ME 328: Medical Robotics
Winter 2019

Lecture 11:
Surgical Simulation

Allison Okamura
Stanford University

images courtesy US National Museum of Health & Medicine,
Rick Satava, companies and institutions as referenced

How does one learn to be a surgeon?

- Historically: See one, do one, teach one
- Ideally (Vozenilek et al. 2011): see one, simulate many, do one competently, and teach everyone

In 2003, the U.S. regulated working hours for surgical residents, limiting them to an 80-hour work week.

"Although the cap on working hours was designed to enhance patient safety by keeping exhausted residents away from operating tables and other aspects of patient care, rates of surgical complications and reinterventions actually climbed after the rules were imposed."

Jackson and Tarpley, 2009

observing surgery at a distance

Christian Albert Theodor Billroth (1829-1894)

Surgery observation (1995)

(2011)

US National Museum of Health & Medicine archive (undated)

observing minimally invasive surgery

observing MIS cholecystectomy
(gall bladder removal)

(sort of) observing da Vinci surgery (JHU)

models of patients

Construction and repair of model training aids. Armed Forces Institute of Pathology. Sgt. Cortiza at workshop (1950)

models of patients

First Mannequin VR Simulator (David Gaba, 1984).
Courtesy MedSim, Inc. (1991)

David Gaba directs Stanford's Center for Immersive & Simulation-based Learning
http://cisl.stanford.edu/

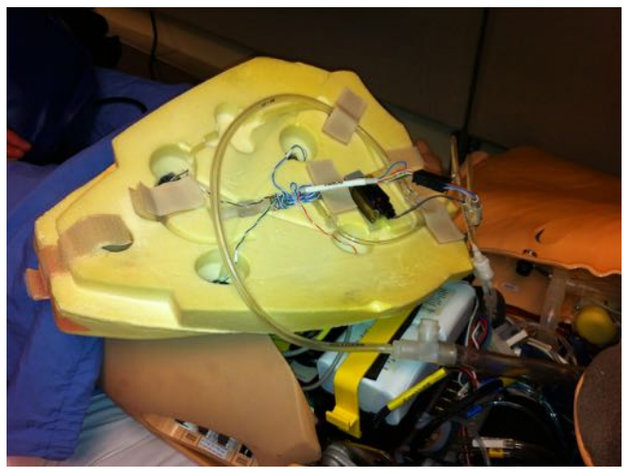
models of patients

METI
http://www.meti.com/

"Researchers program his vital signs and other bodily functions using a Mac equipped with the OS X operating system. With the click of a few buttons, he can suffer a collapsed lung, start to bleed to death after a car accident or show the symptoms of a bioterrorism attack." - WIRED 2004

models of patients

Laerdal's SimMan, http://www.laerdal.com/

Photos of innards taken at U. Washington

Limbs & Things USA

Skills training products for healthcare professionals

1-10 of 22 products displayed | View All

MATT Trainer - Basic
PART 50250
$786.00

MATT Trainer - Standard
PART 50150
$2,616.00

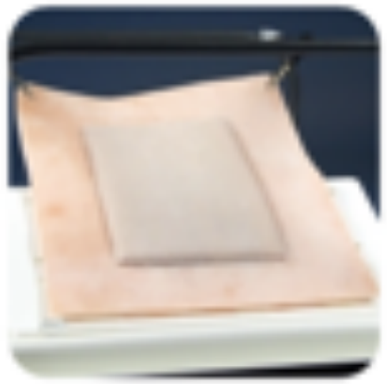
TEP Guildford MATTU Hernia Trainer
PART 50135
$2,448.00

Large Body MITS with 0 Degree SimScope™
PART 3DTRLCD05
$2,575.00

Large Body MITS with 30 Degree SimScope™
PART 3DTRLCD05-30
$2,675.00

Standard MITS with Joystick Simscope™
PART 3DTRLCD07
$2,000.00

Large Body MITS with 0 & 30 Degree SimScope™
PART 3DTRLCD05IGT
$2,950.00



Large Surgical Dissection Pad
PART 50114
$195.00

Small Surgical Dissection Pad
PART 50118
$84.00

Vermiform Appendix
OPTIONS AVAILABLE
$100.00

surgery is even harder...

- procedures are invasive: cutting, removing, sewing
- the environment is highly deformable (and plastic)
- the nature of physical interactions with the patient are critical
- need to simulate what happens when the wrong thing is done (not just the right thing)
- but laparoscopic/robotic surgery at least makes it possible (and probably increases the need)

roles of surgical simulation

- train new doctors
- evaluate doctors
- learn/sell a new device
- patient- or procedure-specific planning
- patient-specific practice
- “warm up” immediately before a procedure

others?

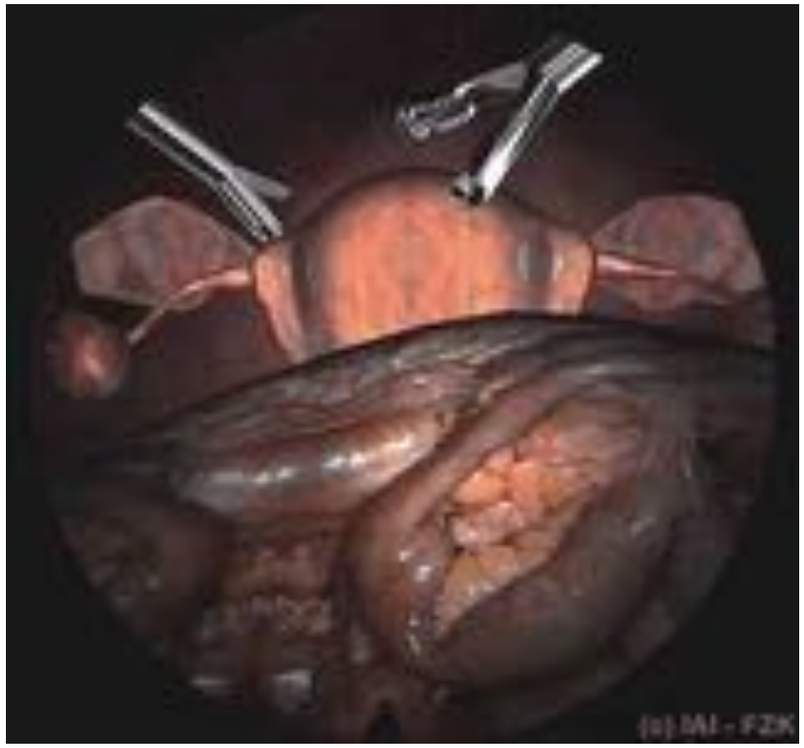
entertainment
... and recruiting?

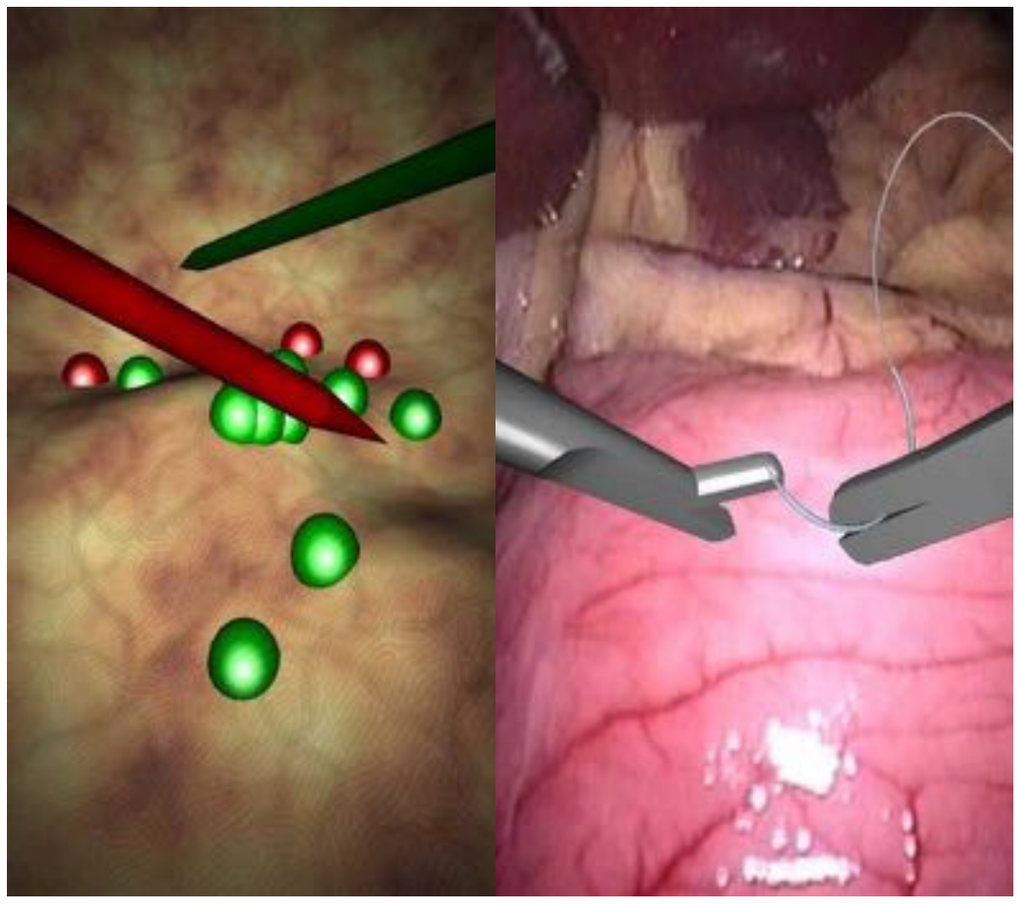
Product Features

- The stylus will be your scalpel -- make incisions, anesthetize problem areas, remove tumors, monitor vital signs, apply bandages, and more
- Use your applied skills to solve the puzzle of each surgery
- Deal with human drama between appointments - Keep a cool head, or you'll be out on the street and all those years of medical school will be for nothing
- Feel the pressure of each tense, challenging operation as detailed graphics bring the human body to life
- Operate on a wide variety of patients in story mode, then return later and try to beat your high scores!

example surgery simulators

Laparoscopic hysterectomy (van Lent, ICT, CA)

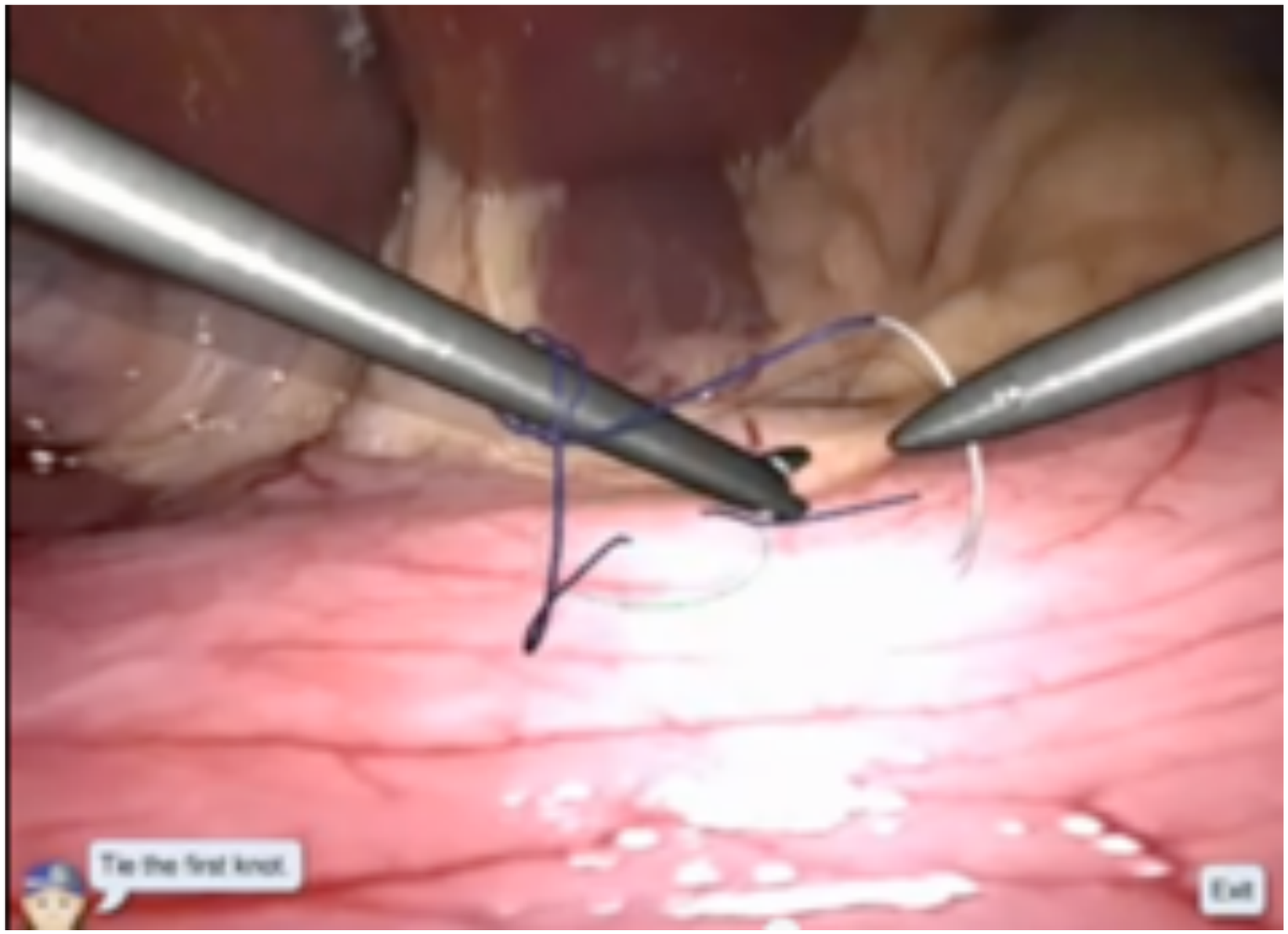




LapSim simulator tasks - abstract & texture mapped (Hytland, Surgical Science, 2000)

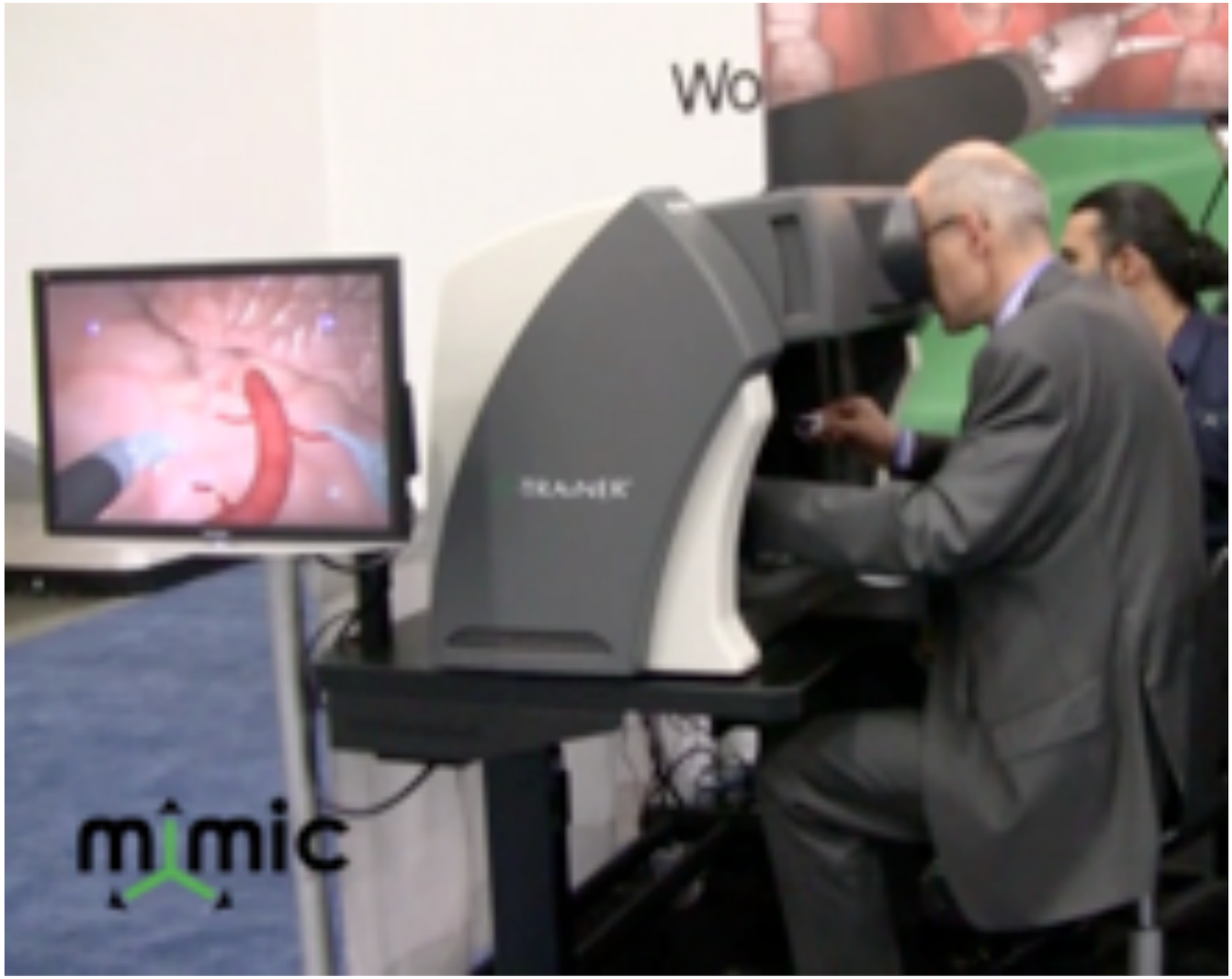
Laparoscopic Simulator with haptic feedback (Launay, Xitact, Switzerland)

Surgical Science's LapSim



http://www.youtube.com/watch?v=ayIVh2FtIDc

mimic technologies' dV Trainer



haptic cow

Sarah Baillie, Royal Veterinary College in London

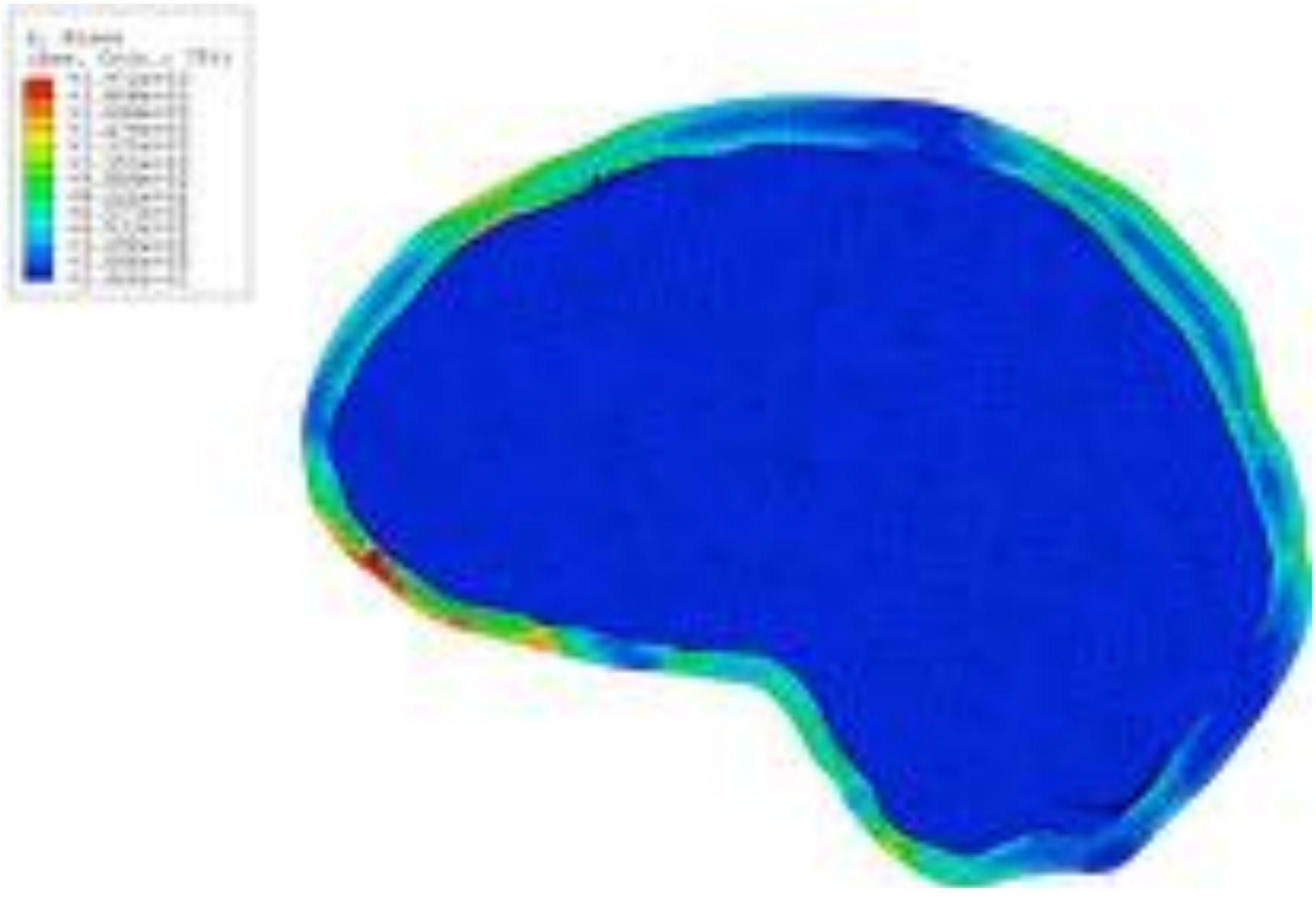
how are these simulators created?

Tissue Modeling Methods

- FEM (Finite element models)
  - Physical basis continuum mechanics
  - depends on few parameters: constitutive law
  - slow
- Mass-Spring systems
  - Fast
  - no straightforward way to select (the many) parameters
- BEM (Boundary Element models)
- Specialized local models (E.g., reality-based modeling)
- Meshless/Particle (Basic research is ongoing)

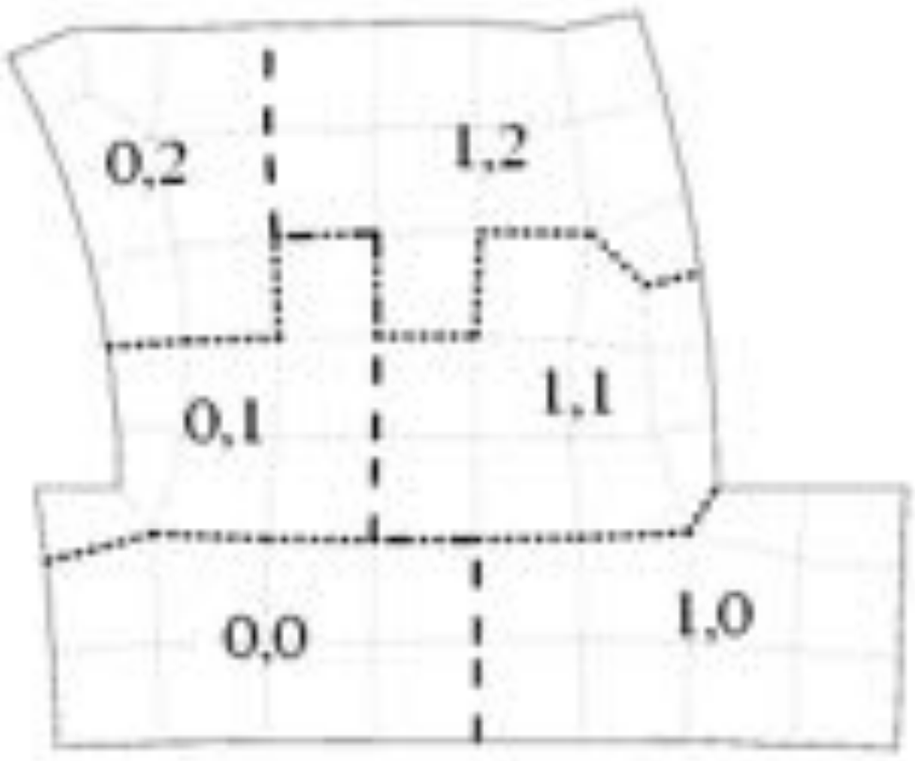
Commercial Software for FEM

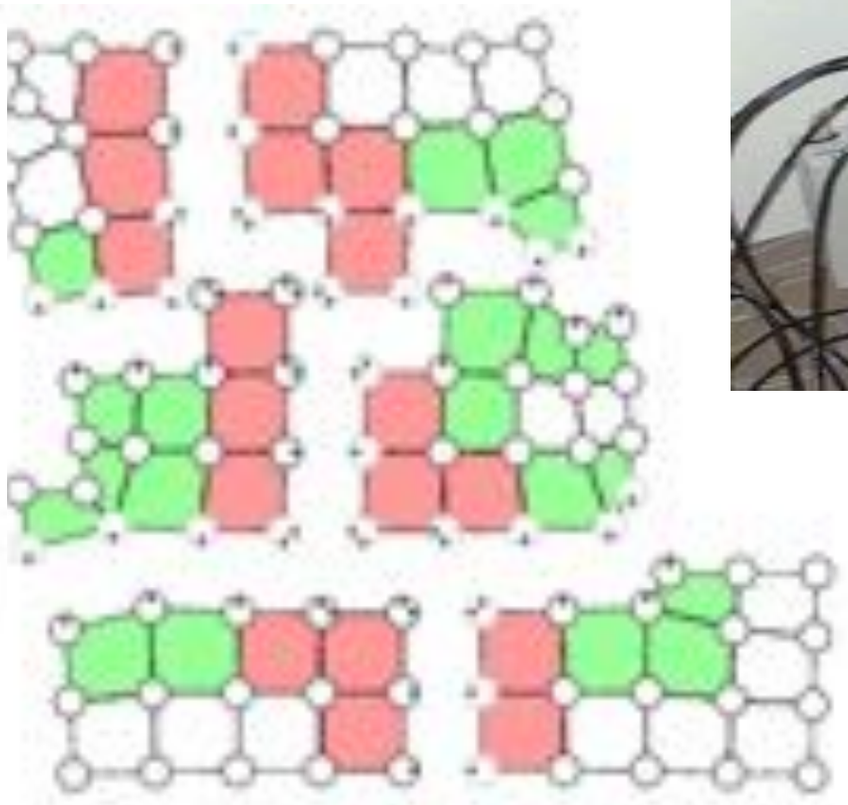
- ABAQUS
- ADINA
- ANSYS
- DYNA3D
- FEMLAB
- GT STRUDL
- IDEAS
- NASTRAN



Real-time FEM

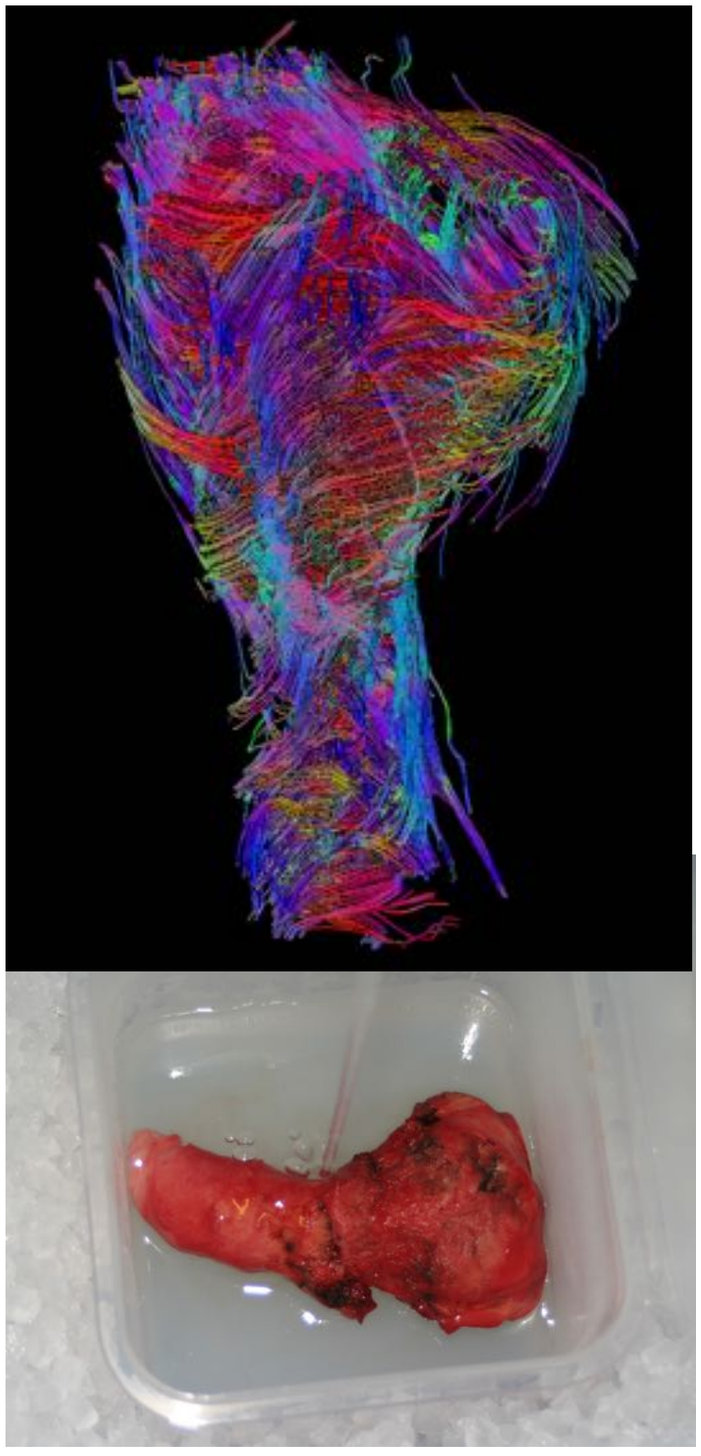
- Parallelization
- Tessellation of the problem
- Scalable approach





Székely (ETH)

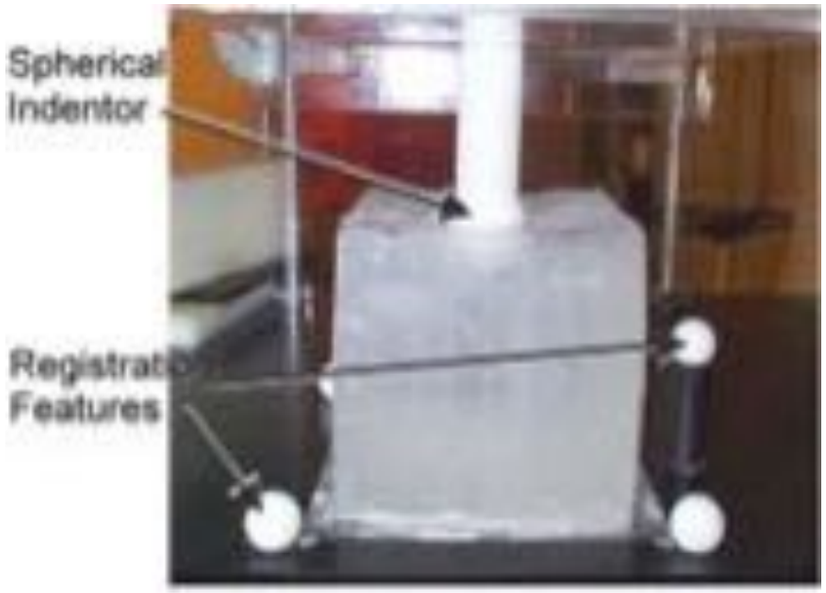
What can FEM achieve?

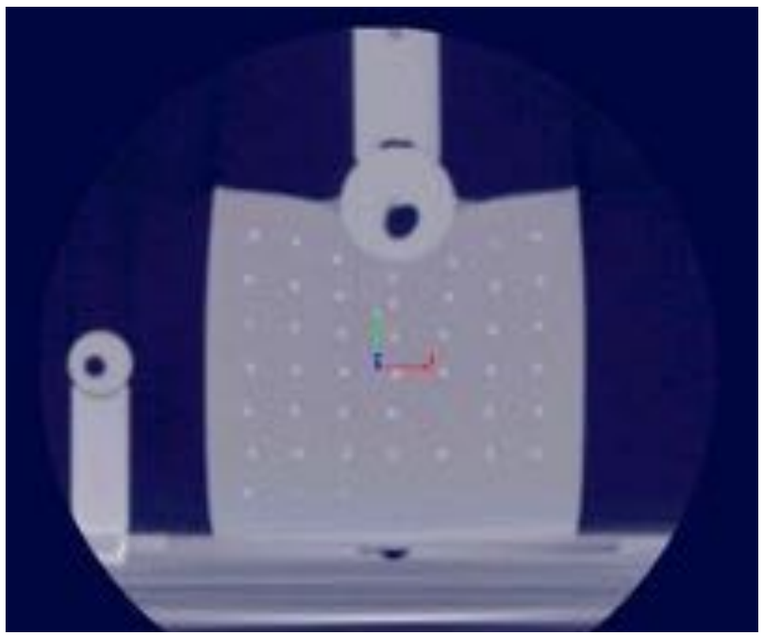


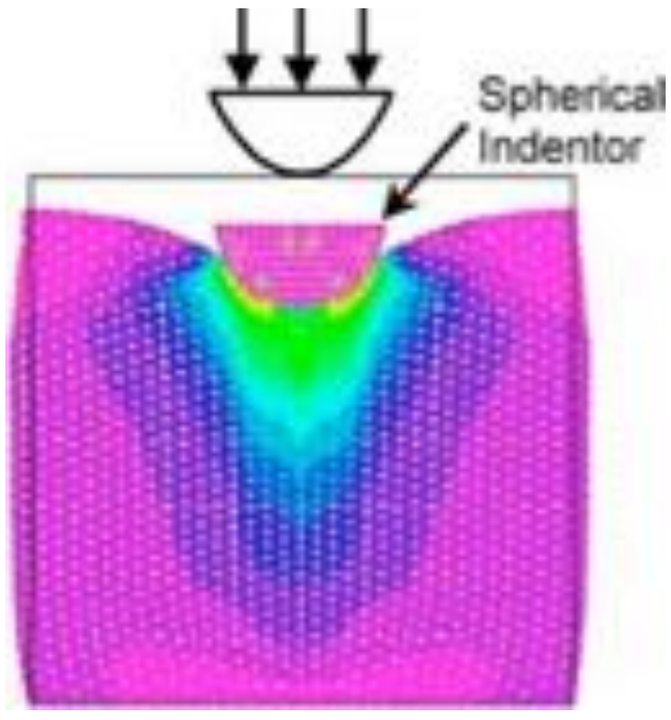
- Precise predictions are possible, but maybe not in real time
- Cannot be better than the underlying tissue model
- Simple non-linearities are not sufficient
- Tissue is usually non-homogeneous and non-isotropic
- Resolution limits
- Uterus example
  - determining fiber structure
  - not known from anatomy
  - MRI DTI measurements

Székely (ETH)

Measuring Tissue Properties





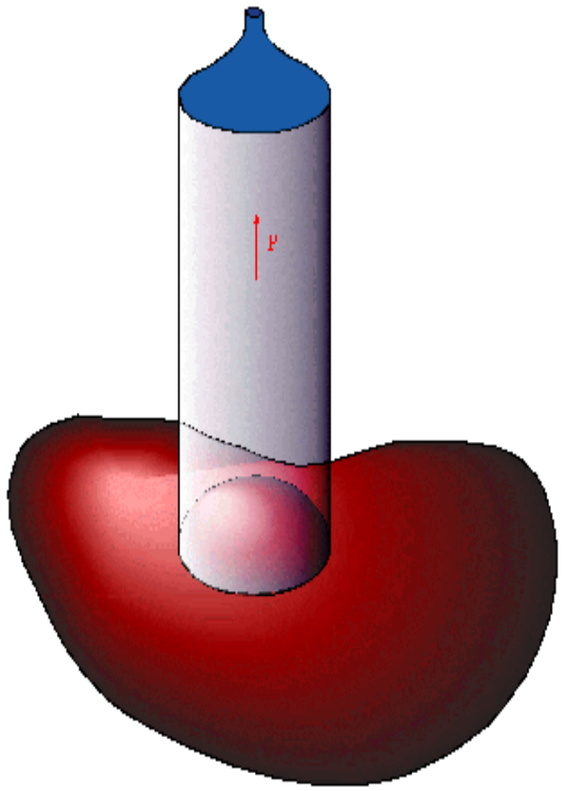


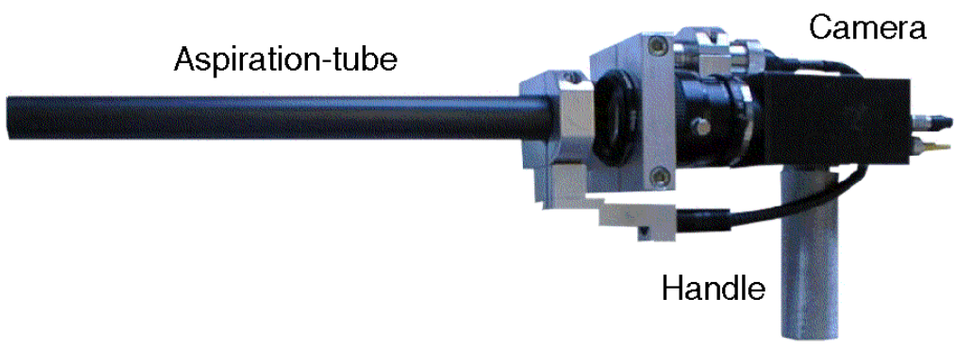
"Truth Cube"

Kerdok & Howe (Harvard)

Measuring Tissue Properties

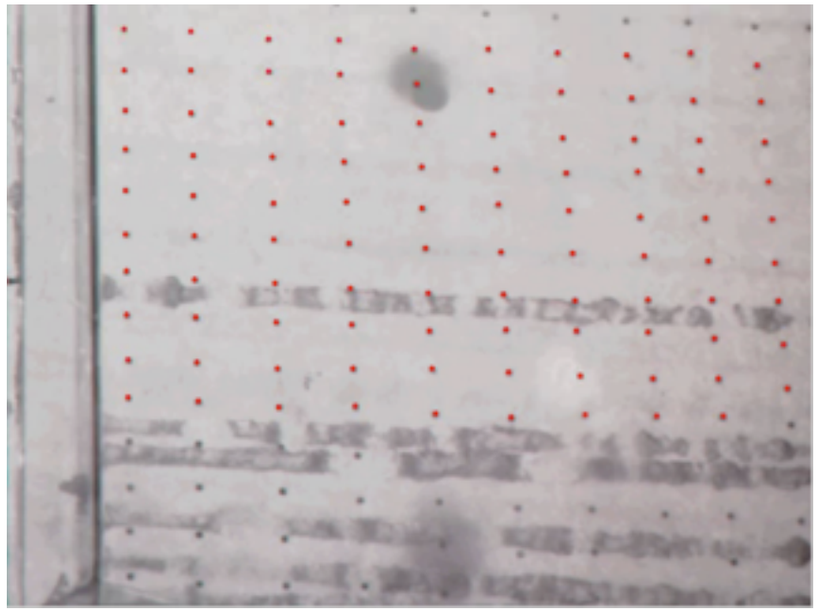
Aspiration



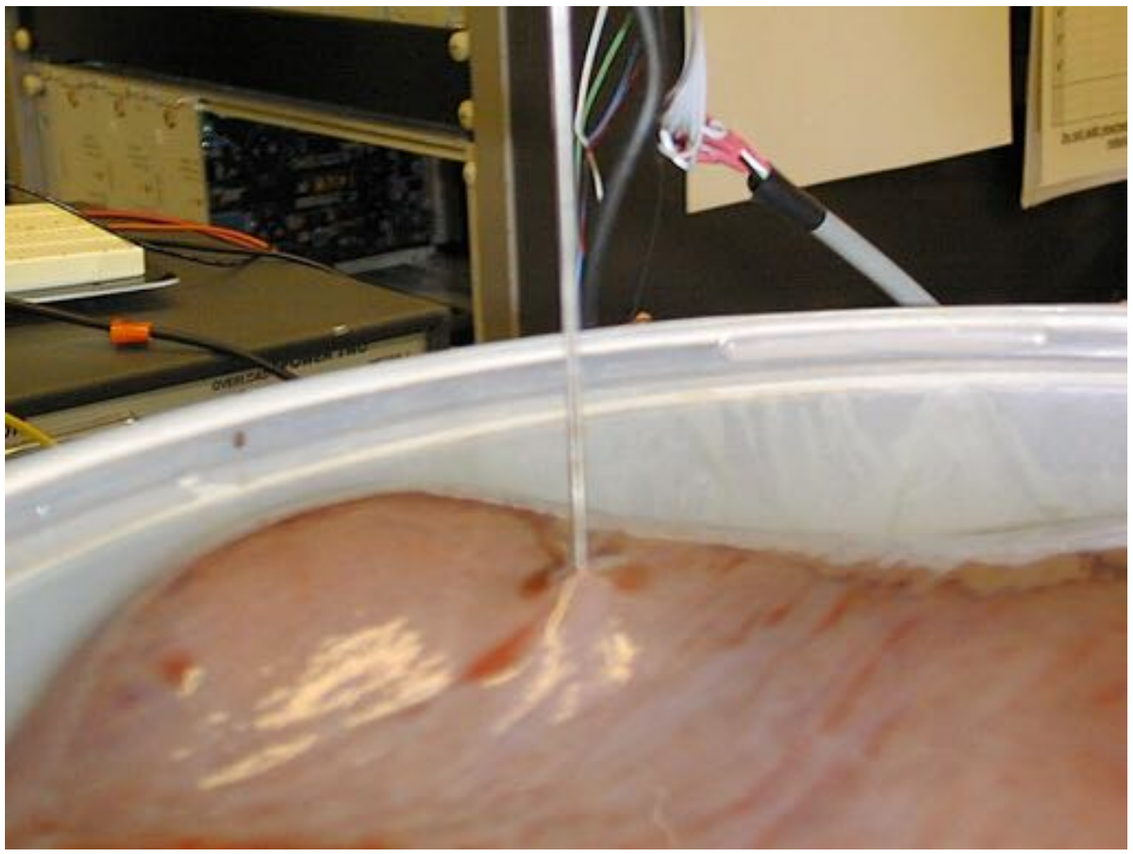


Székely (ETH)

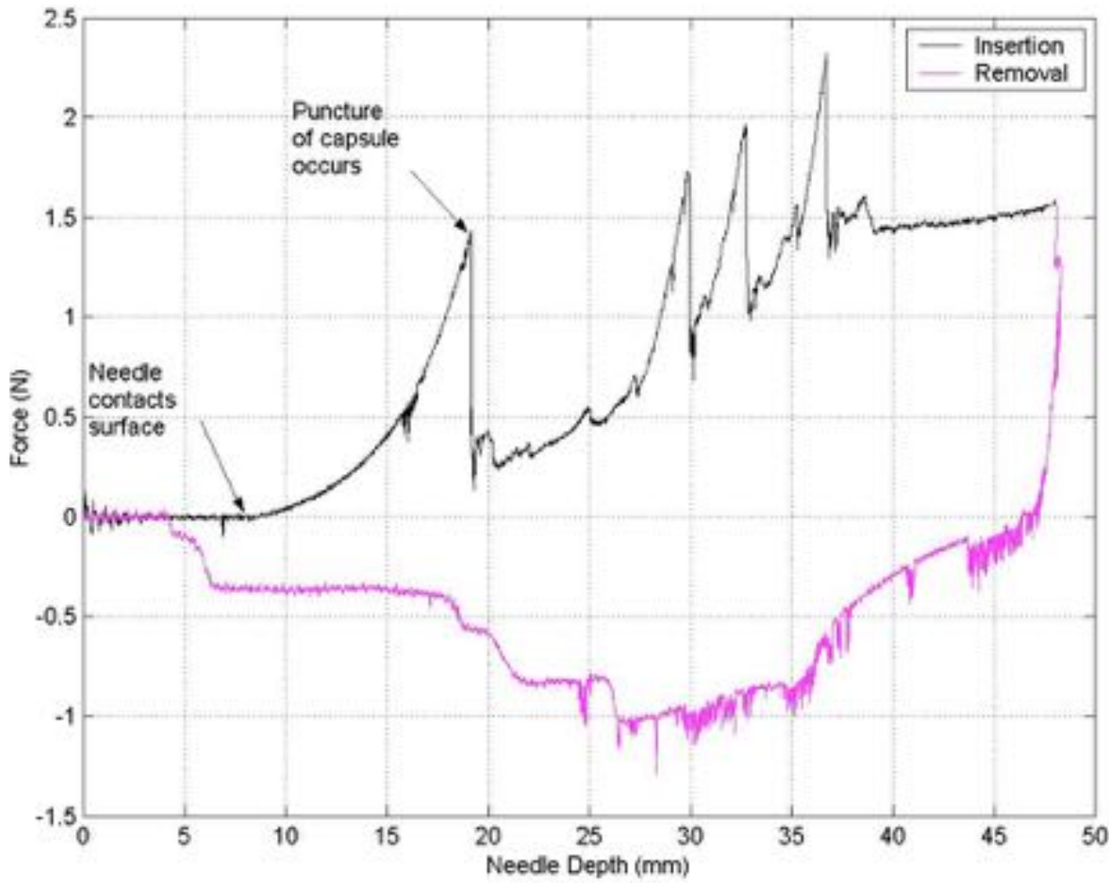
“Invasive” Tool-Tissue Interaction



Crouch, et al. 2004



Okamura, et al. 2004



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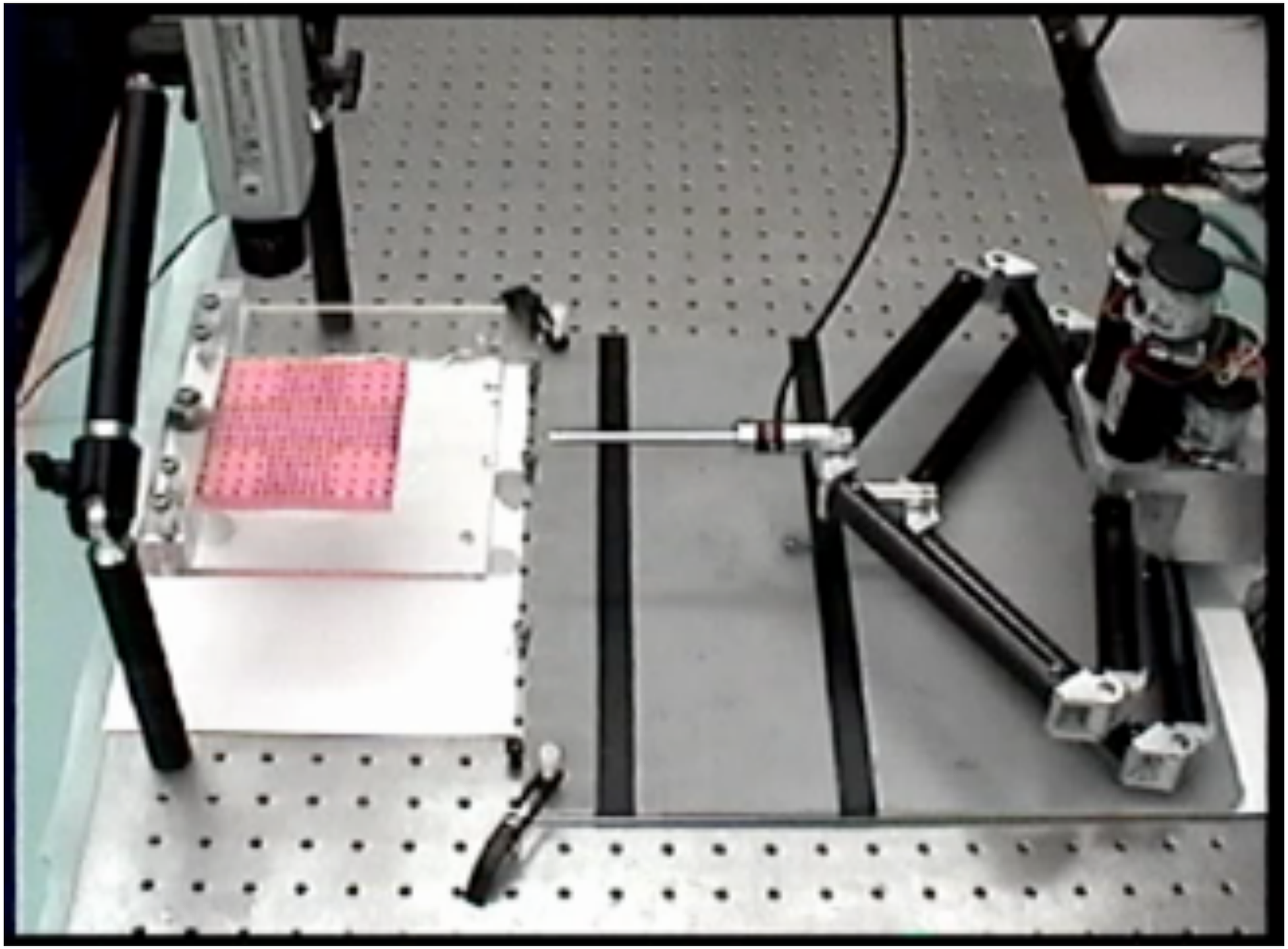
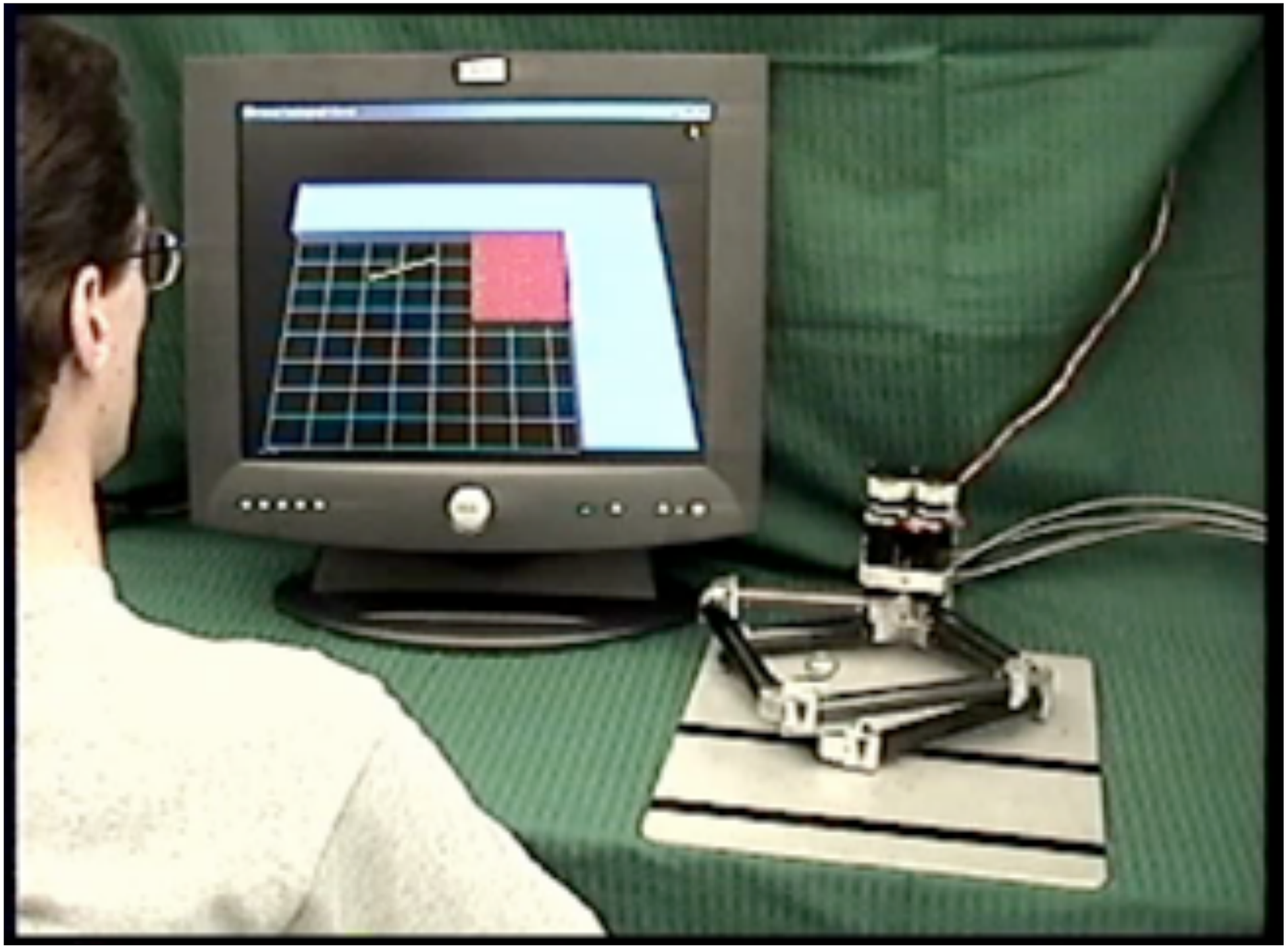


DiMaio & Salculdean 2002 (UBC)

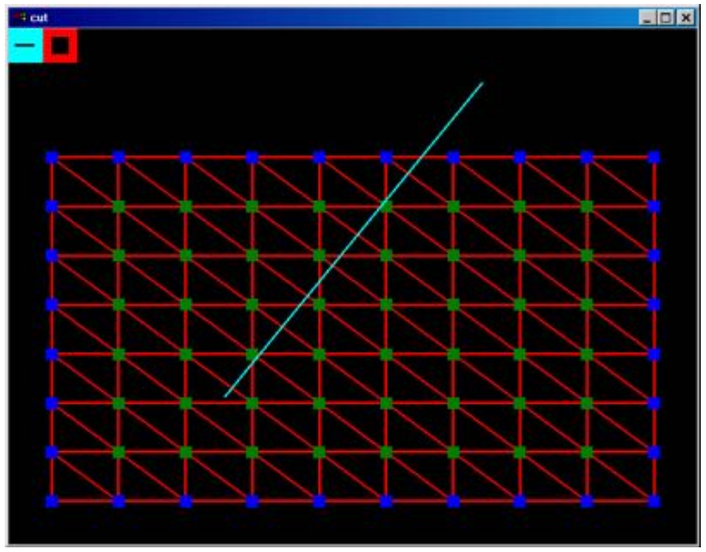
Simulation

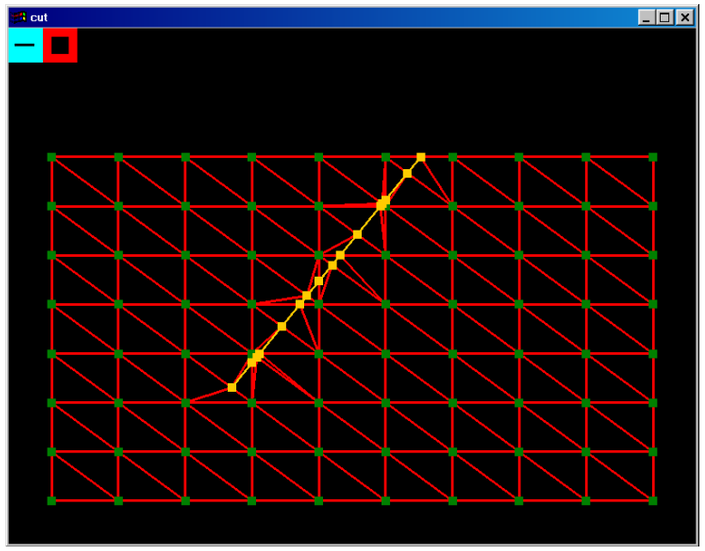


DiMaio & Salculdean 2002 (UBC)

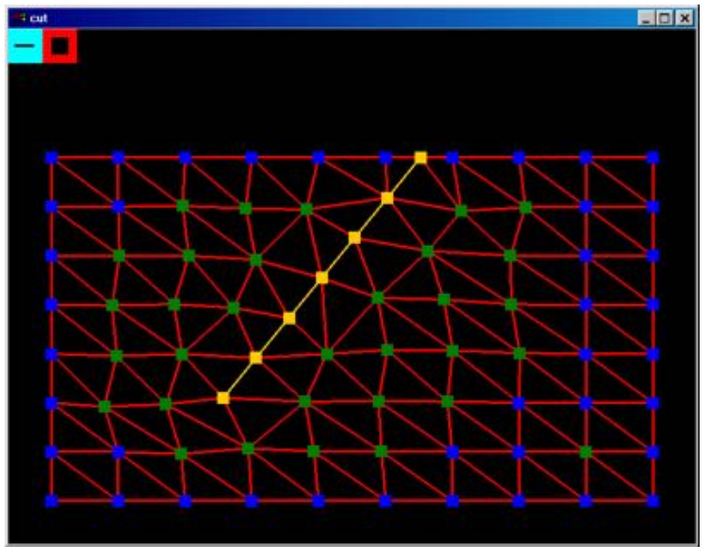
Remeshing Methods

Triangulated mesh



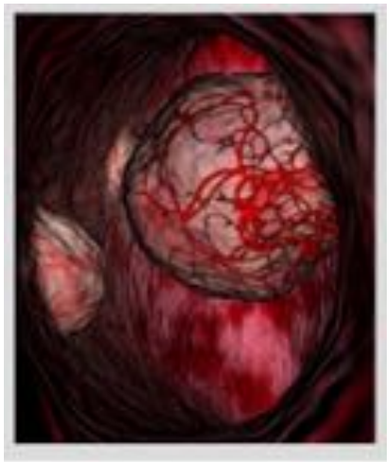


Element subdivision

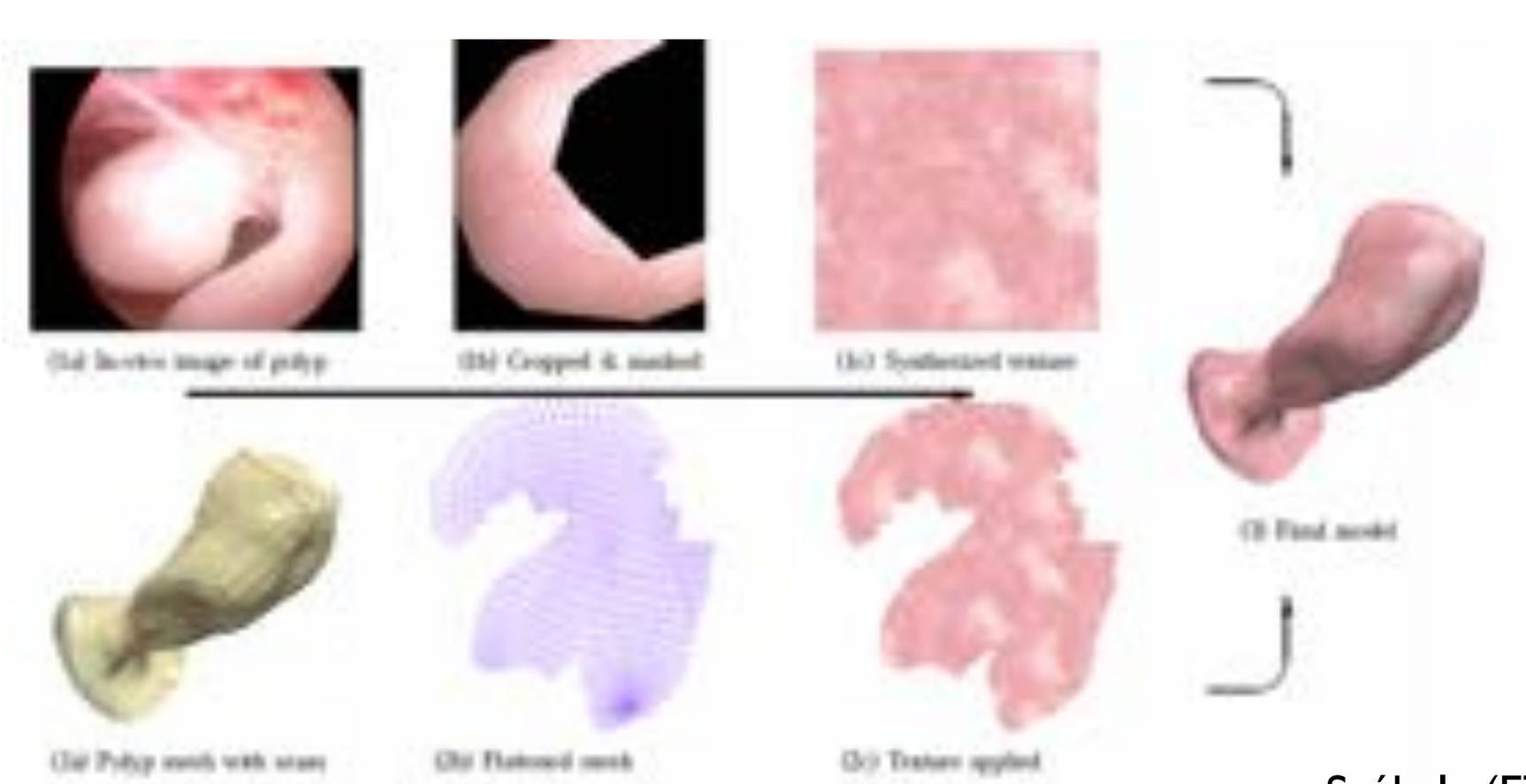


note: may need to happen at "haptic" rates (> 500 Hz)

Realistic organ texturing

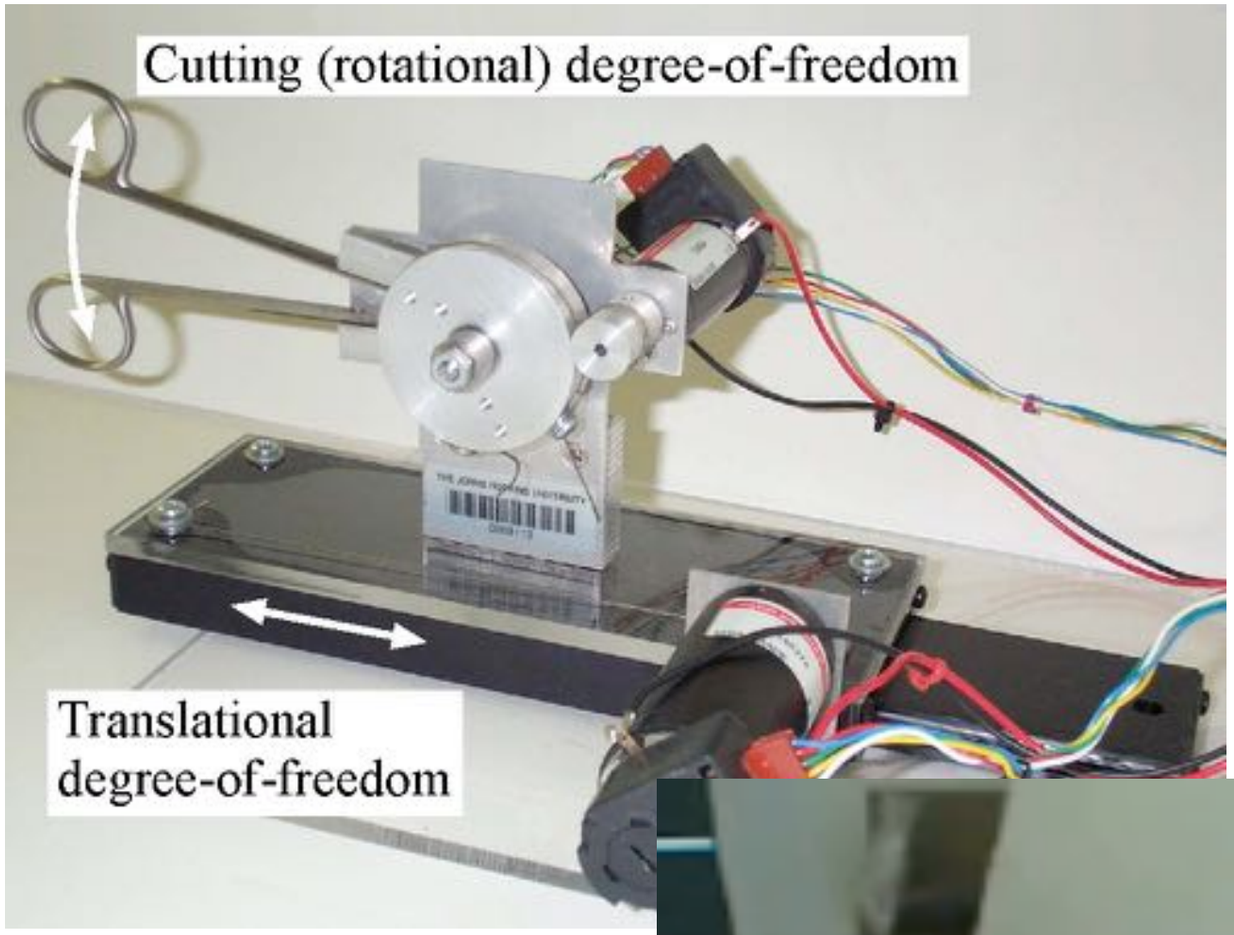


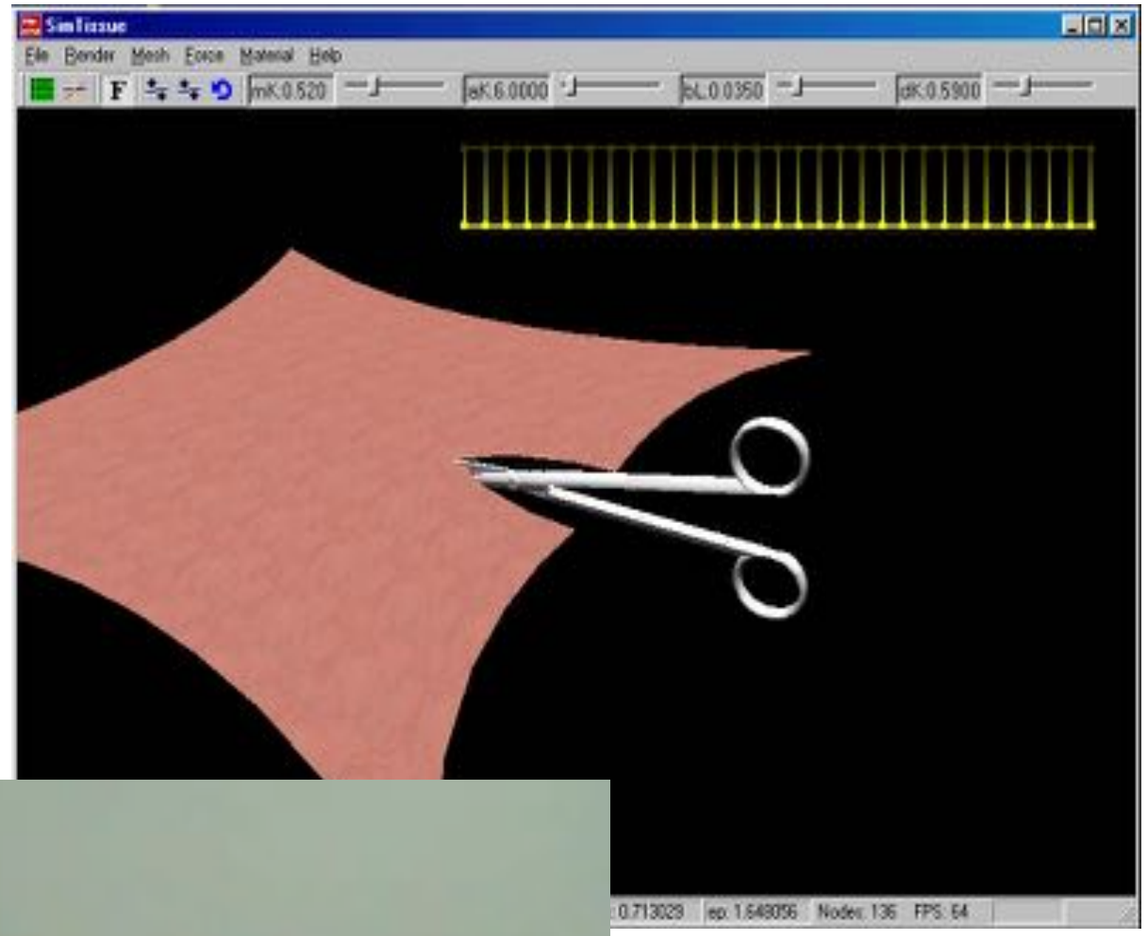
- Based on endoscopic image data base
- Tissue-specific textures: blending
- Surface mapping with possibly minimal distortion
- Real-time processing for cut surfaces



Székely (ETH)

Cutting with Scissors





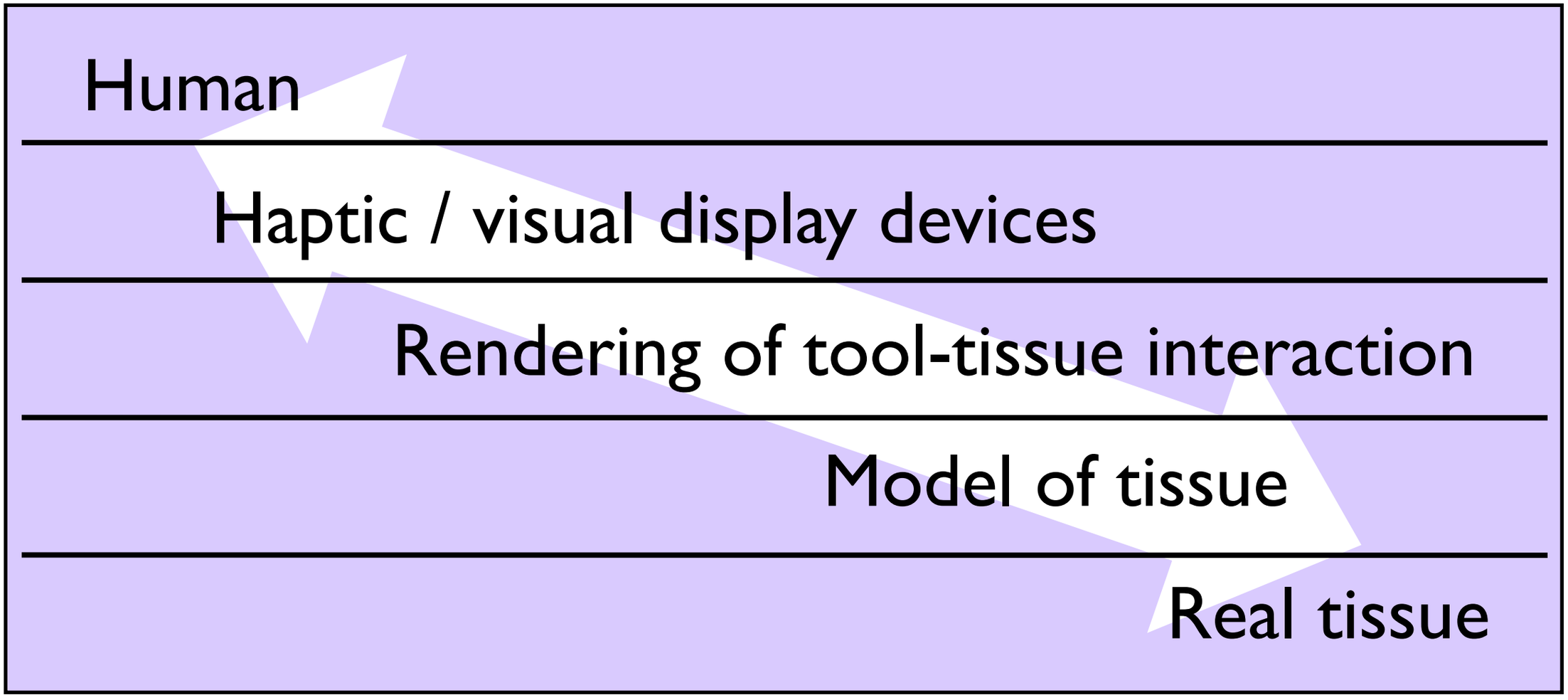
S. Greenish et al. (2002)

Some thoughts about tissue modeling experiments

- Start with phantom (artificial) tissues
- Global deformations → basic models
- Basic models → Global deformations
- Ex vivo / cadaver animal studies are very difficult to do right
- In vivo animal studies can be done “survival”
- Perfusion (Kerdok, Ottensmeyer et al.)

How good do models have to be?

- Perceptual experiments with “experts”
- Examine training effectiveness
- Information transmission through “filters”:



evaluation

is the simulator is any good?

- **Face validity:** does the system present an environment resembling that which is encountered during a medical procedure?
- **Content validity:** is a skill measured by the system measured the specific skill desired, and not a different one?
- **Construct validity:** can the system capture the differences between experts and novices?
- **Concurrent validity:** to what extent does testing performance with the simulator yield the same results as other measures?
- **Predictive validity:** does performance/training with the simulator transfer to improvements in clinical practice?

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which one do you think is...

most important? hardest to measure? most common?

least important? easiest to measure? least common?

is the simulator any good?

Simulator	Number of Studies evaluating	Construct Validity Claimed	Face Validity Claimed
LapSim (Surgical Science Ltd.)	8	8	1
MISTELS/FLS (SAGES)	6	6	3
LAP Mentor (Simbionix Corp.)	6	3	3
Endotower (Verefi Technologies Inc.)	4	3	3
MIST VR (Mentice, Gothenburg, Sweden)	4	2	1
Xitact LS500 (Xitact S.A.)	4	2	2
SIMENDO (Delltatech)	3	2	1
ProMIS (Haptica)	2	2	0
LTS 2000 (Realsim)	1	1	0
Department Developed Device (various)	13	11	7

Korndorffer et al. (2009)