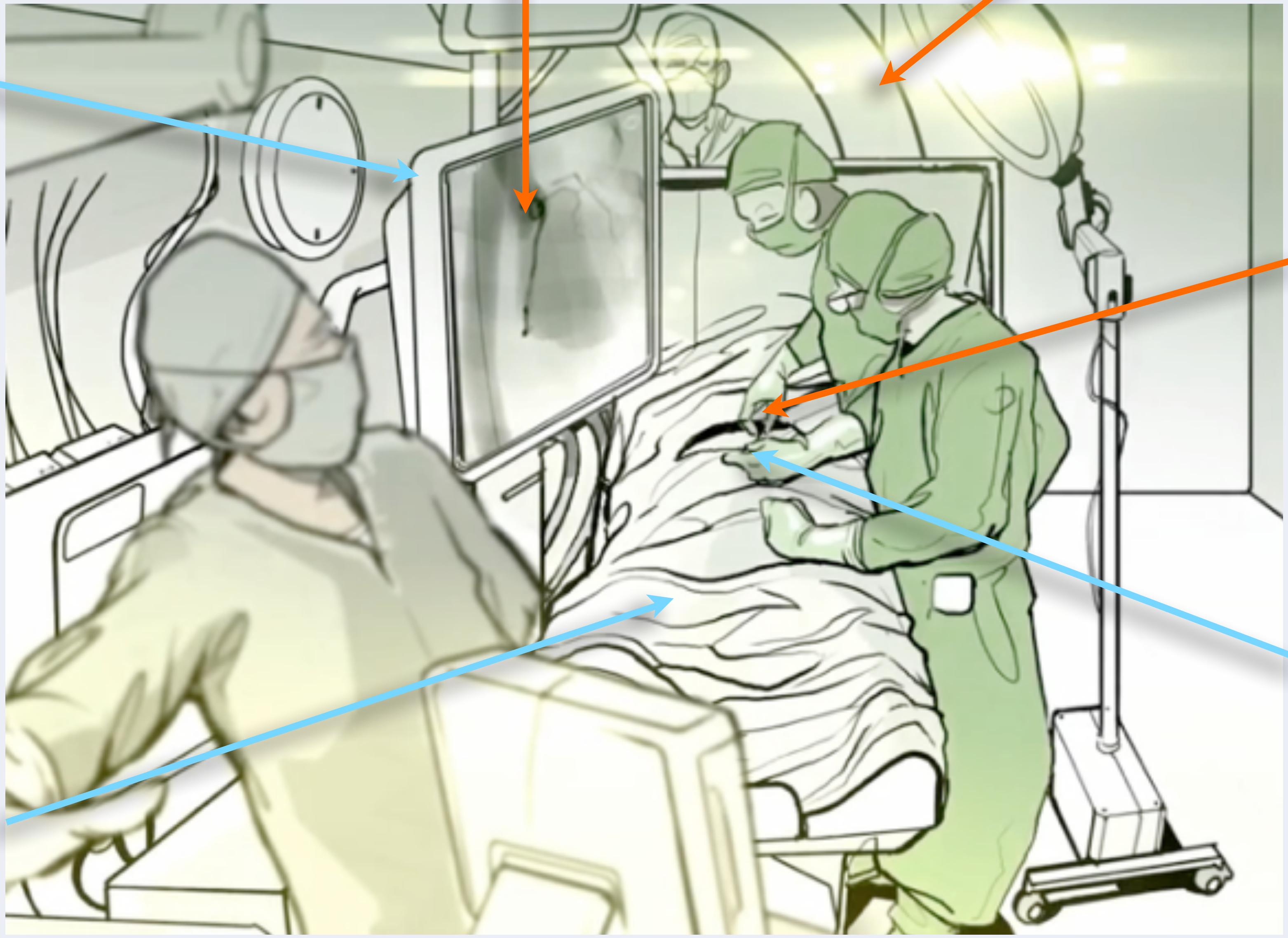
- “3D mouse” with force feedback
- allows for touching (*haptein*) virtual objects
- often necessary for training as visual perception is not sufficient (e.g. cutting of tissue)

- main issue: high refresh rate needed to guarantee the fidelity of rendering
- usually 1000 Hz is reported (although the required minimal frequency rather depends on the mechanical properties of objects being rendered
- other issues: stability, passivity (might depend on the quality of device)

FROM TRAINING...



...TO INTRA-OPERATIVE ASSISTANCE



EXAMPLES

From Training to Navigation

TRAINING: CATARACT SURGERY

- metabolic changes crystalline lens fibers (loss of sight)
- several types of surgery
  - phacoemulsification: standard in developed countries (ultrasonic)
  - extra-/intra-capsular cataract extraction (ECCE, ICCE)
  - manual small incision cataract surgery (MSICS)
    - lens is extracted through a tunnel which is watertight (if created properly)
    - lens capsule is intact
    - outcomes comparable to phacoemulsification
    - much lower cost ($50 vs. $2500) and time (5 to 15 minutes)
    - requires very high dexterity of the pharmacologist

HELP ME SEE PROJECT

- large impact of cataract in the third world
  - estimated 20 million children, 100 million adults blind
- mission:
  - train a large number of ophthalmologists (30,000 in 2030)
  - use a virtual simulator for training
  - shifting paradigm
- large call for project
  - first prototypes tested by skilled ophthalmologists
  - consortium (InSimo, SenseGraphics, MOOG)

InSimo

WE CARE FOR SIMULATION

MSICS SIMULATOR PROTOTYPE

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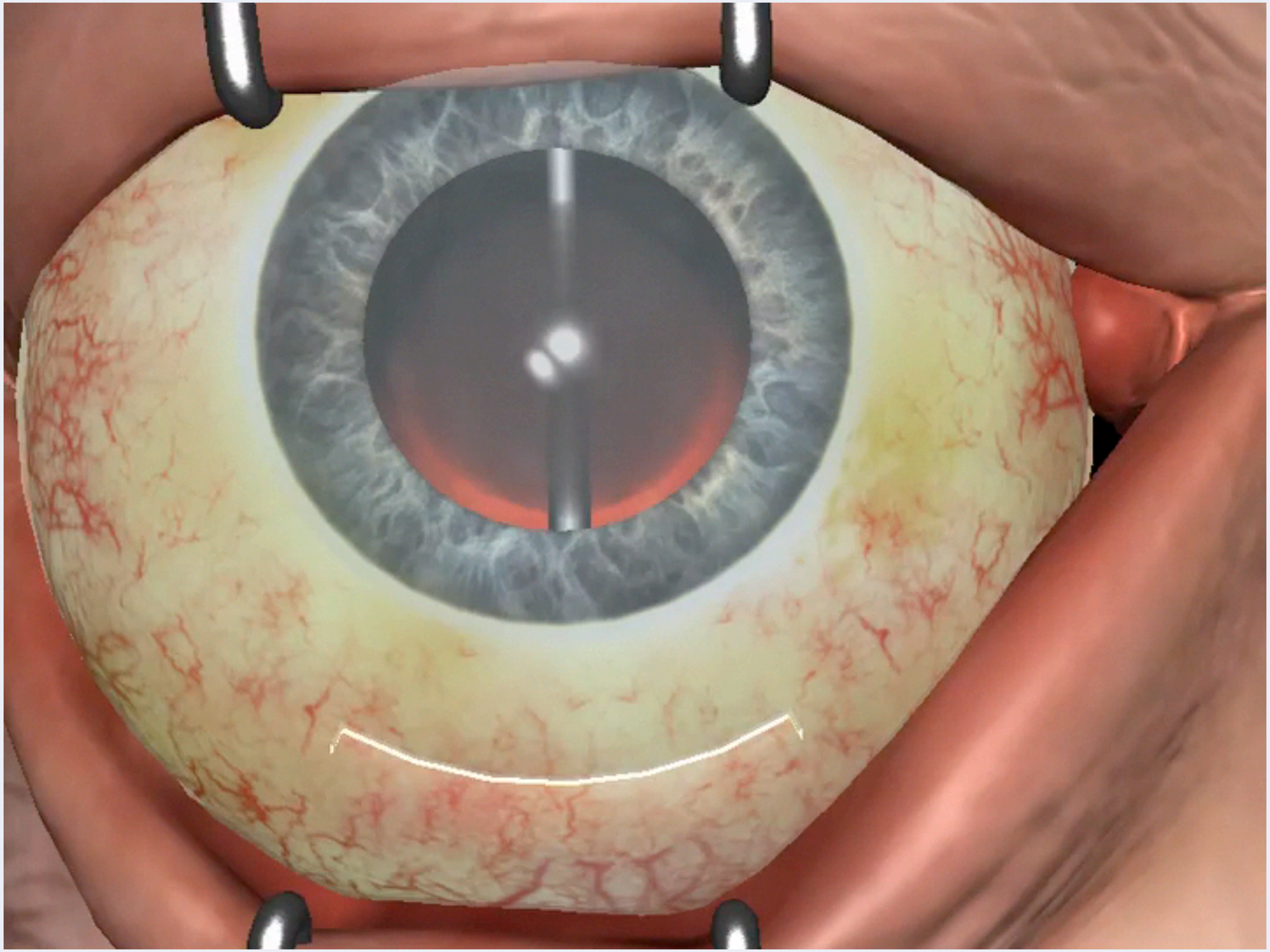
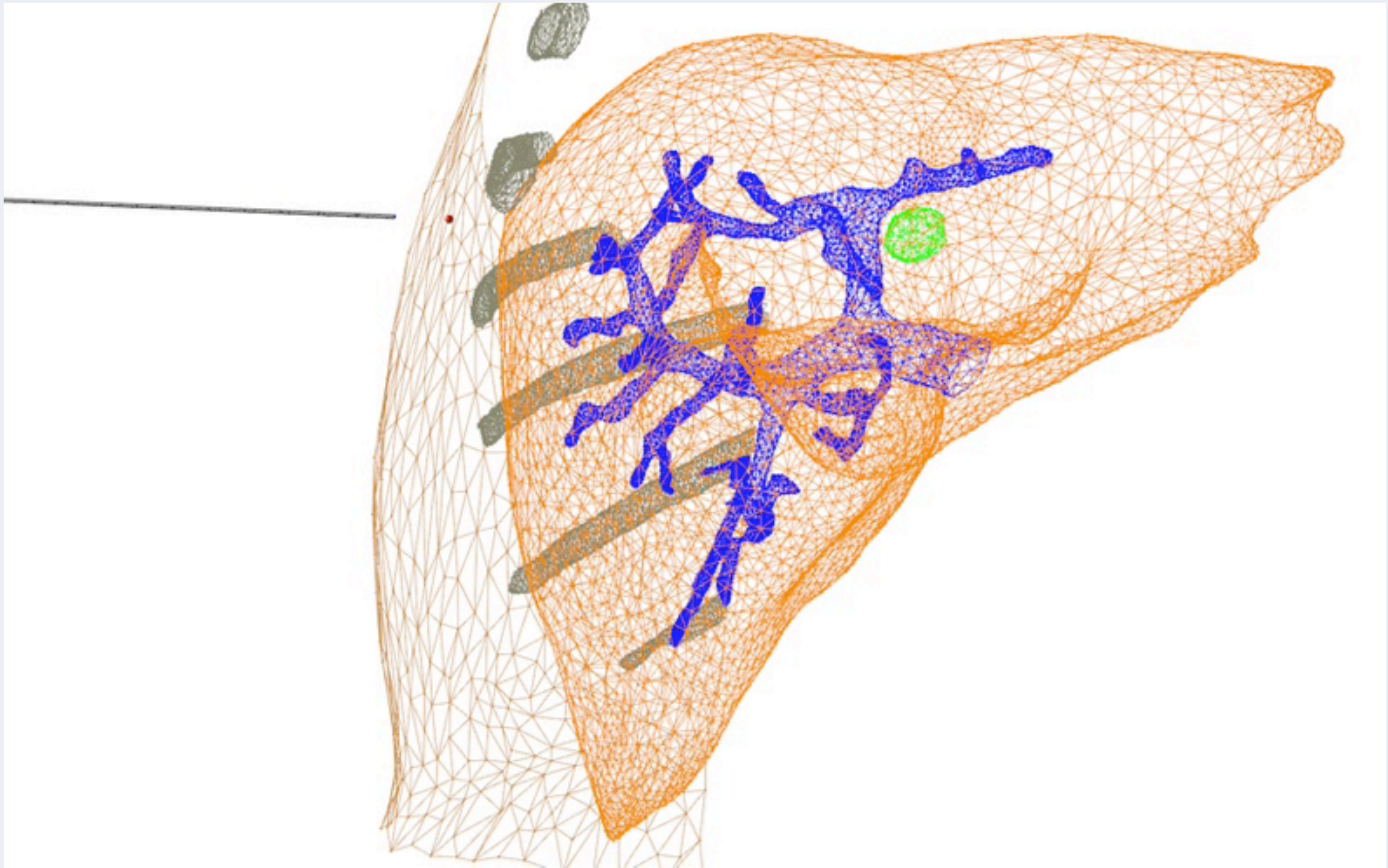


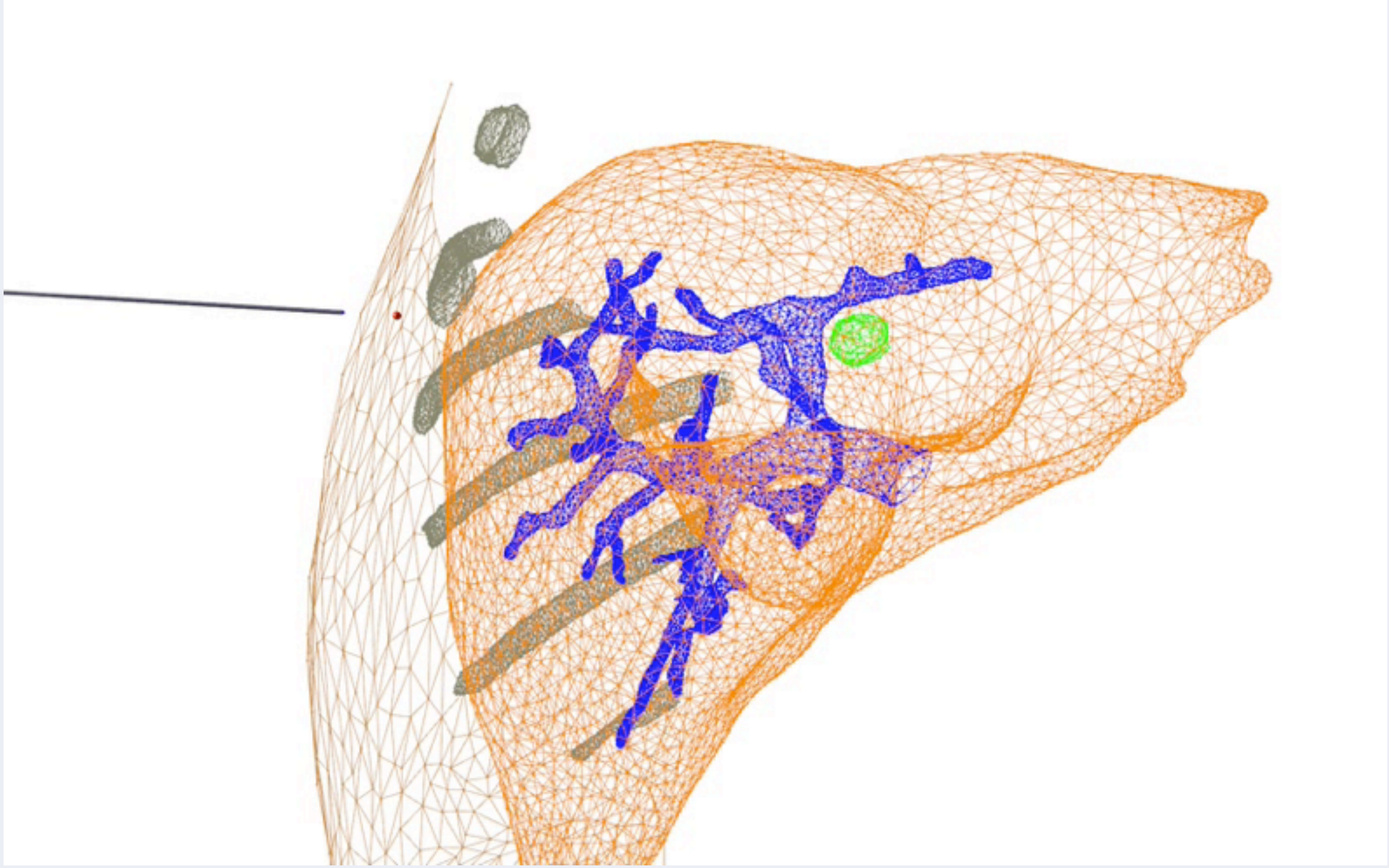
PLANNING: NEEDLE INSERTION FOR CRYOABLATION

- interventional radiology
  - destruction of a tumor using a (steerable) hollow needle
  - argon is used to freeze the tumor by forming an ice-ball (ice-rod)
  - insertion/placement of the needle plays a crucial role
  - avoid important objects during insertion (vessels)
  - insert the needle so that the ice-ball covers the tumor (+safety margin)
  - multiple needles inserted (synergy effect)
- actually, two stages are studied
  - needle insertion planning
  - prediction of ice-ball formation

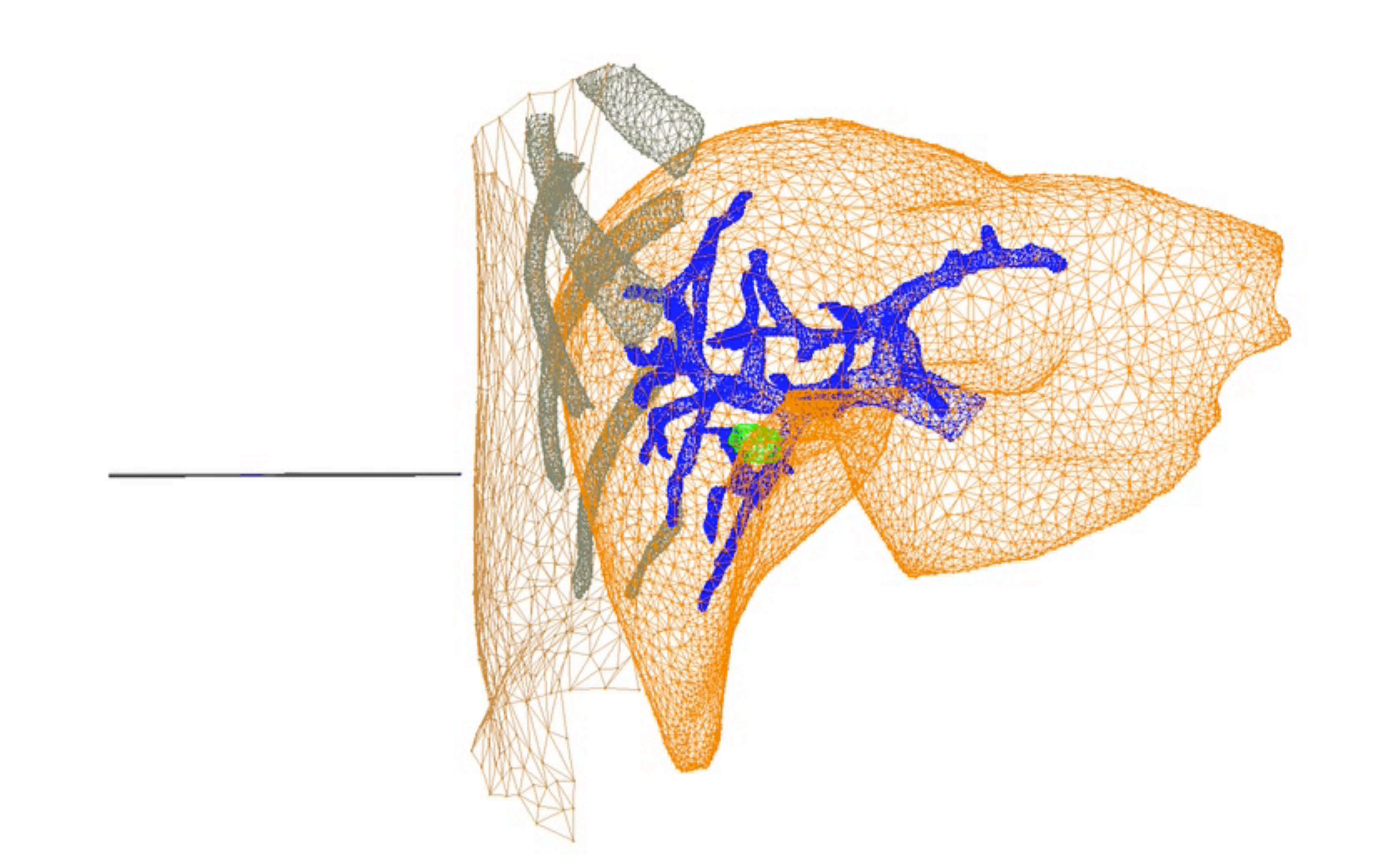
INSERTION PLANNING



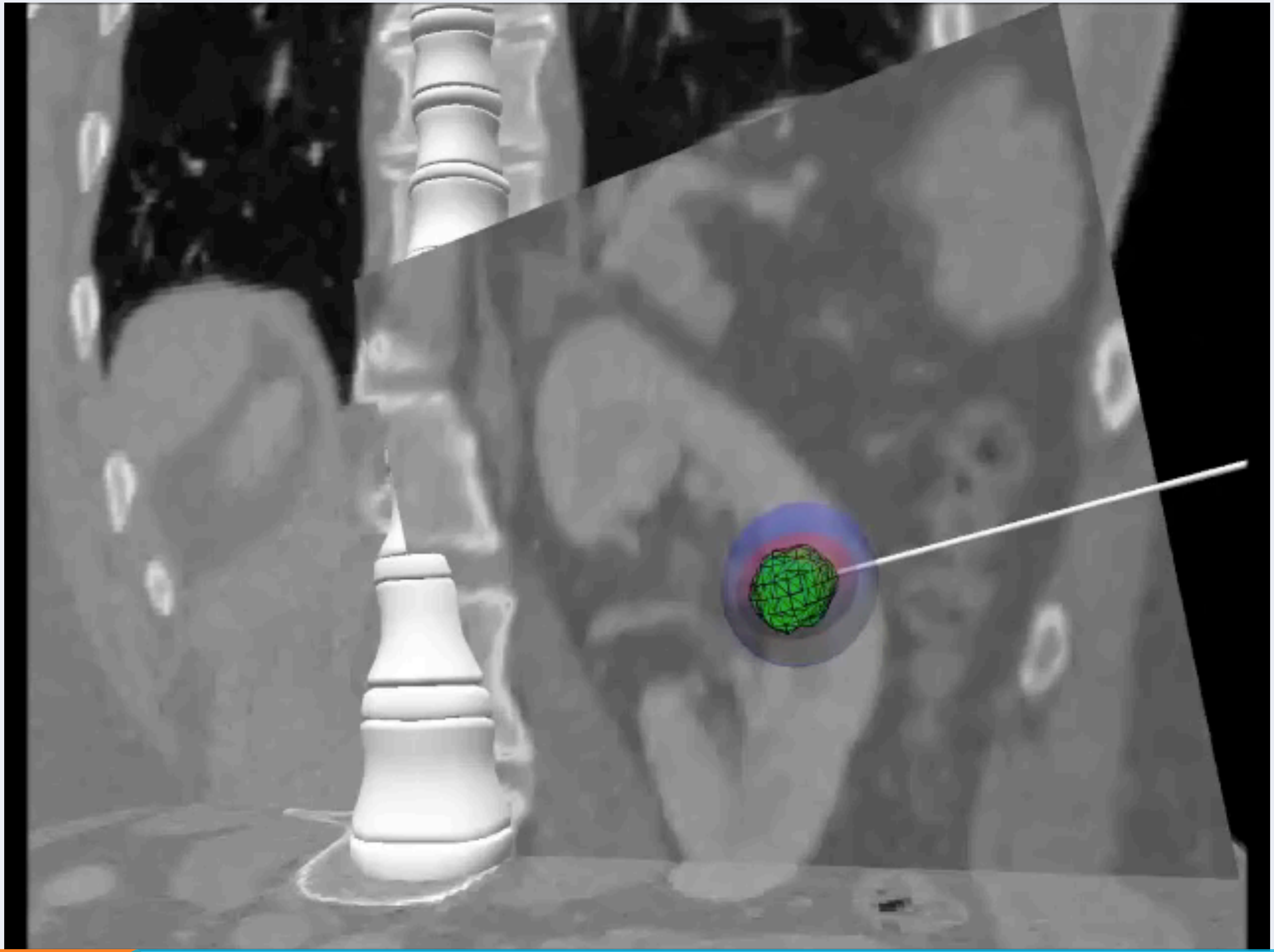
INSERTION PLANNING



ITERATIVE PROCESS



ICE-BALL FORMATION PREDICTION

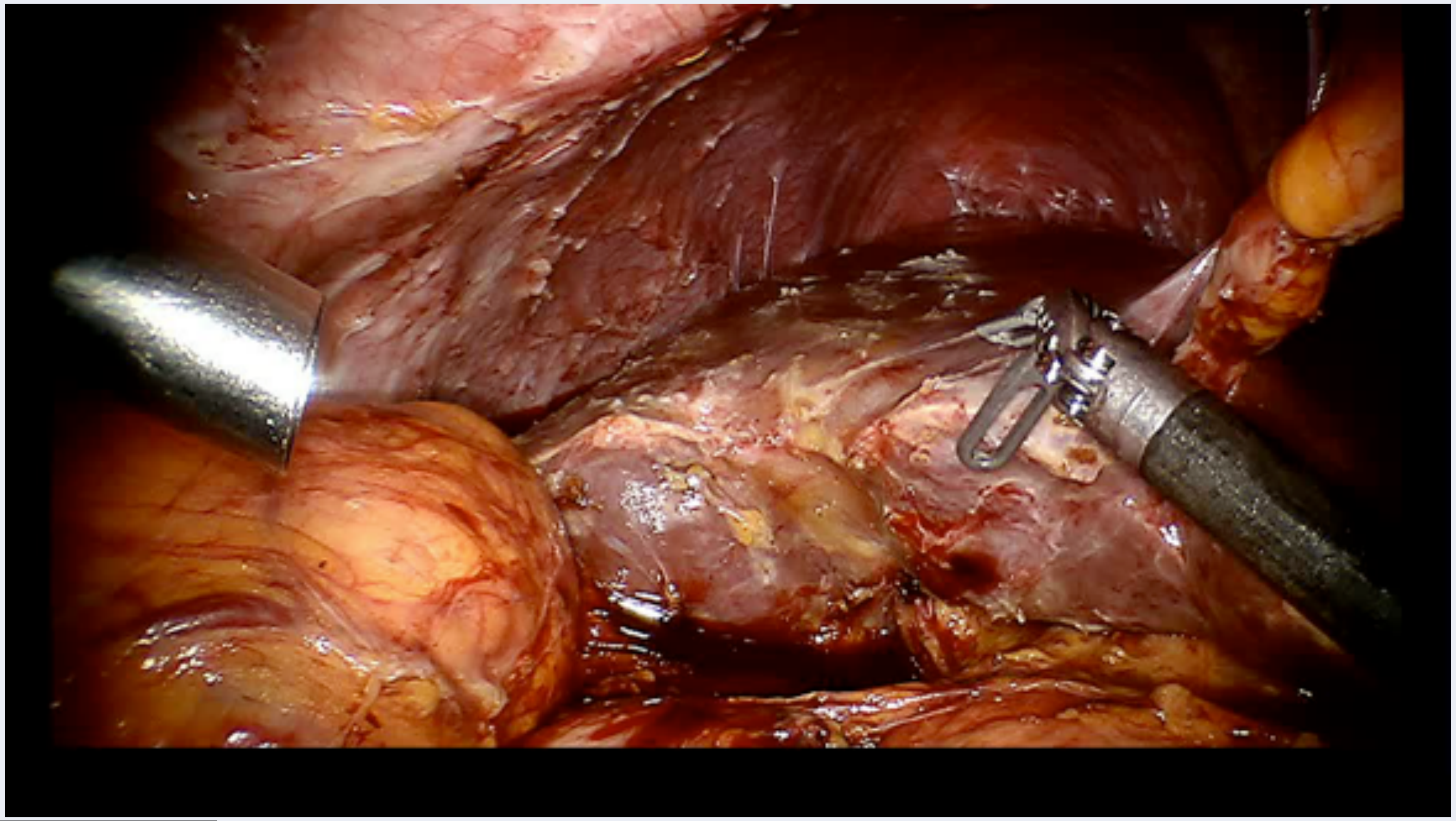


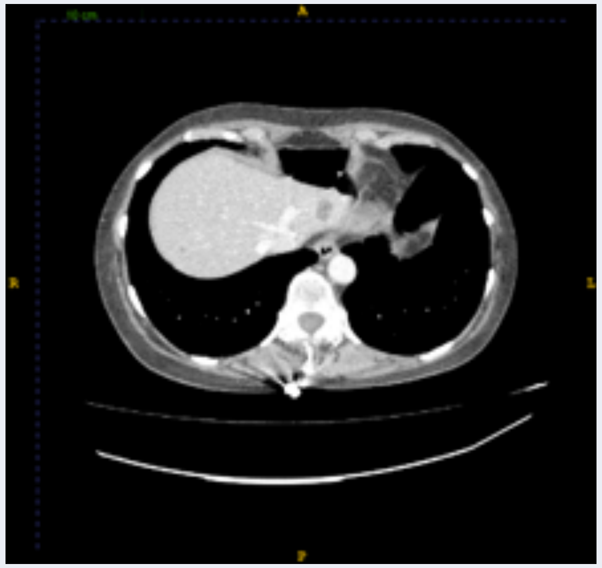
H.Talbot et al. Interactive Planning of Cryotherapy Using Physically-Based Simulation *Proc. Medicine Meets Virtual Reality*, 2014

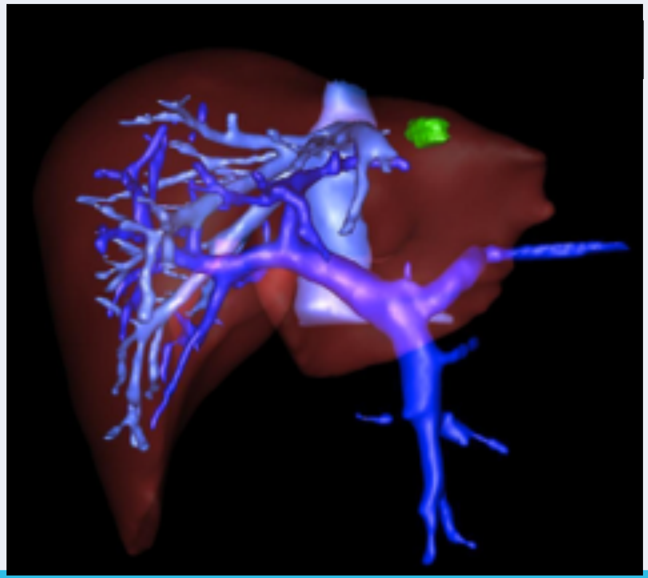
NAVIGATION: AUGMENTED REALITY IN LAPAROSCOPY

- laparoscopy: minimally invasive approach (*keyhole surgery*)
  - operation through small incisions
  - surgeon follows the intervention through camera (mono/stereo)
- pre-operative data available
  - e.g. pre-operative abdominal CT
  - however, the actual position during surgery is often different (e.g. supine vs. flank vs. prone position)
  - huge deformation occurs in abdominal cavity (mainly in patient with higher body mass index)
  - surgeon has to create a mental image

LAPAROSCOPIC HEPATECTOMY

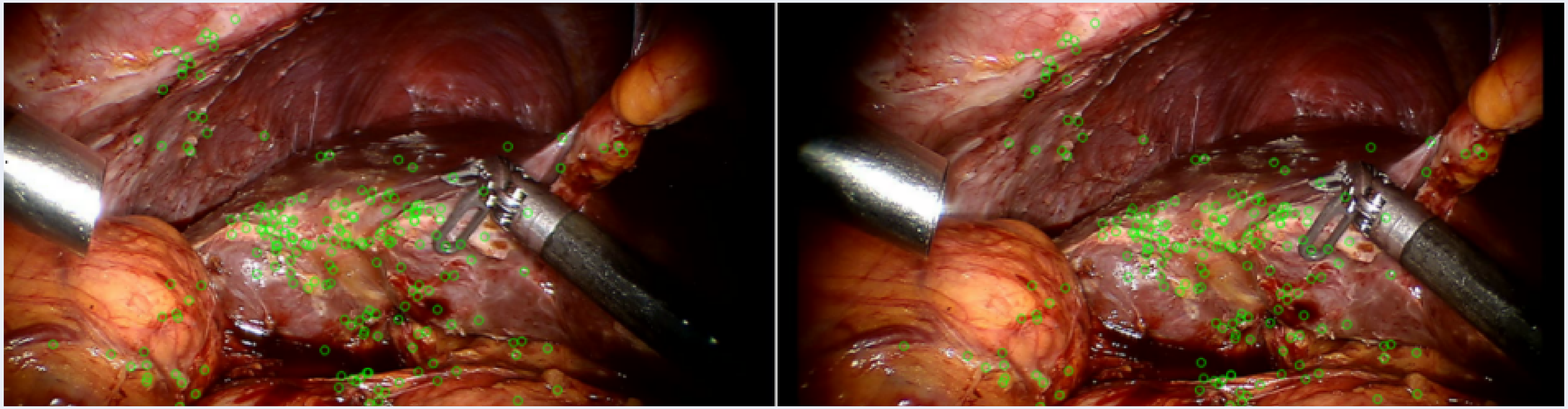


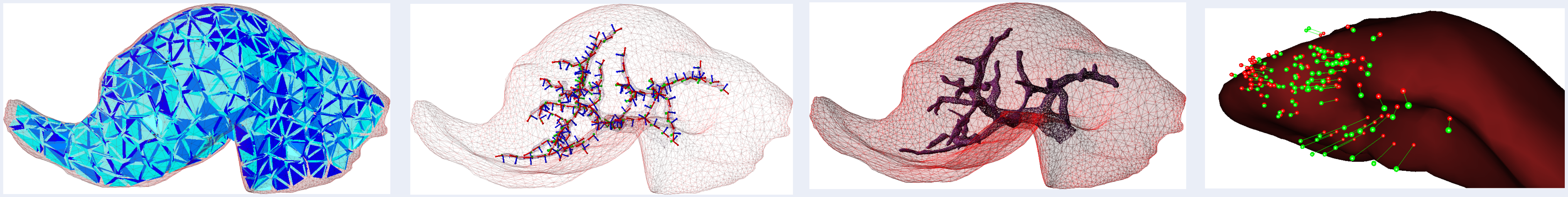




AUGMENTED REALITY I

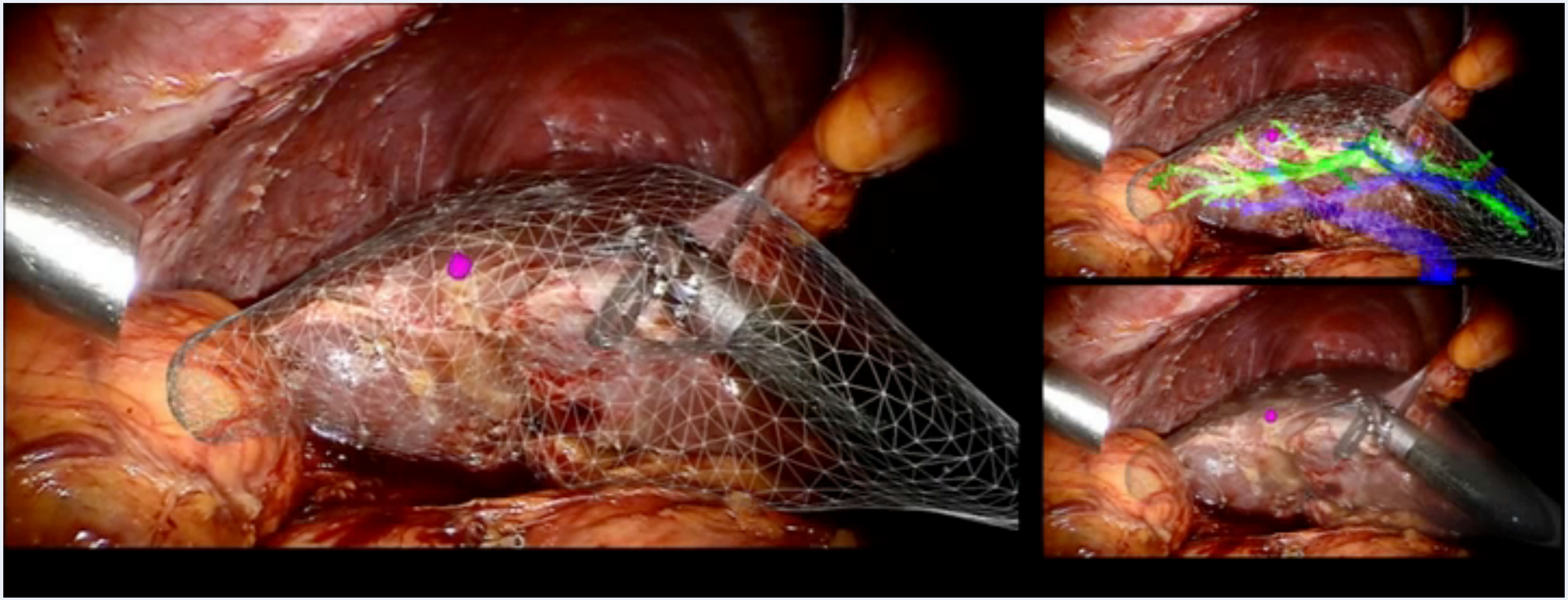
- track the image acquired by the camera (Computer Vision)
- drive the model (from CT data) during the interaction





N. Haouchine, J. Dequidt, **I.P.**, E. Kerrien, M.-O. Berger, S. Cotin. Image-guided Simulation of Heterogeneous Tissue Deformation For Augmented Reality during Hepatic Surgery. In *ISMAR* proc. 2013

AUGMENTED REALITY II



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TRAINING, PLANNING, NAVIGATION: COMPARISON

Physics-based

Performance

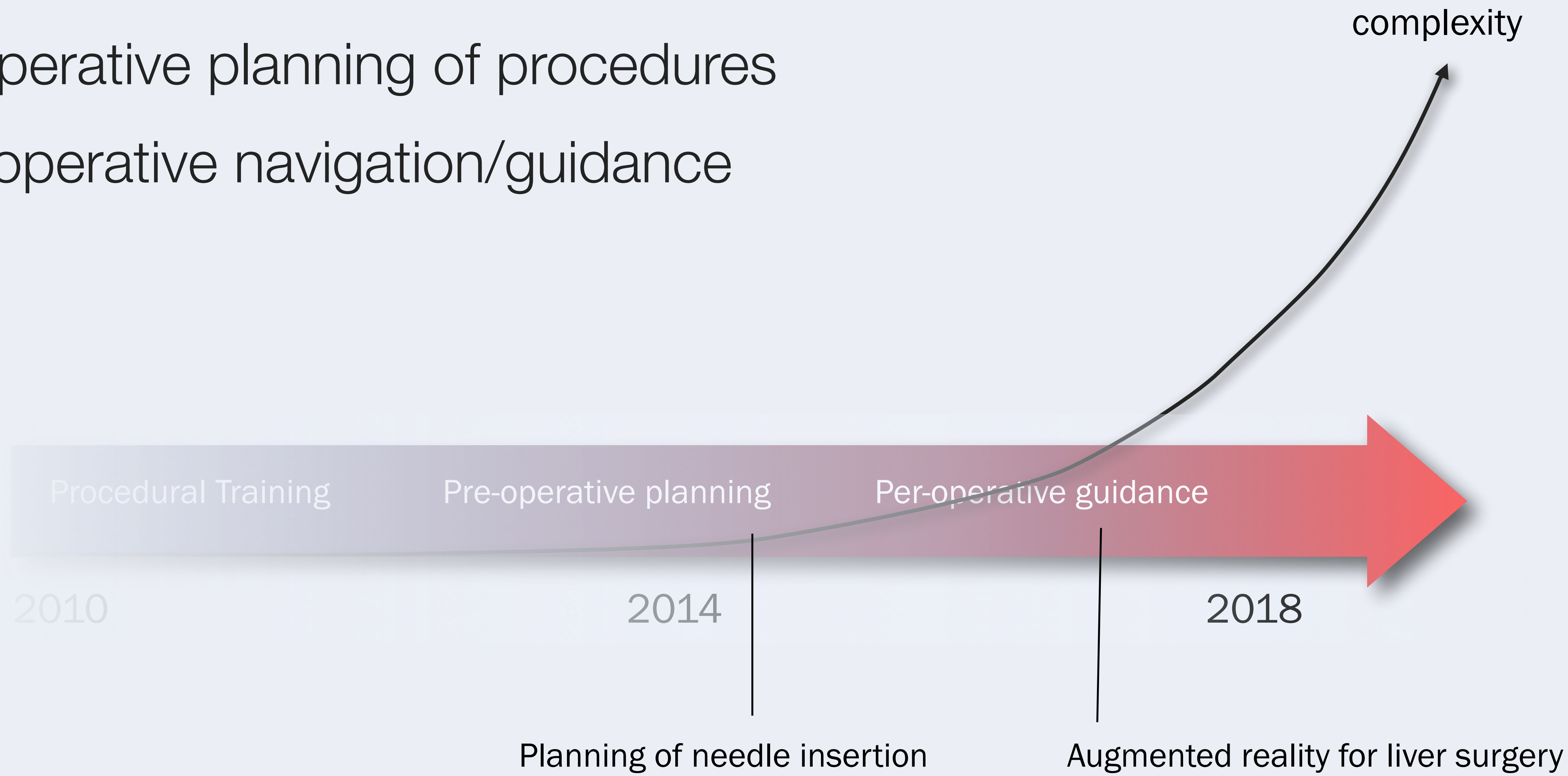
Specificity

- medical training
  - example: cataract surgery
  - realistic, interactive (visual and haptic rendering), generic models
- pre-operative planning
  - example: needle insertion planning in cryoablation
  - realistic, not necessarily interactive, patient-specific models
- intra-operative navigation
  - example: augmented reality for laparoscopic surgery
  - realistic, interactive, robust, patient-specific

TRAINING, PLANNING, NAVIGATION: SUMMARY

- Starting point: simulation for training
- Ongoing transition towards
  - pre-operative planning of procedures
  - intra-operative navigation/guidance

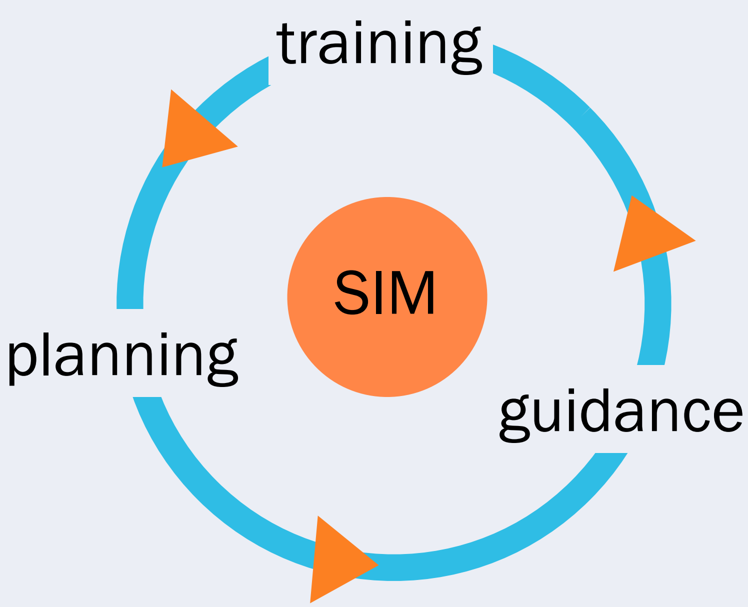
Physics-based
Performance
Specificity

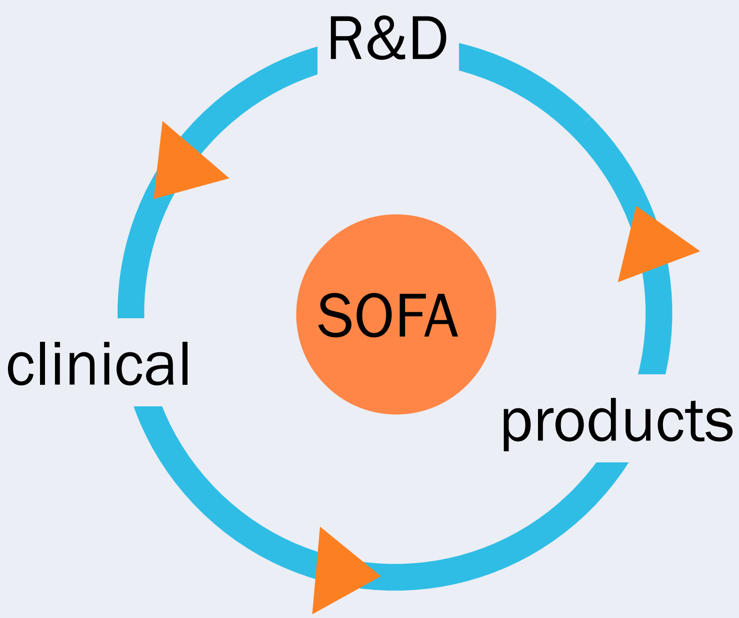


SYNERGY

- Parameter identification of simulation models
- Patient-specific modeling for real-time simulation
- Medical robotics

- Continue working on all objectives as they influence each other
- And transfer as many things as possible





COURSE OUTLINE

- 23/10: Motivation, context, examples. Images vs. Models.
- 30/10: Geometry: creating a mesh. Gmsh, CGAL, Paraview, SOFA.
- 06/11+?: Kinematics, kinetics, linear elasticity. Finite element method.
- 20/11: Modeling a simple quasi-static deformable object. First simulation in SOFA: linear solvers, mappings, rendering.
- 27/11: Including non-linearities: co-rotational and hyper-elastic models. Non-linear solvers, convergence.
- 04/12: Dynamics: explicit vs. implicit time integration methods.
- 11/12: Advanced topics: contacts, interaction, visual and haptic real-time.
- 18/12: Discussion, perspectives, practicals…