NSF Engineering Research Center for Computer-Integrated Surgical Systems and Technology

CISST Research Program: Current and Future Trends

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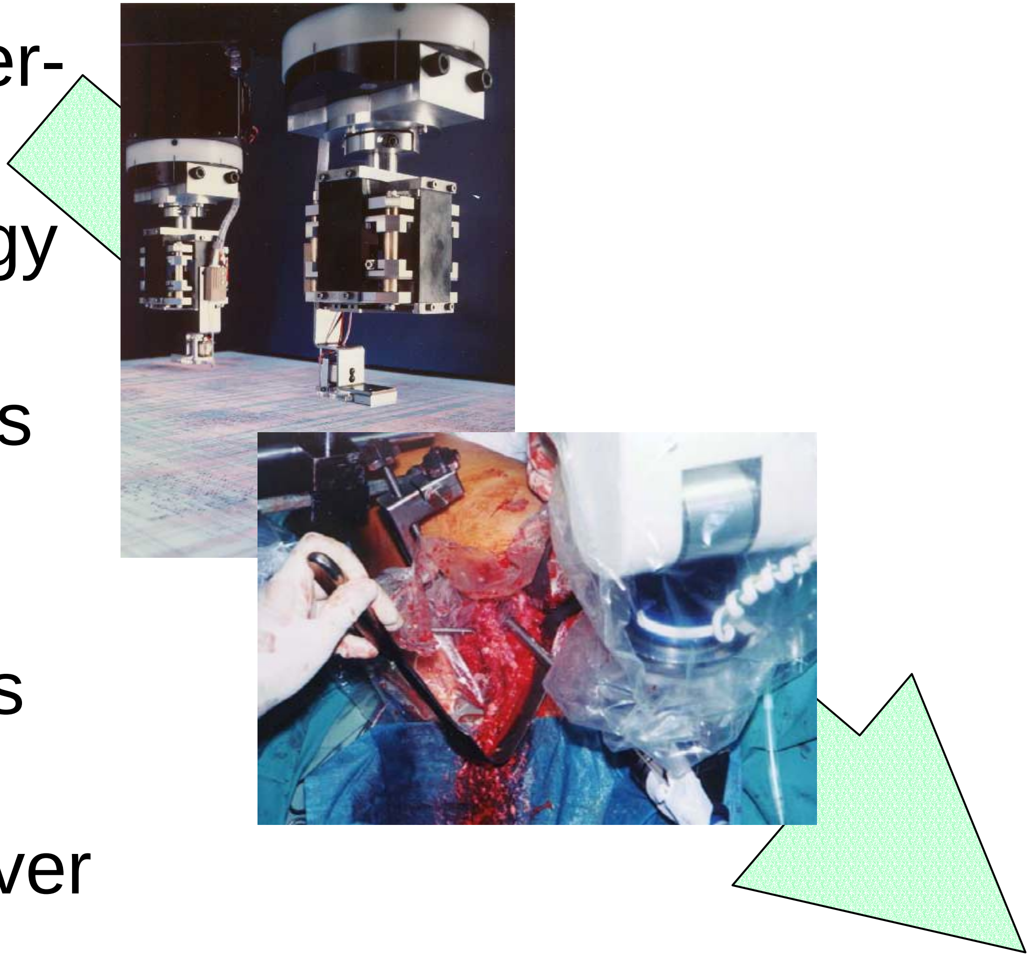
NSF Engineering Research Center for Computer-Integrated Surgical Systems and Technology

- Established 1998
- Multi-institution, multi-disciplinary center
  - Johns Hopkins University + Medical Institutions
  - MIT + Brigham & Women's Hospital
  - CMU + UPMC
  - Others: Morgan State, Georgetown, Harvard, Penn, Columbia
- Funding
  - Core NSF Grant + NIH + Industry; Total = $9-10M
- University researchers, <u>clinicians</u>, industry
- Research, Systems, Education, Outreach

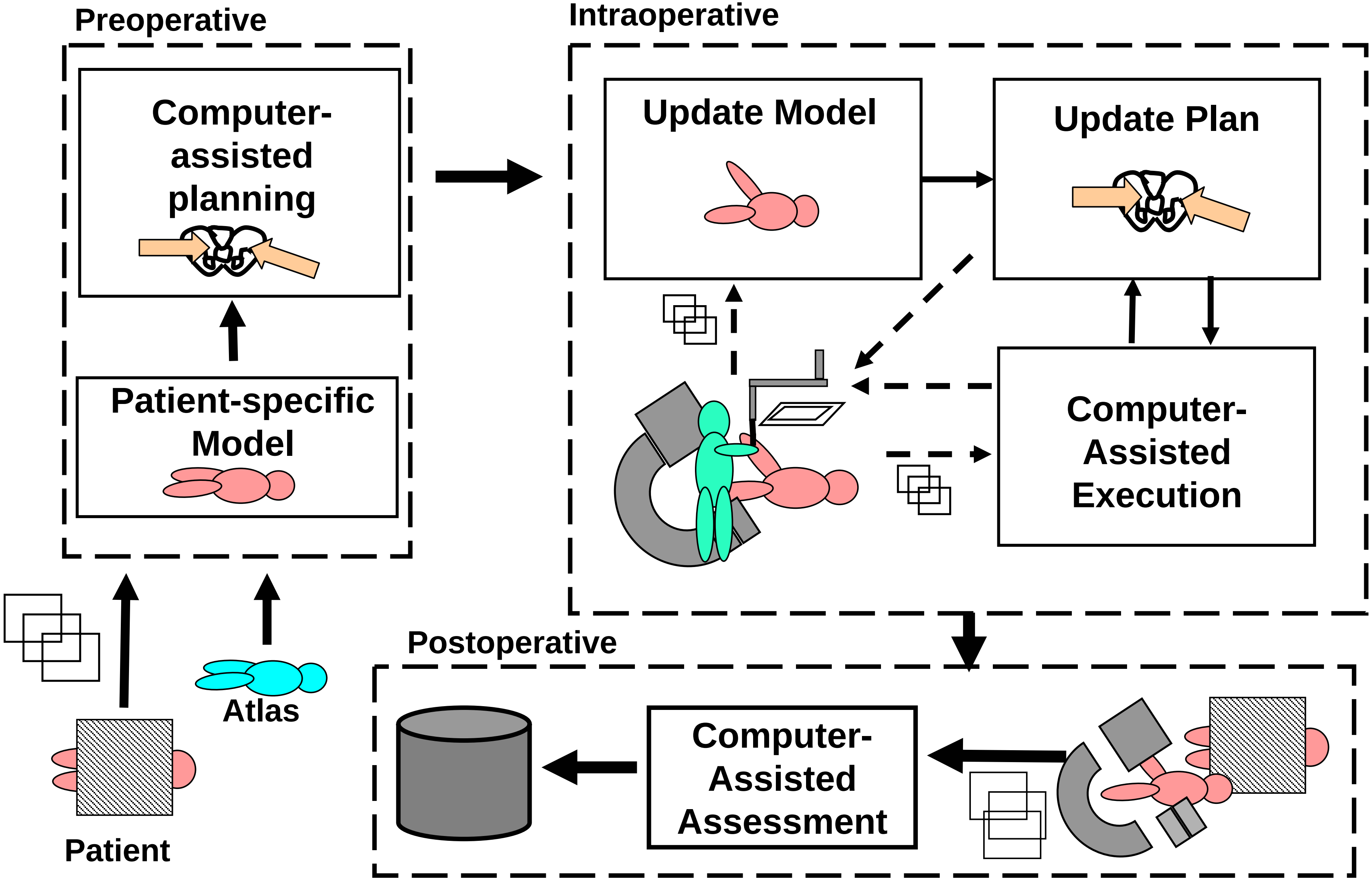
CISST Premise

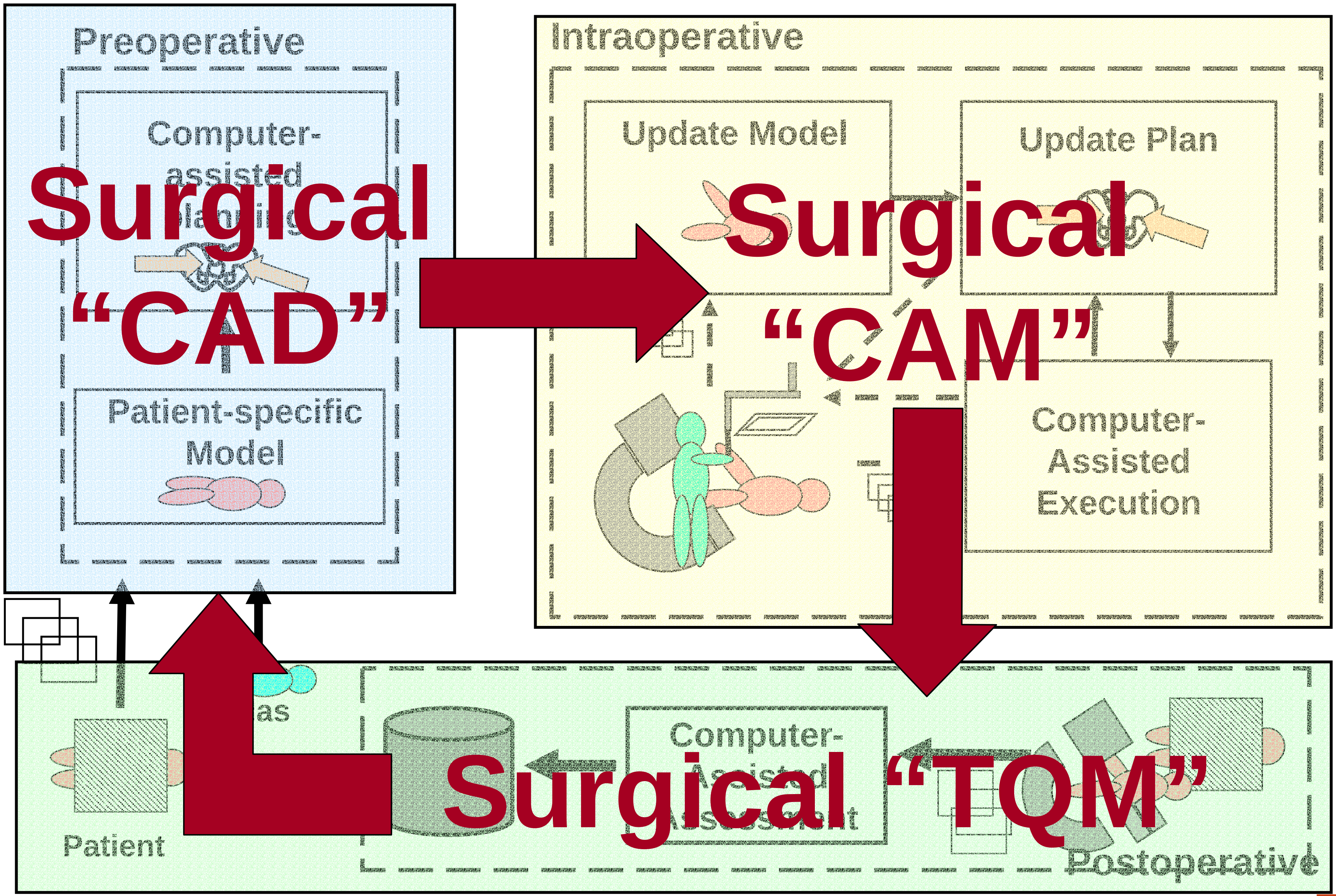
The impact of computer-integrated surgical systems and technology on medical care in the next 20 years will be as great as the impact of computer-integrated manufacturing systems and technology on industrial production over the past 20 years.



Engineering Research Center for Computer Integrated Surgical Systems and Technolog

CIS Systems Vision





Preoperative
Computer-assisted Planning
Patient-specific Model
Surgical "CAD"
Intraoperative
Update Model
Update Plan
Computer-Assisted Execution
Surgical "CAM"
Patient
Surgical "TQM"
Computer-Assisted Assessment
Postoperative

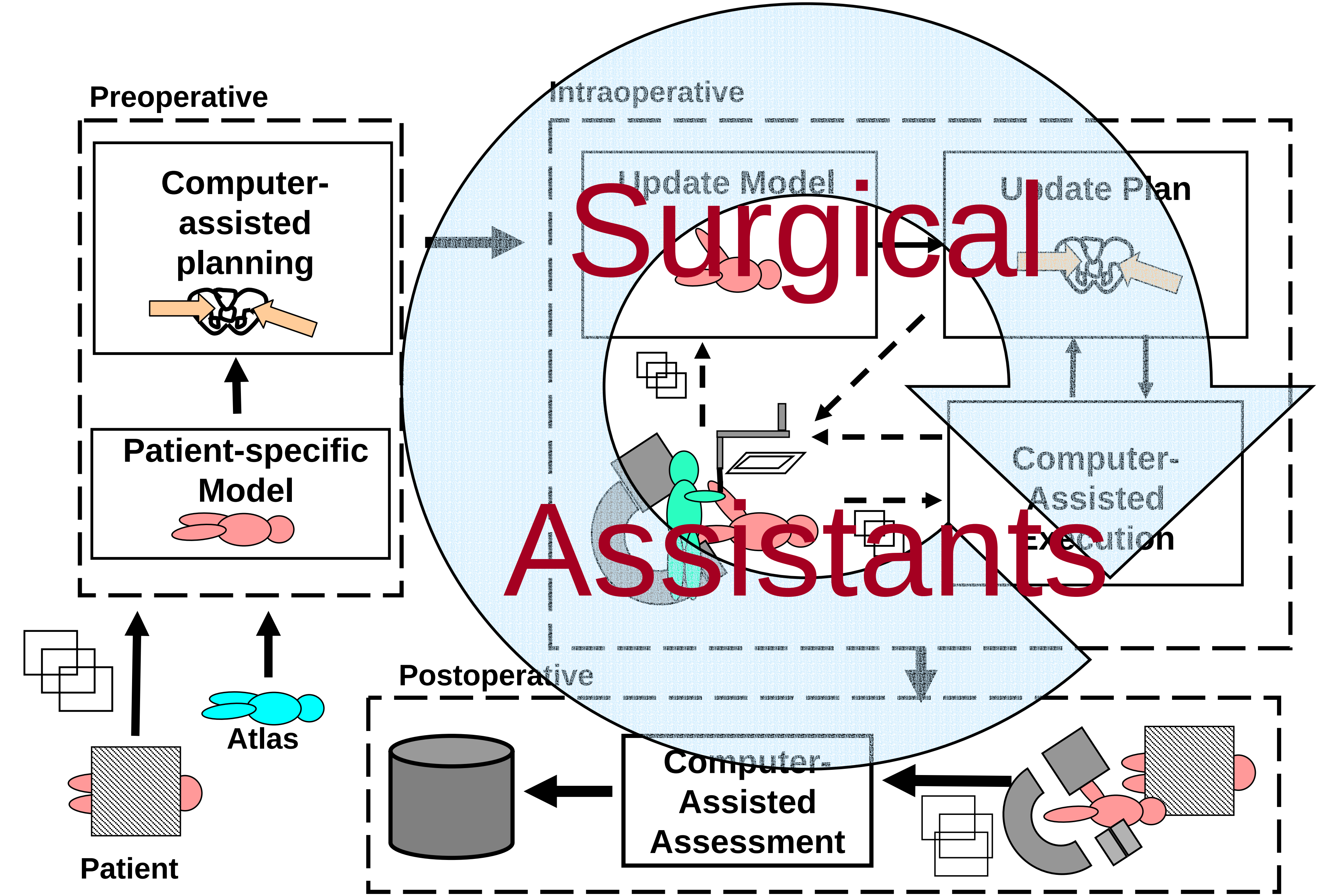
Surgical CAD-CAM Activities

Prostate	Liver	Spine
200,000 cancers/year 1M biopsies /year 10M BPH currently 25% of men affected in lifetime	Metastasis from colorectal cancer 130,000 new /year 60,000 death /year Hepatitis worldwide	$120 billion cost 70% of population affected in lifetime **Bone** 400,000 metastatic cases/year

United States numbers

Why these?

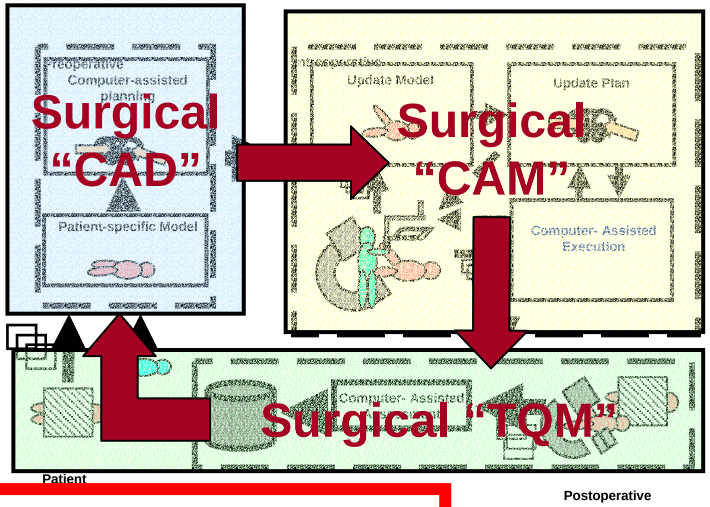
- Significant health problems
- Clinical collaboration
- Experience
- External funding
- Suitable mix for prototyping

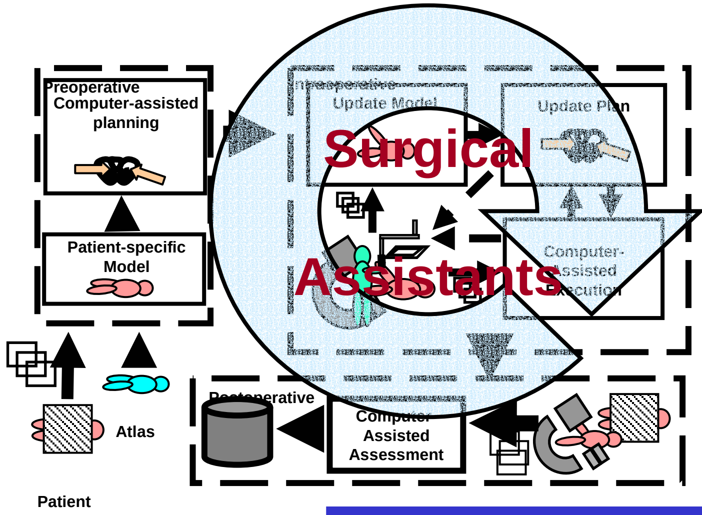

Surgical
Assistants
Preoperative
Computer-assisted planning
Patient-specific Model
Atlas
Patient
Intraoperative
Update Model
Update Plan
Computer-Assisted Execution
Postoperative
Computer-Assisted Assessment

Surgical Assistance Activities

	Eye	Ear	Sinus	Throat	Brain	General MIS
Engineering Faculty	Hager, Okamura Riviere. Cole-Rhodes, Etienne-Cummings	Whitcomb	Taylor Hager	Taylor Simaan Okamura	Taylor Kazanzides Hager Riviere	Okamura, Hager Taylor, Kanade Riviere, Kazanzides
Clinical Faculty	Handa Humayen DeJuan Thompson	Rothbaum Francis	Ishii	Flint	Long Clatterbuck Engh	Yuh, Gott Talamini Choti Marohn, Hanly
Principal Focus	Tremor reduction and image-based guidance	Accessing the Scala-Media	Advanced visualization with SHR guidance	High dexterity in confined spaces	Integration of Navigation and Robotics Needle steering	Telesurgery and human factors/ Robot-assisted ultrasound
Platform	JHU SHR with adapted Doheny Eye Institute cannulae CMU Micron with same	JHU SHR with special delivery system	EndActive endoscope	New JHU snake design, Intuitive Surgical da Vinci system	JHU SHR, Medtronic Stealthstation Steered Needle	Intuitive Surgical da Vinci system Lars Ultrasound robot
Tasks Involved	1, 2, 3, 4	1	2, eventually 1, 3 and 4	1, eventually 2, 3, 4	1	2, 3, 4
Clinical Status	Phantom trails (Micron, SHR) ongoing	New delivery system under development.	Cadaver and Phantom trials	Phantom trials	Phantom trials in August	System development/ infrastructure underway
External Funding Status	NIH R01 (Micron) NIH R21 Submitted (Image-guided Micron) Planned NIH (SHR)	Seeking NIH funding	NIH R21 under revision	NIH R21	Pittsburgh Foundation ABC^2 pending NIH R21/33 pending	NIH R01, SBIR P1, Whitaker, NSF Other NIH, Army pending

The Spectrum of CIS Systems





Modeling & Analysis
- Segmentation
- Registration
- Atlases
- Optimization
- Visualization

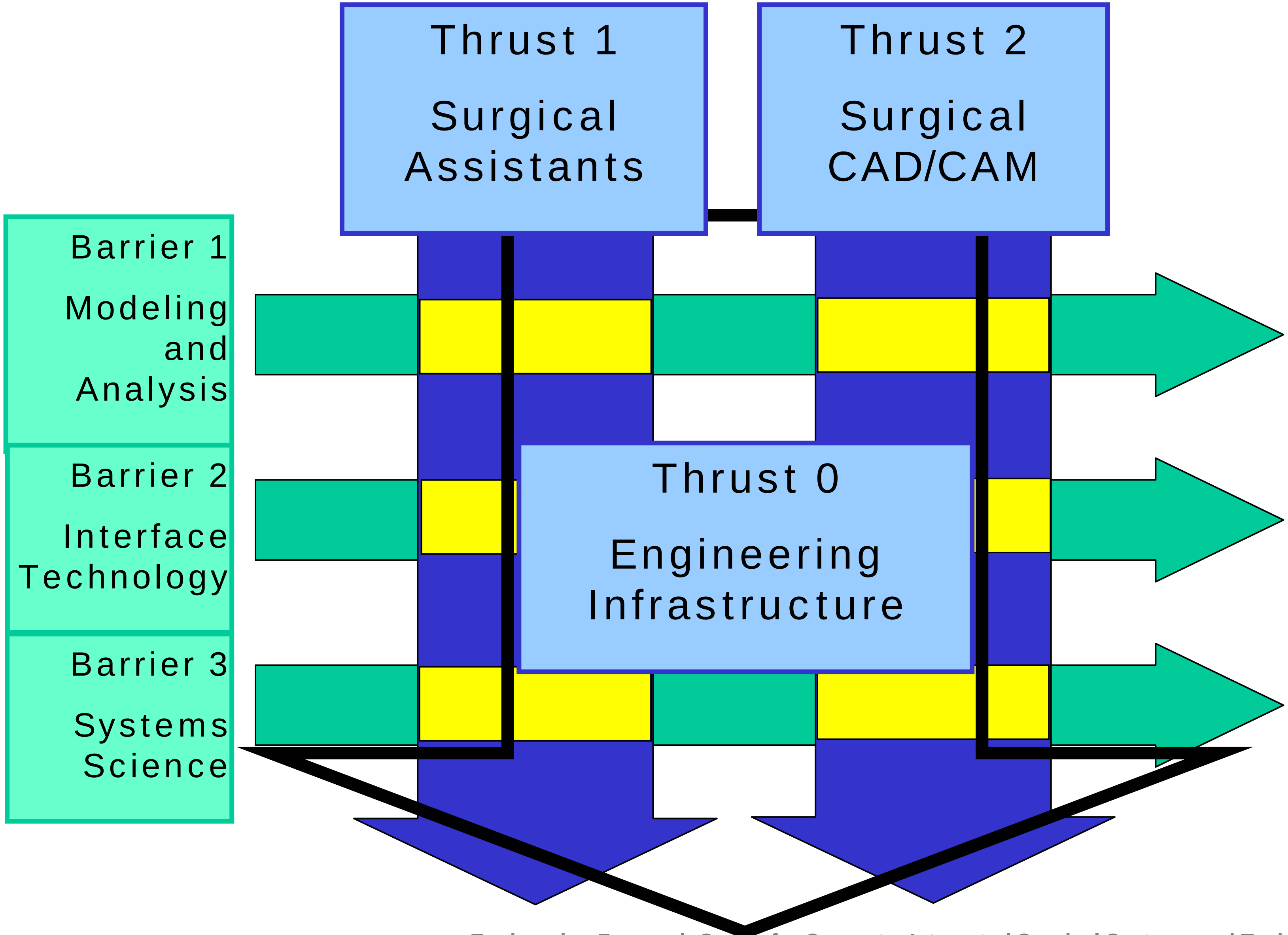
Systems
- Safety & verifiability
- Usability & maintainability
- Performance and validation

Interface Technology
- Sensing
- Robotics
- Human-machine interfaces

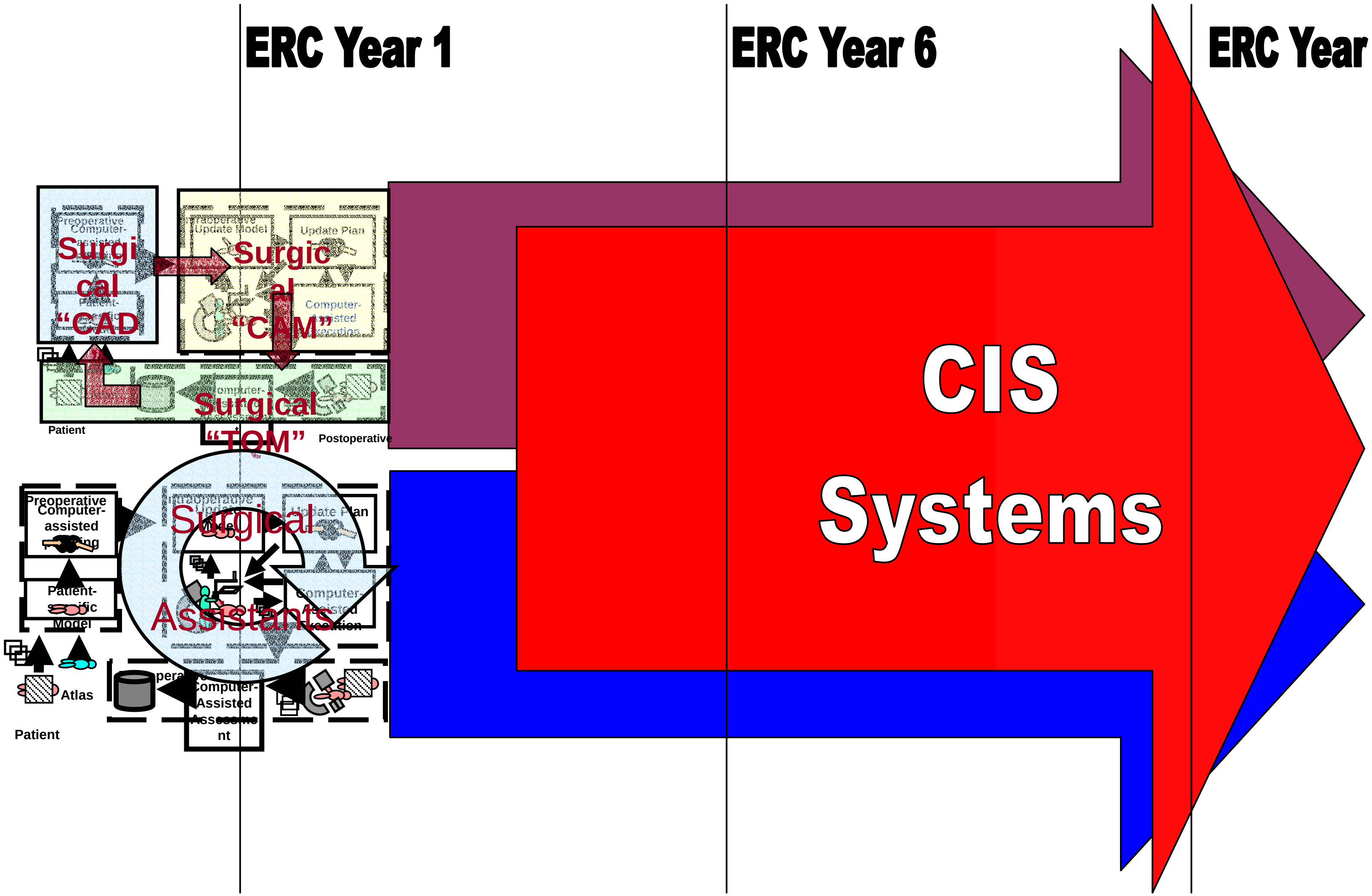
Interface Technology
- Robotics

Modeling & Analysis
- Real-time registration
- Visualization
- Task characterization

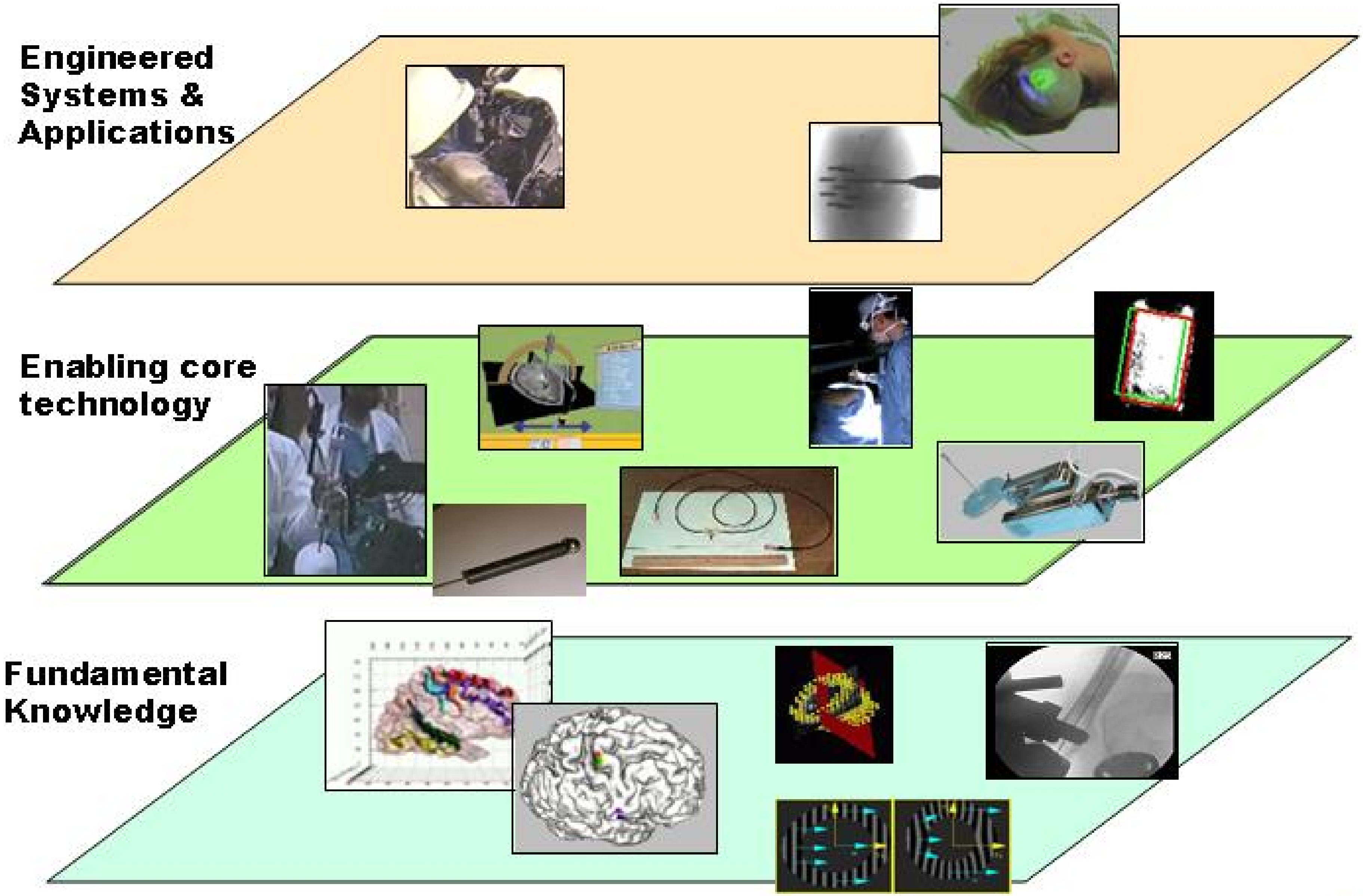
CISST Research Organization

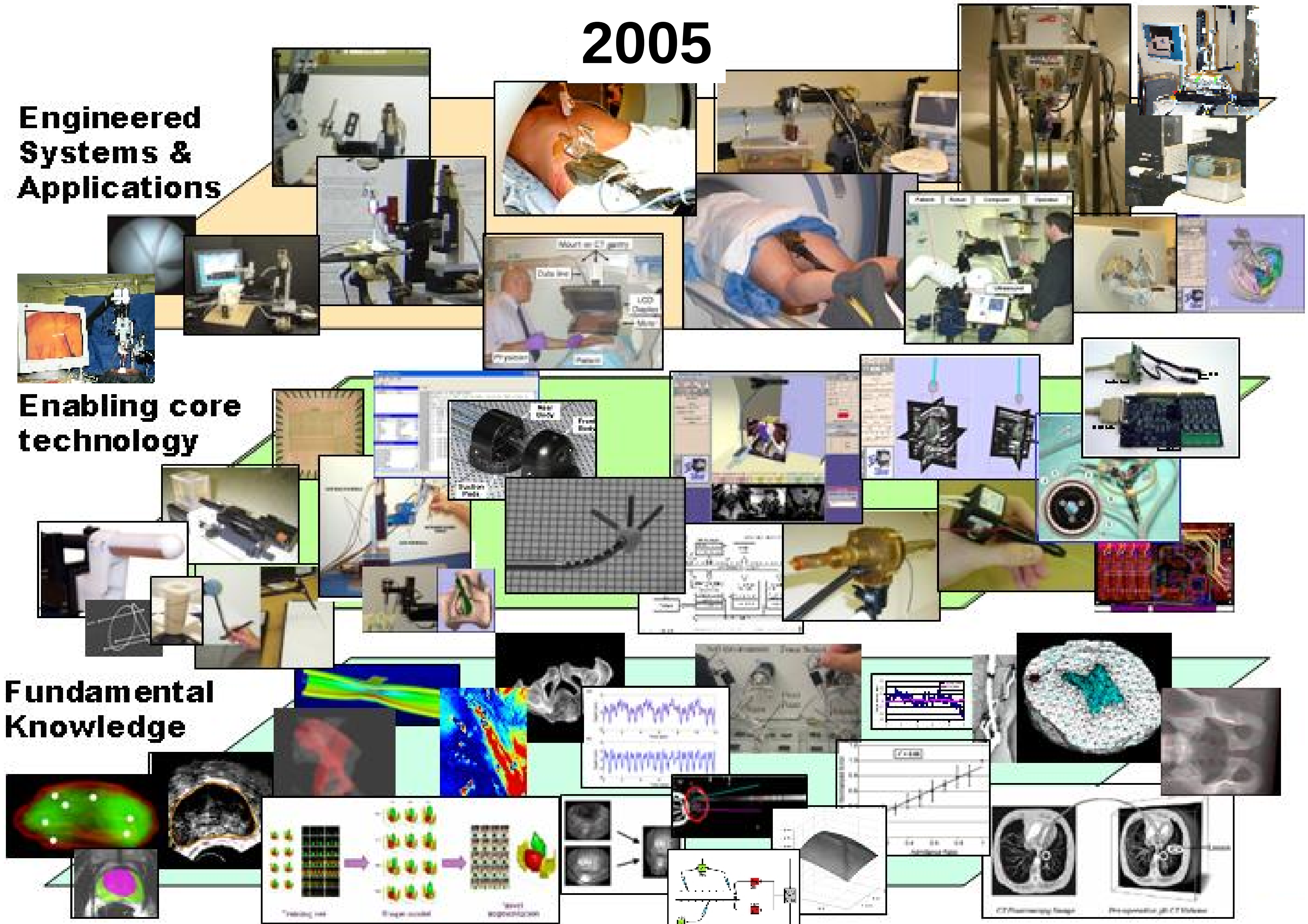


Planned CISST Systems Evolution



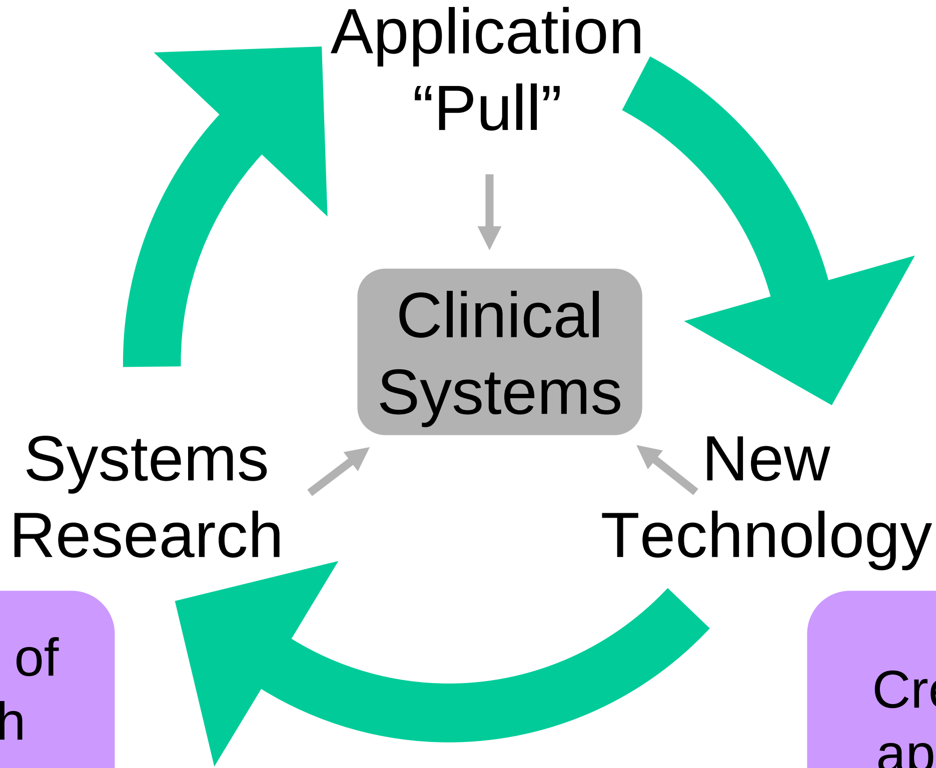
1998


Engineered Systems & Applications
Enabling core technology
Fundamental Knowledge


2005
Engineered Systems & Applications
Enabling core technology
Fundamental Knowledge

CISST Research Program Today

Developed through clinical and industrial collaborations



The translation of basic research into practice

Created based on application needs

The basis for a rich, self-sustaining program of basic and applied research, and academic and industrial collaboration

Future Trends

- Combine imaging, visualization and action in the OR
  - Multi-modal registration, intra-operative imaging, statistical atlases
  - In-scanner robots
  - Real-time US calibration and 3D elastography
- Novel instruments/sensors for specific applications
  - Micron (Cam Riviere, CMU)
  - Scalable snake robot
  - Heart Lander (Cam Riviere, CMU)
- Real-time information update and assistance
  - Virtual fixtures for safety and guidance
  - Novel instruments and sensory substitution
  - Context Aware Surgical Assistance (CASA)

Surgical CAD-CAM: Motivation

Prostate Cancer

- 1 Million prostate biopsies annually
- 230,000 new cases
- 30,000 deaths in U.S. in 2004

Current Practice

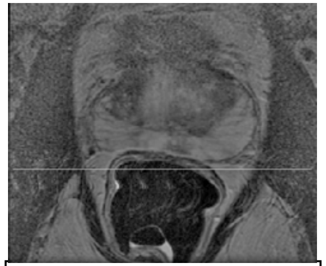
Clinical Standard: Ultrasound guided biopsy

- Poor tissue contrast
- 'Blind' systematic biopsy of the gland (6-12 samples)
- False negative 20-30%
- Gleason score on US biopsy of 25% of patients is being 'upgraded' at time of surgery

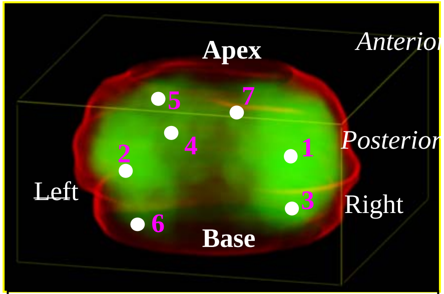
Advantages of MRI:

- MRI with endo-rectal coil has excellent sensitivity for detecting tissue abnormalities and may allow for 'targeted' biopsy.
- High SNR improves diagnostic accuracy, especially for MRSI and DCE-MRI.

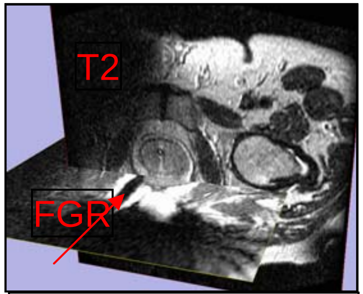
MRI-Guided Prostate Interventions



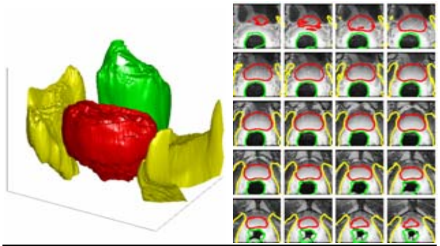
Signal correction (Warfield)



Deformable Prostate Atlas (Davatzikos, Shen)



Deformable Fusion (Kikinis, Warfield)



Prostate Segmenter (Wells, Grimson)

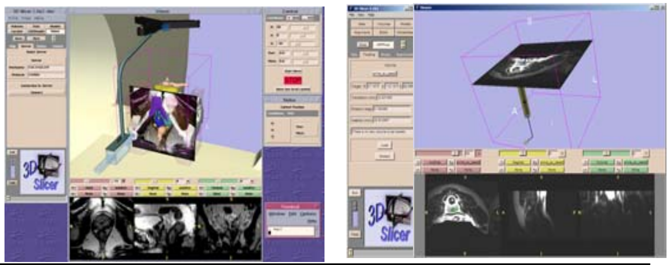
Penn

NIH center
3xRO1
BRP, PO1

BWH

JHU

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.



Planning (DiMaio, Fichtinger)

Needle Tracking (DiMaio)

IMRT Robot (Chinzei, Kikinis)

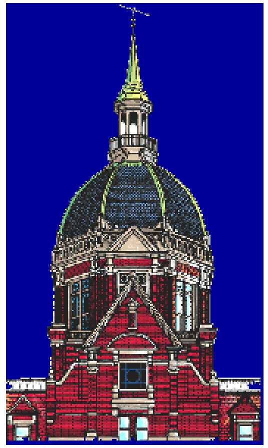
QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

3T Prostate Robot (Whitcomb Fichtinger, Atalar, et al.)

MRI Guided Prostate Interventions

A. Krieger[1,2], R. C. Susil[3], Cynthia Ménard[5], Jonathan Coleman[6], Anurag Singh[5], L. L. Whitcomb[1], E. Atalar[2], G. Fichtinger[2,4]

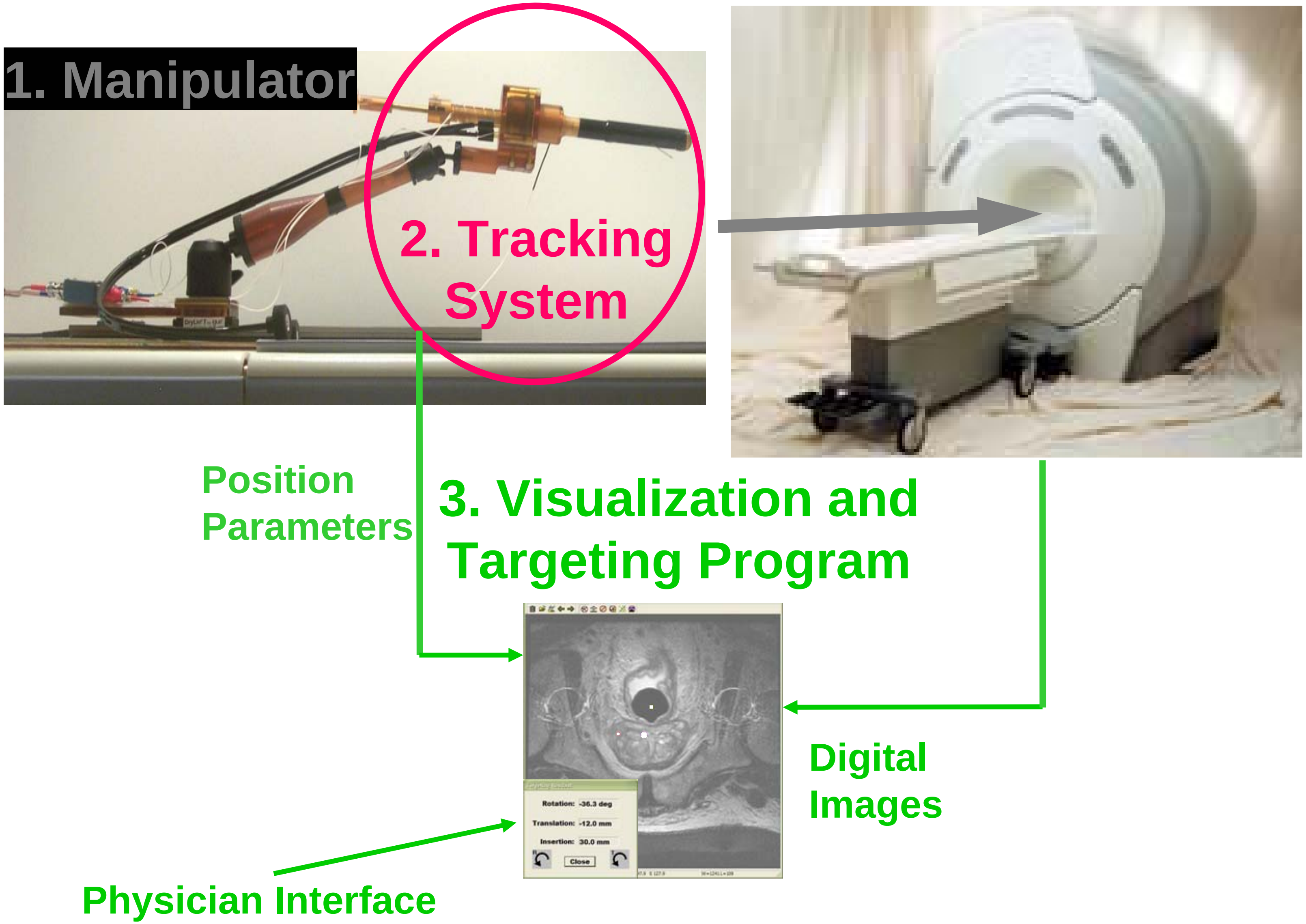
[1]Department of Mechanical Engineering
[2]Department of Radiology
[3]Department of Biomedical Engineering
[4]CISST Engineering Research Center
Johns Hopkins University, Baltimore, MD



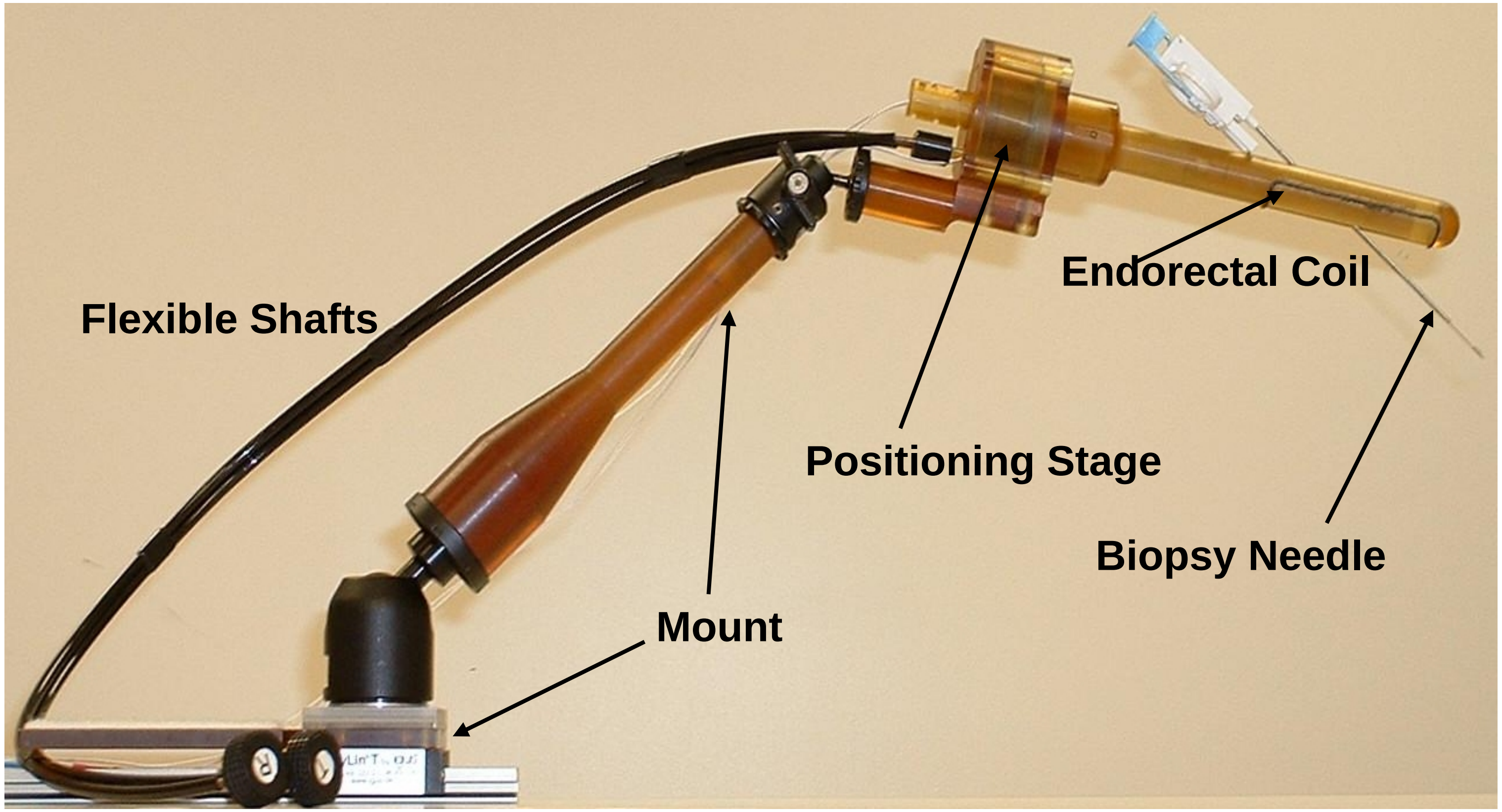
ERC | CISST

[5]Radiation Oncology Branch, NCI - NIH-DHHS
[6]Urologic Oncology Branch, NCI - NIH-DHHS

Overall System



Manipulator



Simulation

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

Visualization and Targeting Program

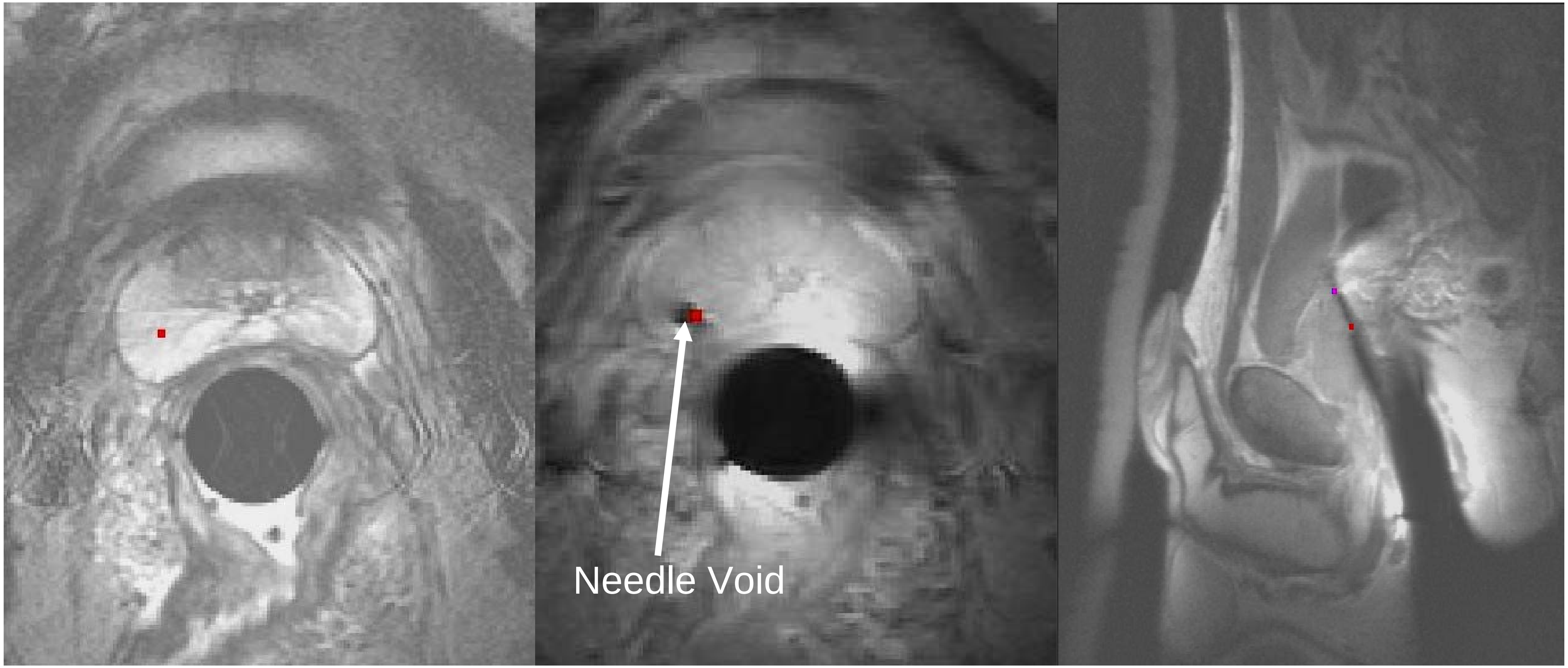
Results
Clinical Trials under 1.5T and 3T

- **Gold marker seed placements**
  Implantation of 4 gold marker seeds to guide external radiation beam therapy.
  16 patients with 4 seed implants each

- **Biopsies**
  15 patients with 4-10 biopsies each

- No severe adverse events
- Average targeting accuracy between 2.8mm and 7.4mm

Results



MR images during a clinical procedure:

Left: A target (red dot) is selected on an axial TSE T2-weighted image.

Middle: The needle tip void is visualized in an axial TSE Proton Density image. The desired target matches the actual position of the needle.

Right: The needle void is visualized on a sagittal TSE Proton Density image, where the estimated needle path (red and purple dots) matches the actual path.

Current and Future Work

Redesign of the Prostate Interventional System

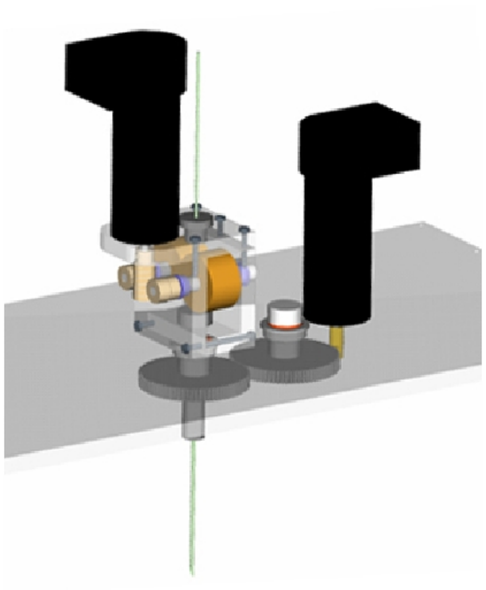
- Faster procedure time
- Easy implementation with different scanner architectures

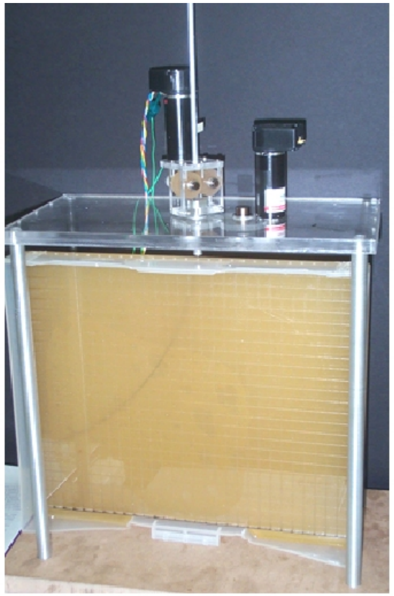
Improvements include:

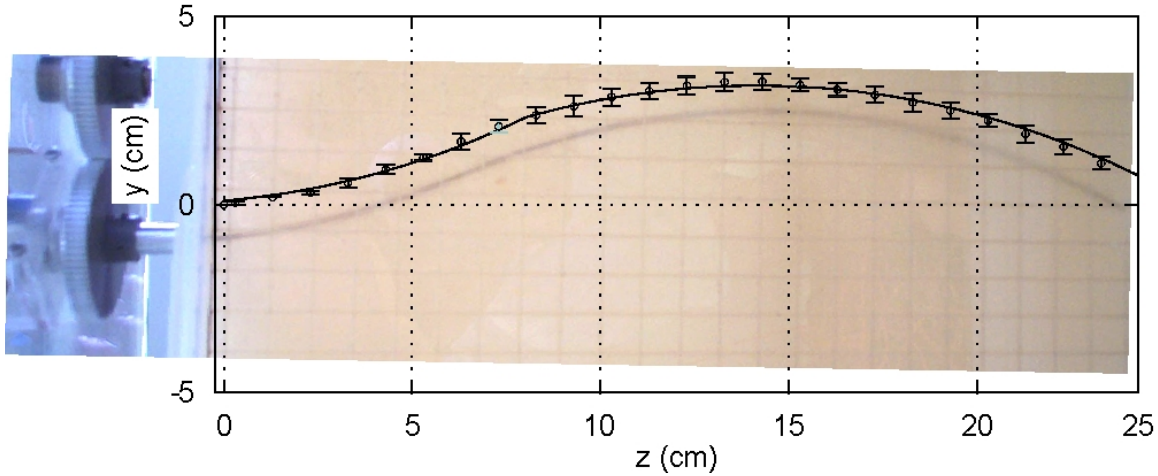
- Steerable needle guide
- New tracking scheme

Steerable Needles

A. Okamura, N. Cowan, G. Chirikjian, K.T. DeWeese, K. Murphy

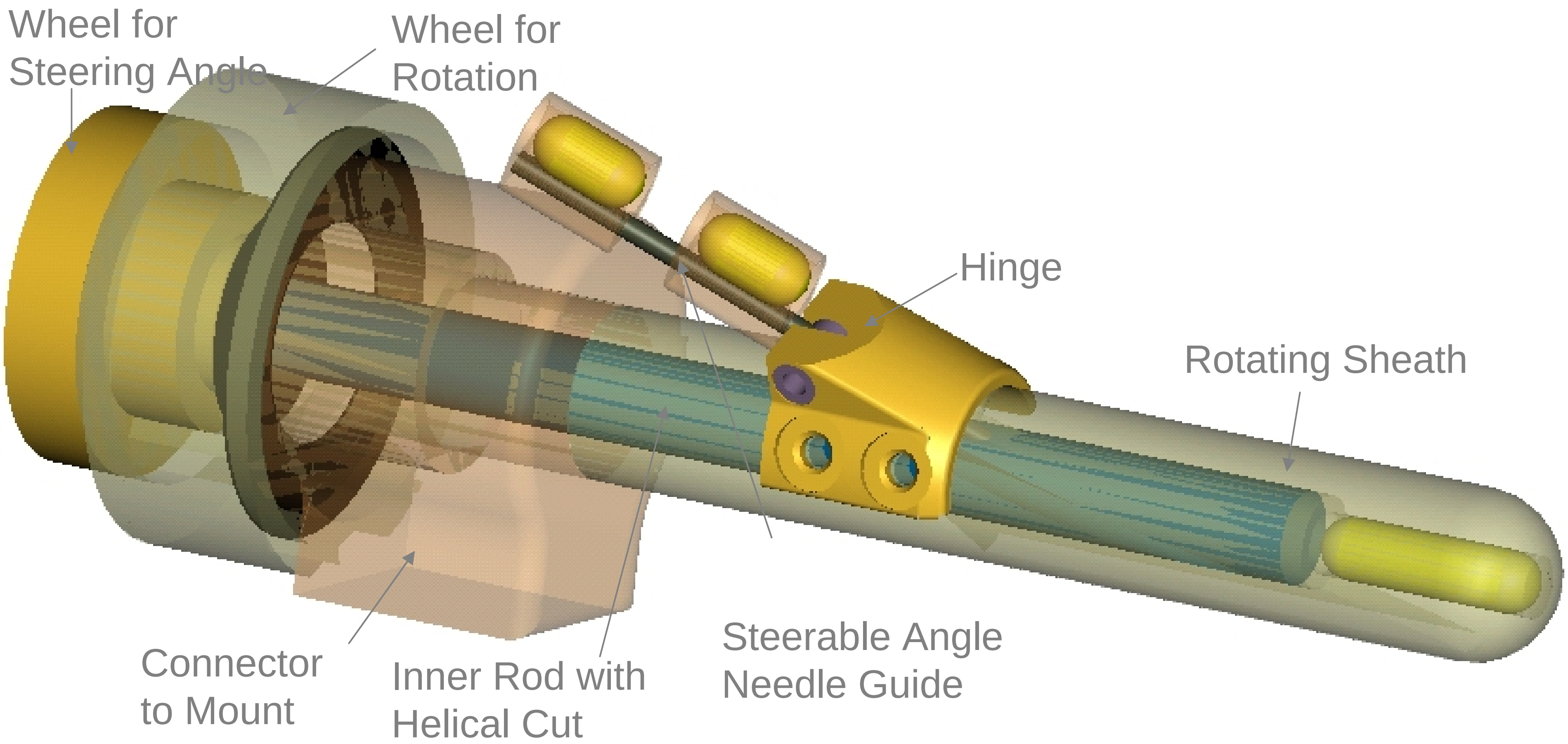




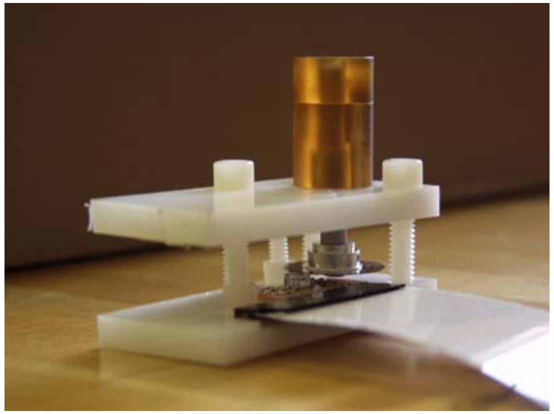


http://www.haptics.me.jhu.edu/publications/iser04-webster.pdf

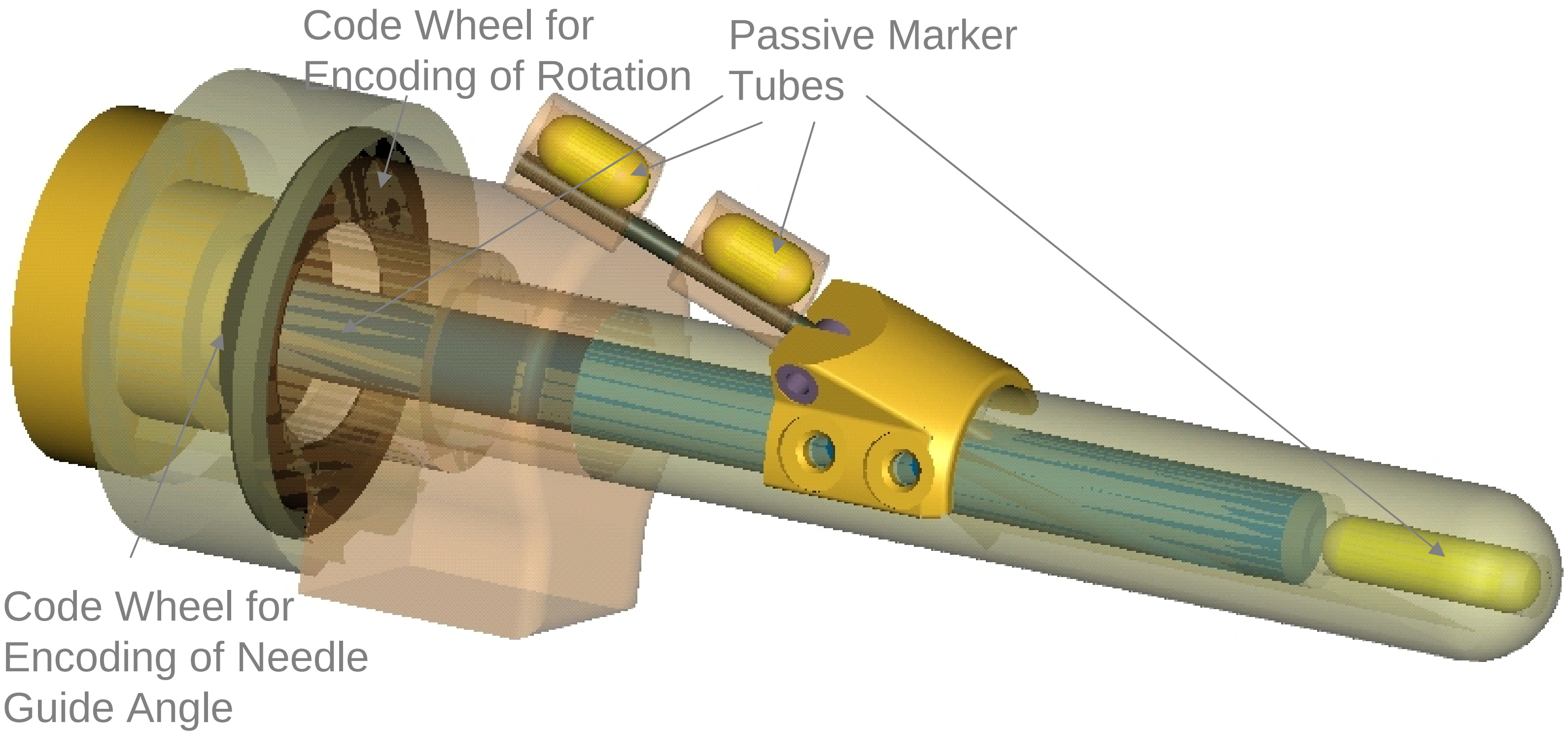
Steerable Needle Guide Design



New Tracking Scheme

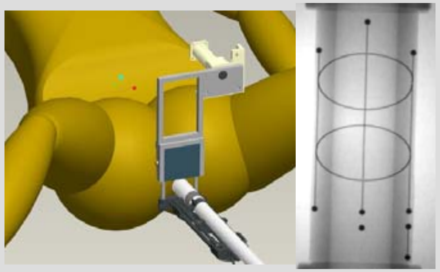


Combination of
- Passive Tracking for initial registration
- Optical Encoders for rotation and needle angle



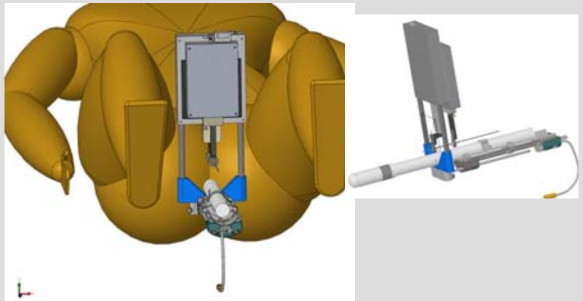
US Guided Prostate Interventions

Registration of Ultrasound to Fluoroscopy



- SBIR Phase-1
- DoD Clinical trial award
- Burdette ½ fellowship
- SBIR Phase-2 (pending)
- SPORE supplement (pending)
- DoD fellowship (pending)
- R21 (pending)
- **IRB/clinical trial approved**

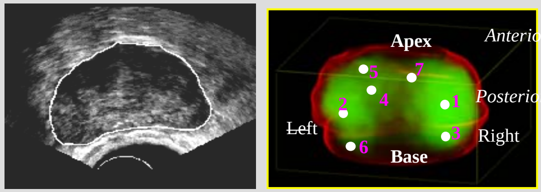
Robotic Brachytherapy



- SBIR Phase-1
- SBIR Phase-2
- **IRB/clinical trial approved**

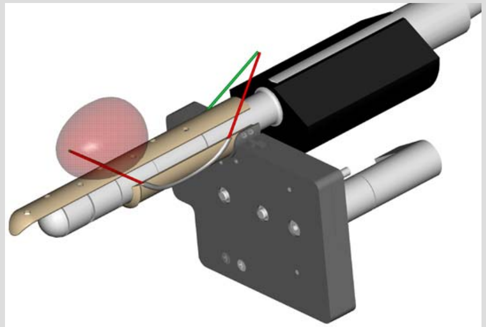
TRUS Guided Brachytherapy (Burdette Medical Systems)

Atlas Based US Biopsy



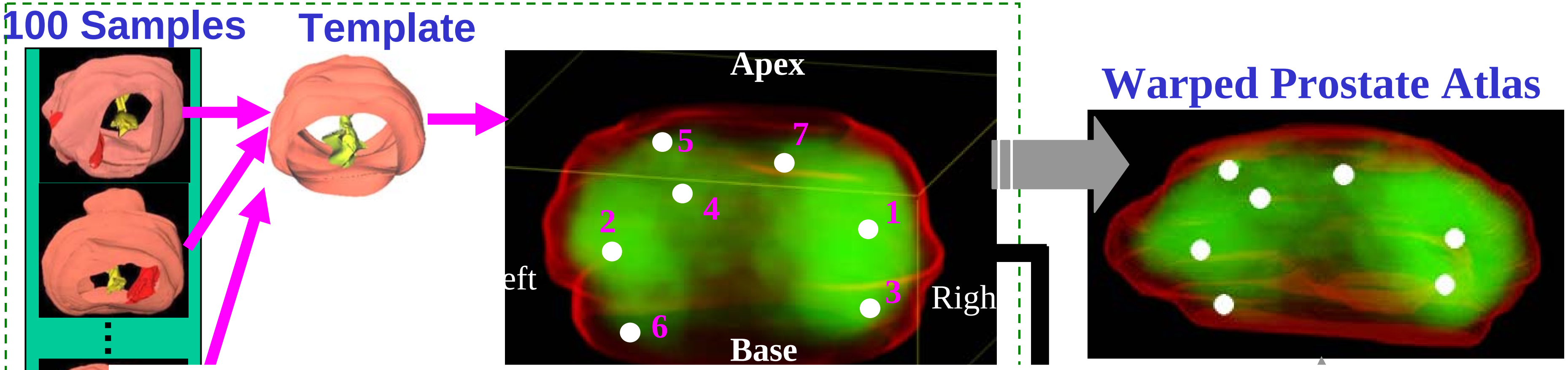
- RO1 -- atlas
- RO1 – segmentation (pending)

Transrectal US Ablation



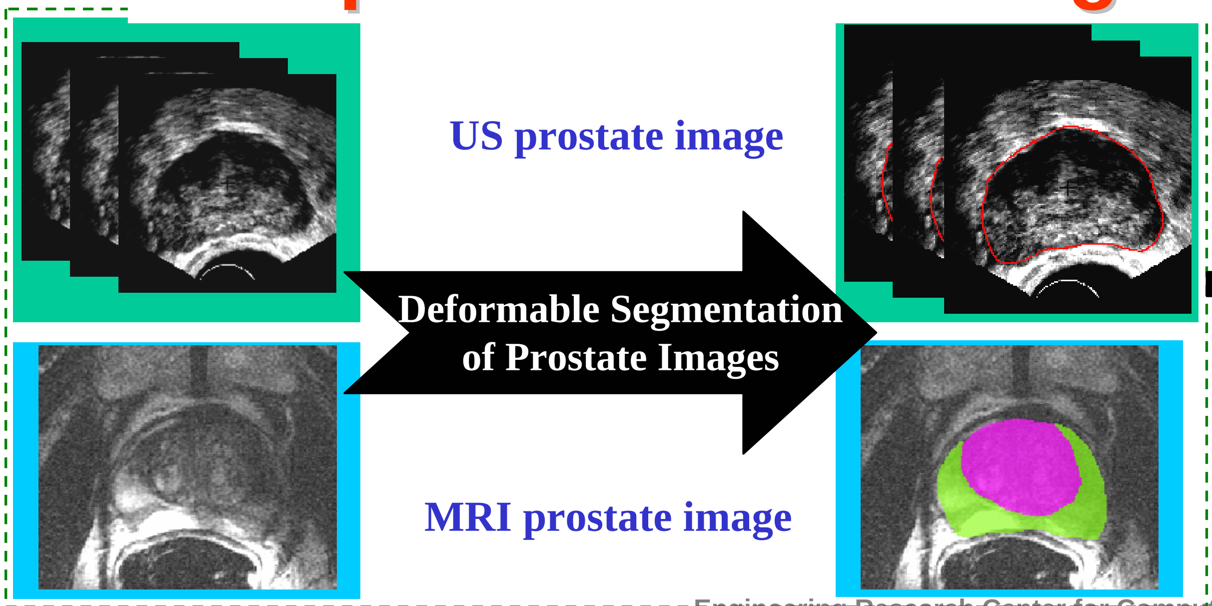
- STTR Phase-1
- Burdette ½ fellowship

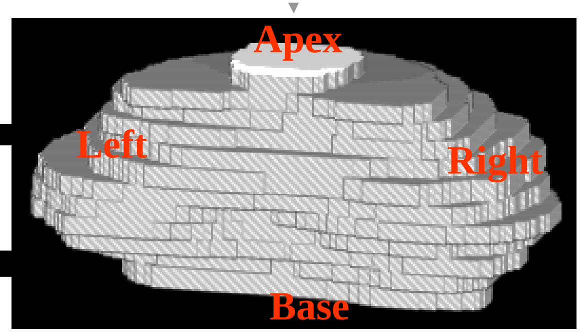
Example: Atlas-based, image-guided prostate biopsy



Detection Rate of > 99%!

Compared to 77% using standard methods





Segmented 3D Prostate

Faculty members: *D. Shen, C. Davatzikos, C. Tempany, G. Fichtinger, S. Haker*

Example: Biomechanical Simulation of Medical Needle Insertion

Ron Alterovitz, Ken Goldberg (UC Berkeley)
Jean Pouliot, I-Chow Hsu (UCSF)

- *Goal*: Reduce radioactive seed placement error in prostate cancer brachytherapy treatment using biomechanical simulation
- Developed 2D dynamic finite element model of needle insertion in tissue
- Interactive simulation: 24 fps on a 750MHz PC
- *Applications*: Physician training and treatment planning

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

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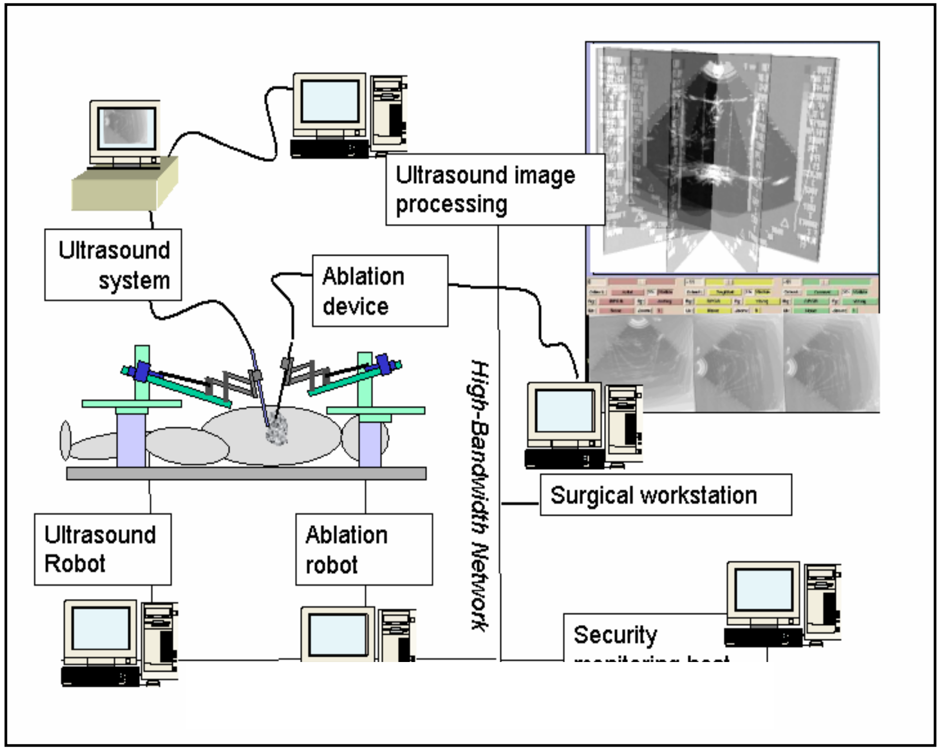
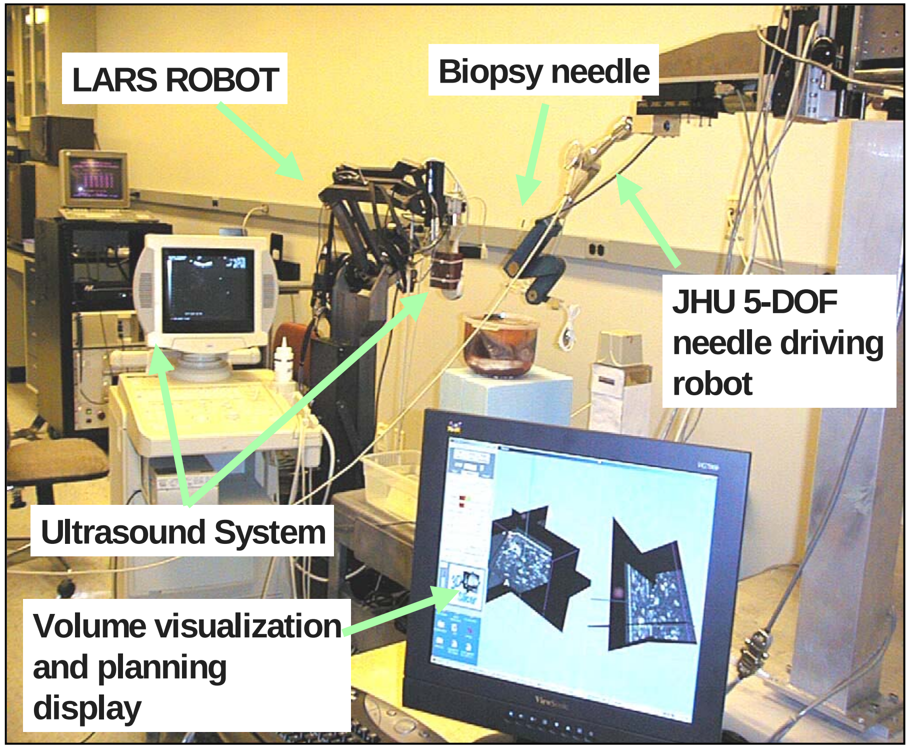
YUV420 codec decompressor
are needed to see this picture.

Tissue deformations cause seed placement error

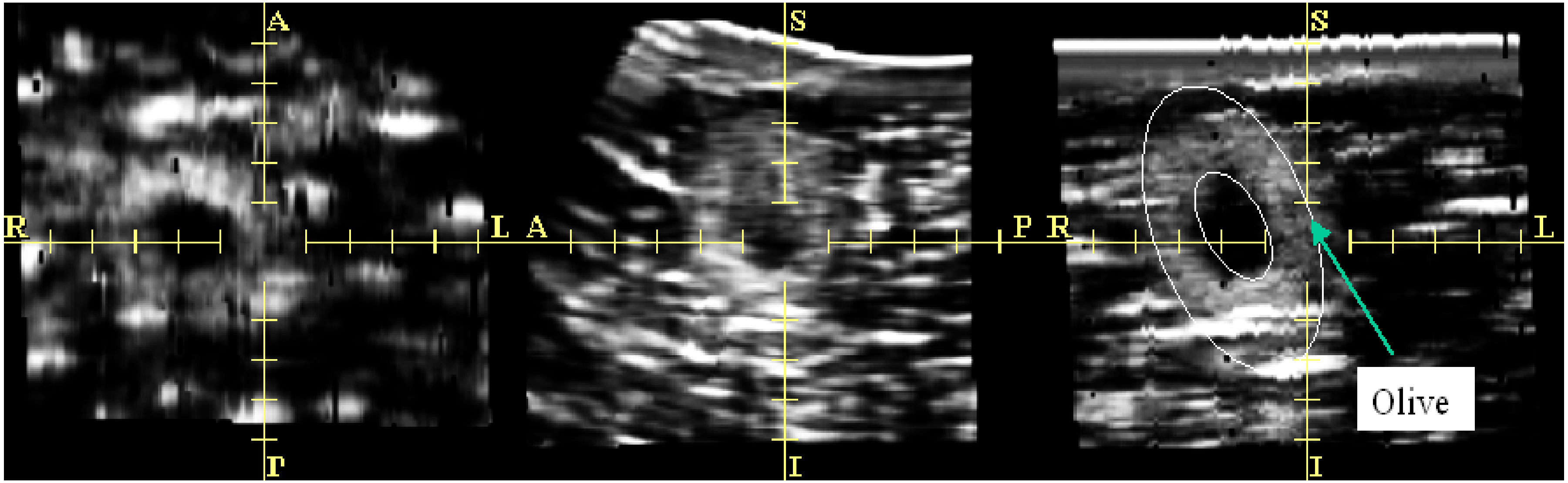
Planner computes offsets to compensate for simulated tissue deformations

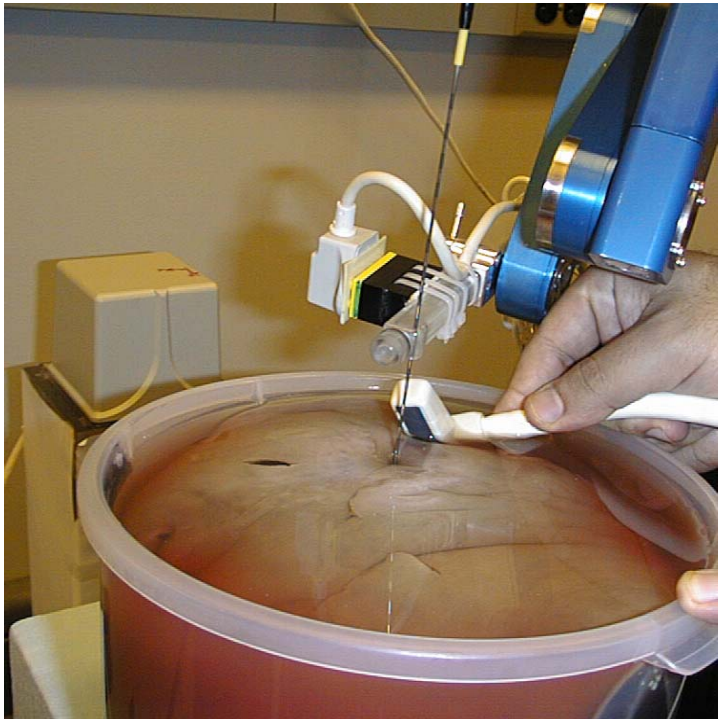
Robot-Assisted US-Guided Liver Therapy

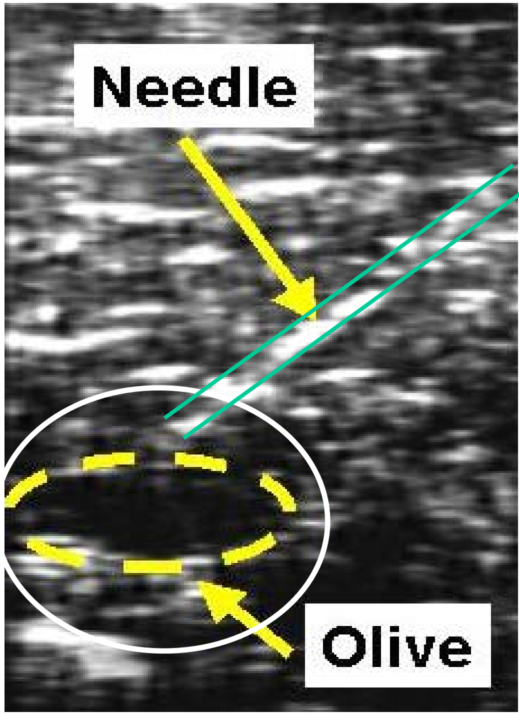




JHMI: Choti (Surg), Kavoussi (Urology) , Solomon (Radiology)
WSE: Fichtiger, Taylor, Boctor, Jain, Fischer, Vishwanathan, *et al.*
Industry : Burdette Medical, Intuitive Surgical, Aloka, Siemens



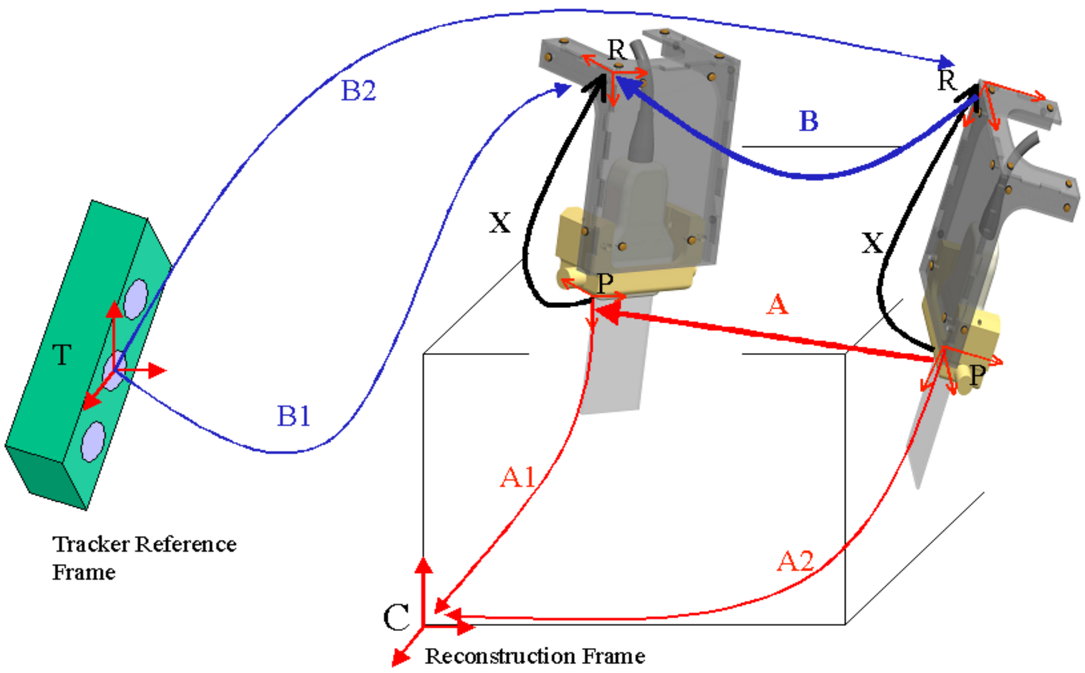


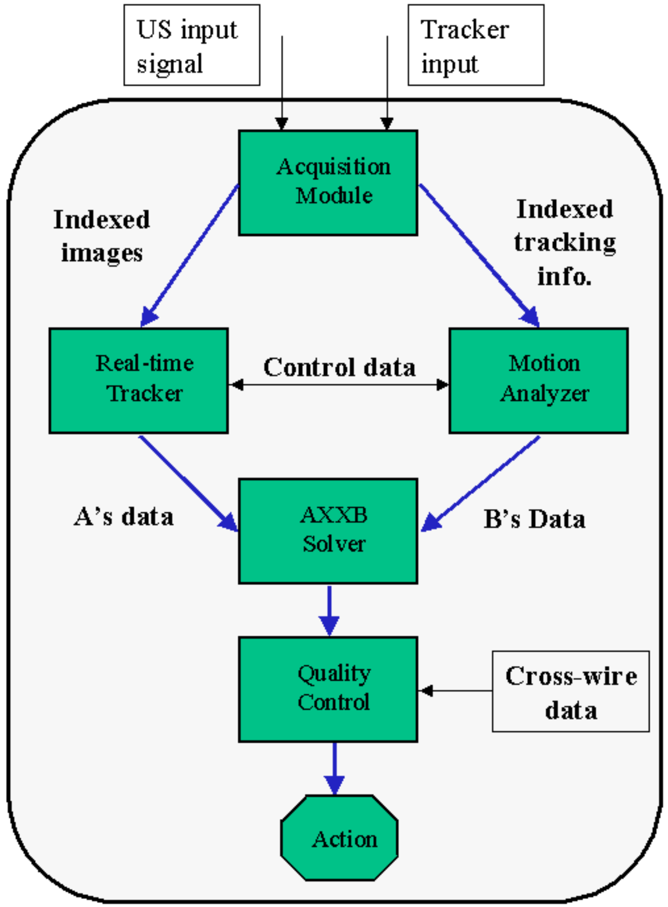


- **Average error for 10 trials ~3mm**
- **Main limitation was EM tracker**

Credit: <u>Boctor</u>, Fichtinger, Vishwanathan, Fischer, Taylor, Jain, Choti, *et al.*

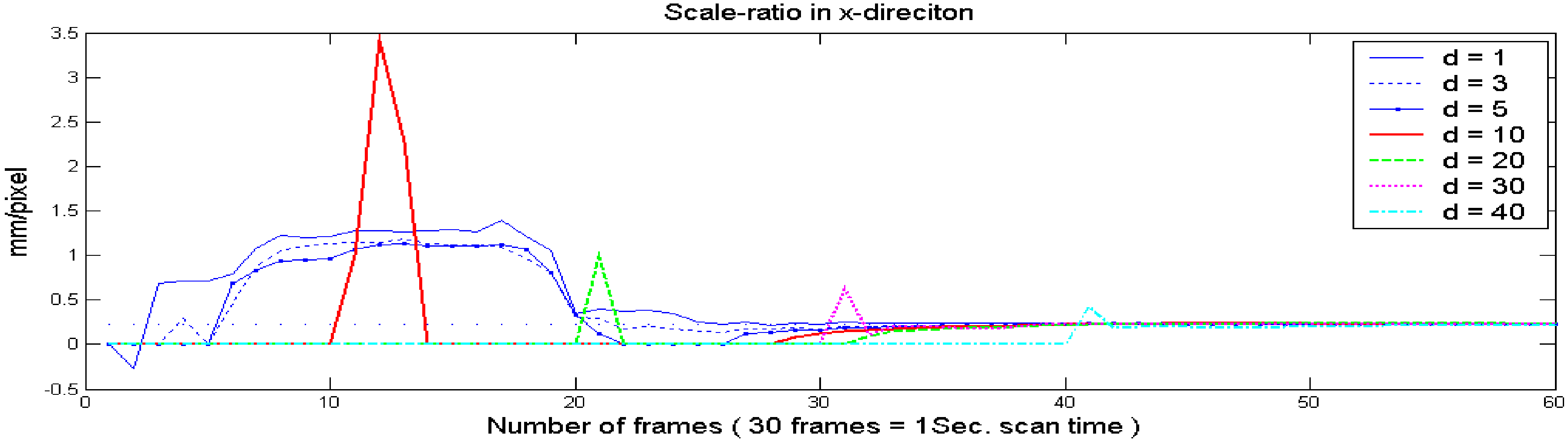
In-Vivo Ultrasound Calibration

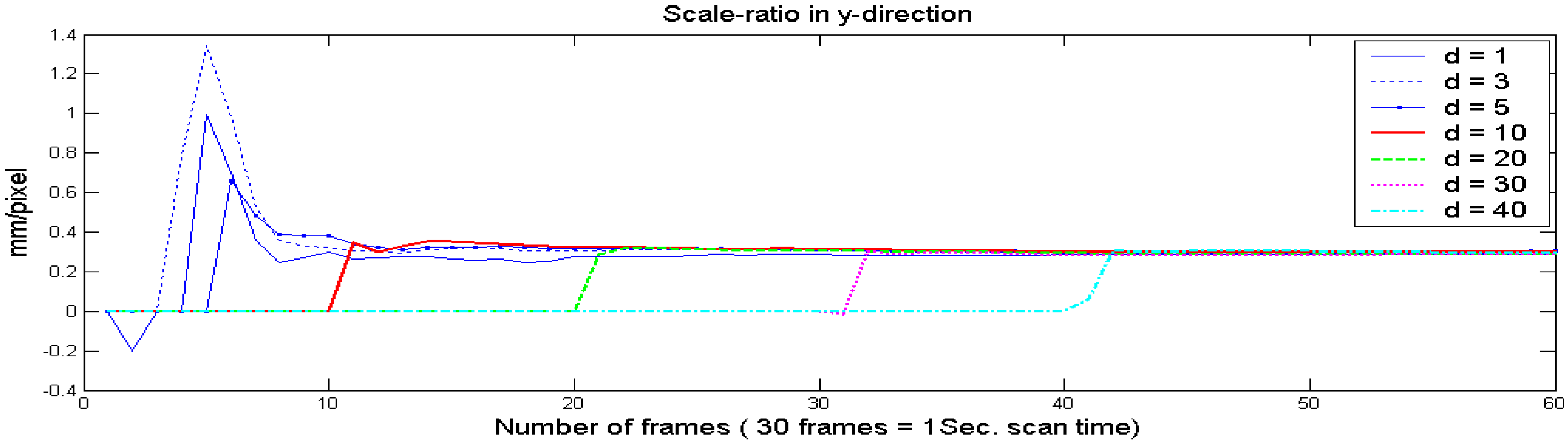




Track motion in probe images and supply it to AX = XB solver: provides online estimation of calibration

Online Calibration: Results





Convergence in < 1 sec at 3mm travel/sec.

Problem: How do you monitor therapy?

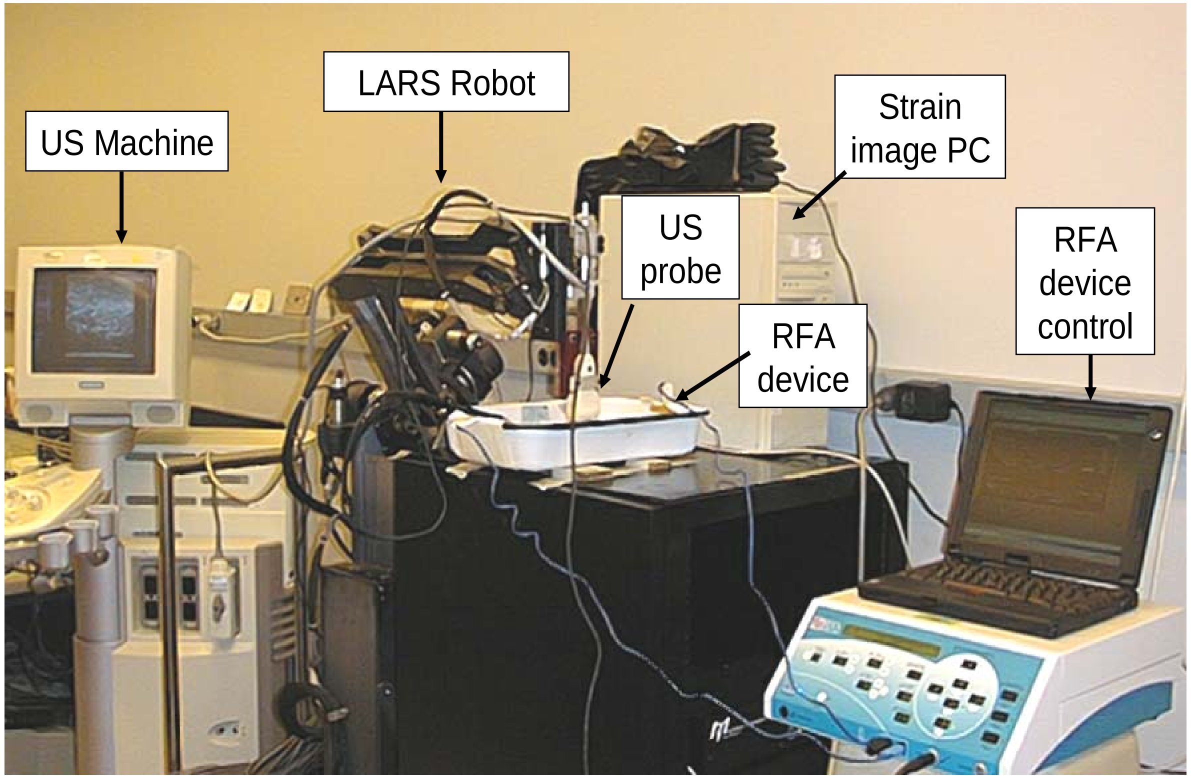
QuickTime™ and a
decompressor
are needed to see this picture.

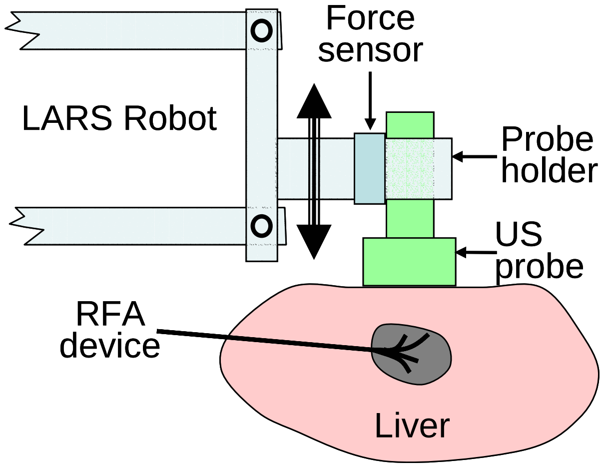
What are boundaries of ablated region?

Credit: Emad Boctor

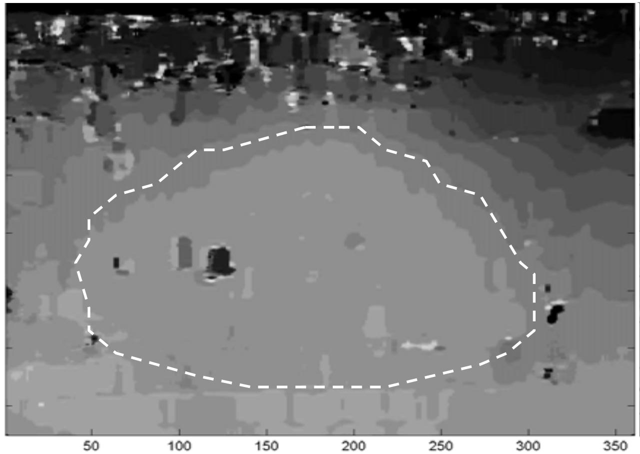
Strain Imaging with Ultrasound

Emad Boctor, *et. al.*

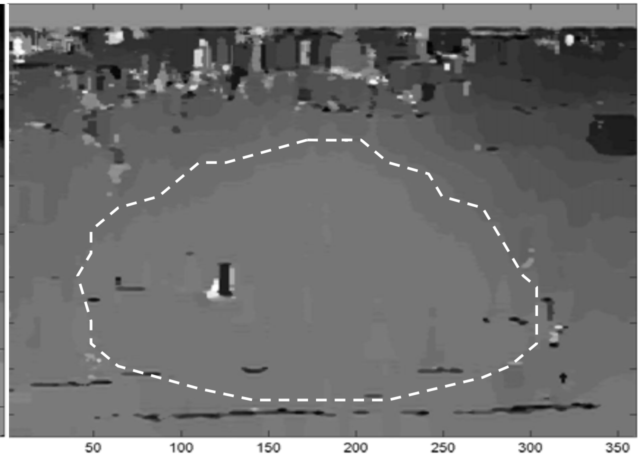




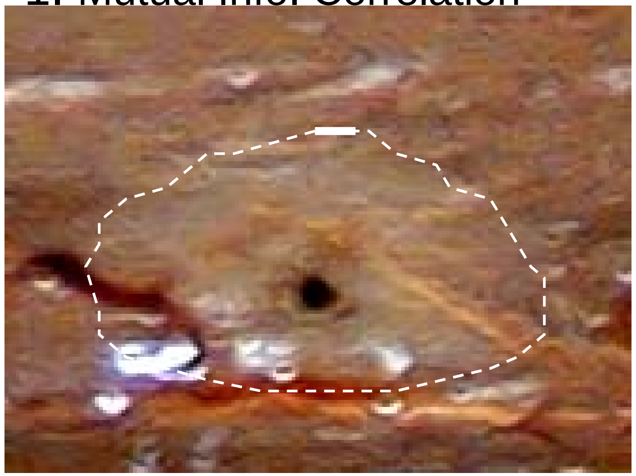
Engineering Research Center for Computer Integrated Surgical Systems and Techno



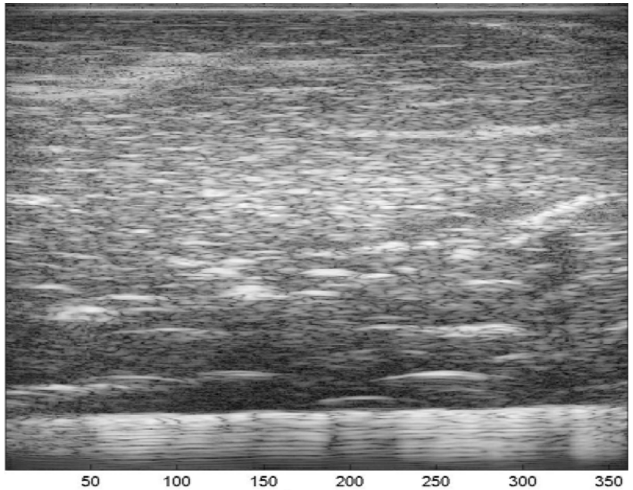
1. Mutual Info. Correlation



2. Norm. Cross Correlation



3. Pathological Image



4. B-Mode Ultrasound Image

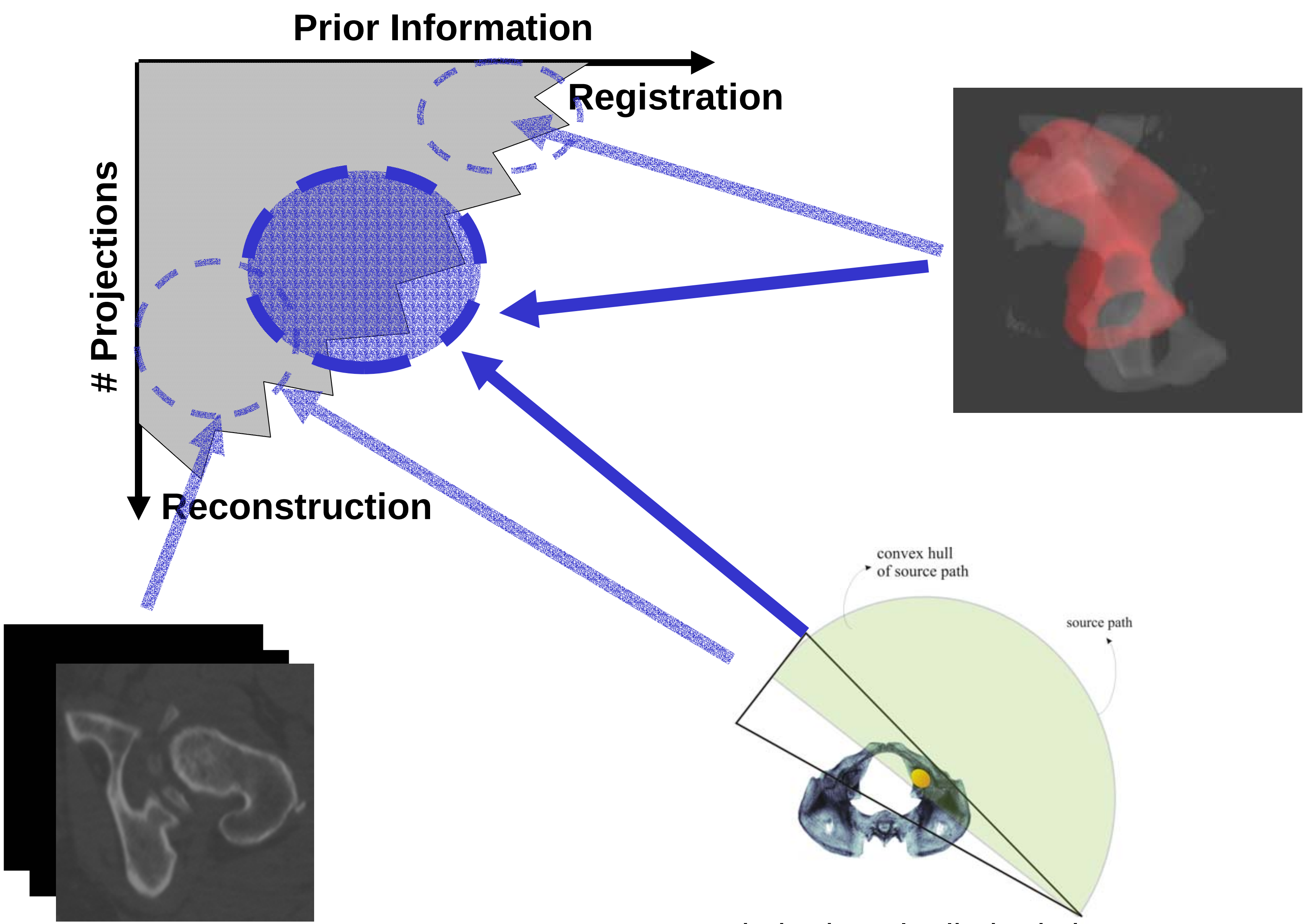
Strain images with corresponding pathology and B-mode images at 100ºC, with the RFA device perpendicular to the plane of imaging. The white contour is created on the pathological picture and matches with the determined strain images.

Credit: Emad Boctor

Strain Imaging: Next Steps

- Cyclic compression of tissue combined with out of plane motion
- Resulting 3D elastography can be used for segmentation of tissues structures
- Applications: TRUS-guided EBRT

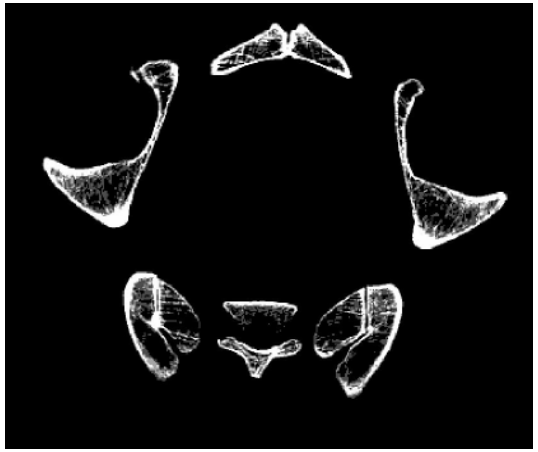
3D reconstructions from limited 2D projections



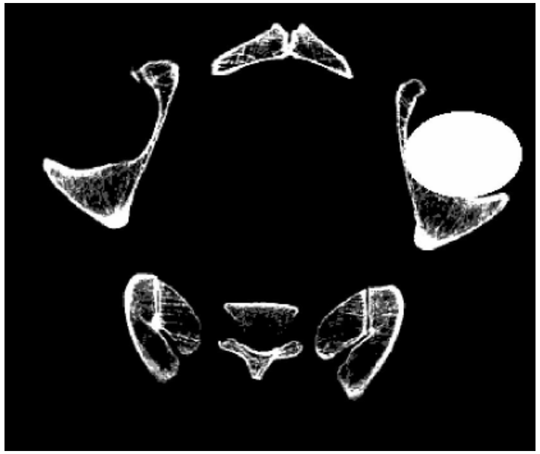
Limited angle, limited view

Using prior CT to fill in missing data

Jerry Prince, Krishna Ramamurthi



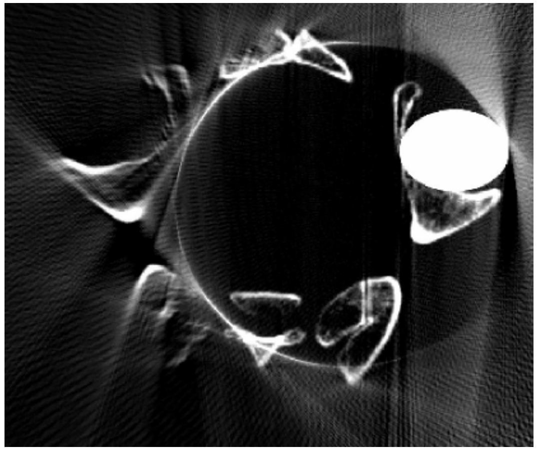
Original CT

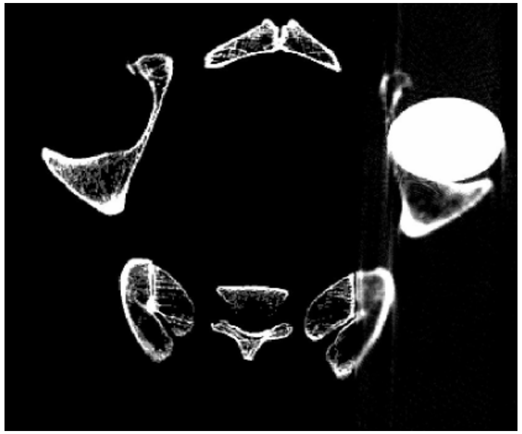


Simulated implant

Projections

Feldcamp result (standard method)

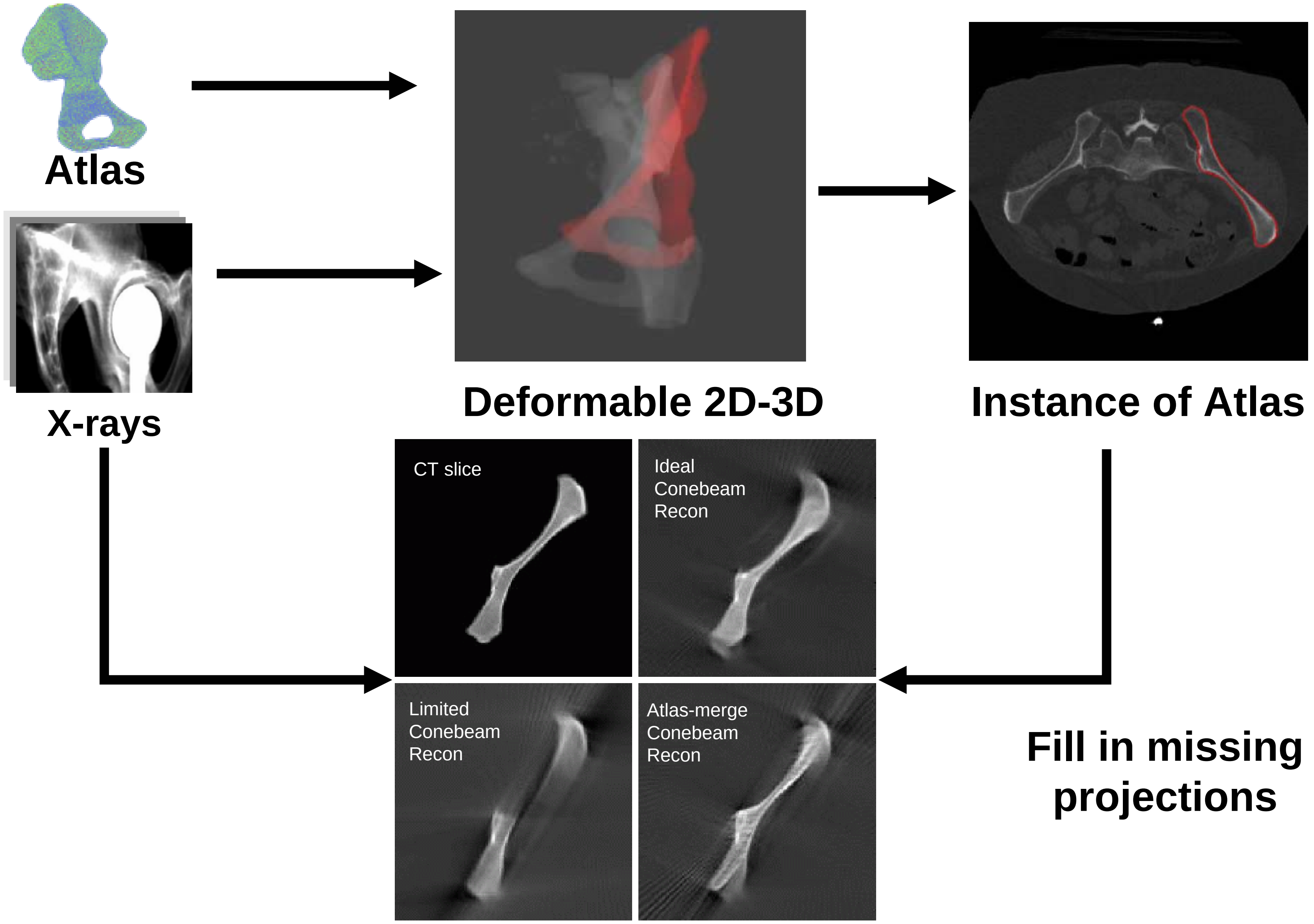




Prince & Ramamurthi result

Atlas-augmented X-ray Reconstruction

Taylor, Prince, Yao, Sadowsky, Ramamurthi

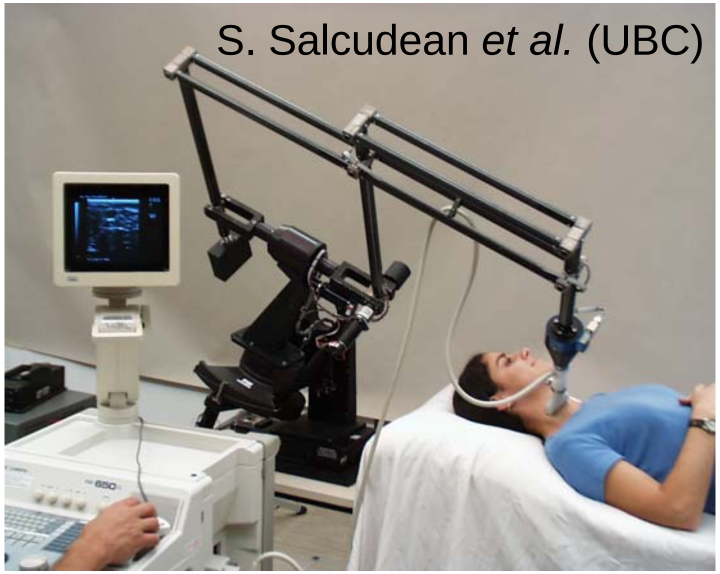


Future Trends

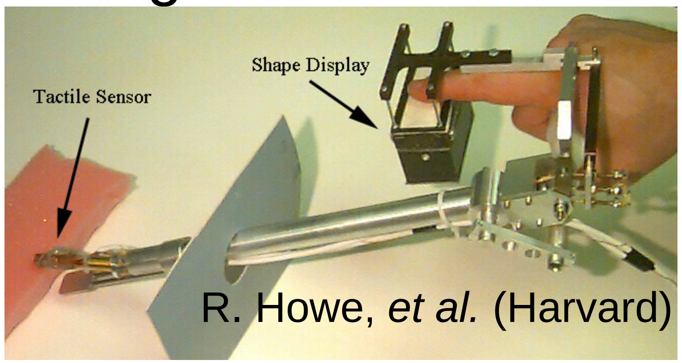
- Combine imaging, visualization and action in the OR
  - Multi-modal registration, intra-operative imaging, statistical atlases
  - In-scanner robots
  - Real-time US calibration and 3D elastography
- **Novel instruments/sensors for specific applications**
  - **Micron (Cam Riviere, CMU)**
  - **Scalable snake robot**
  - **Heart Lander (Cam Riviere, CMU)**
- Real-time information update and assistance
  - Virtual fixtures for safety and guidance
  - Novel instruments and sensory substitution
  - Context Aware Surgical Assistance (CASA)

Novel Instruments

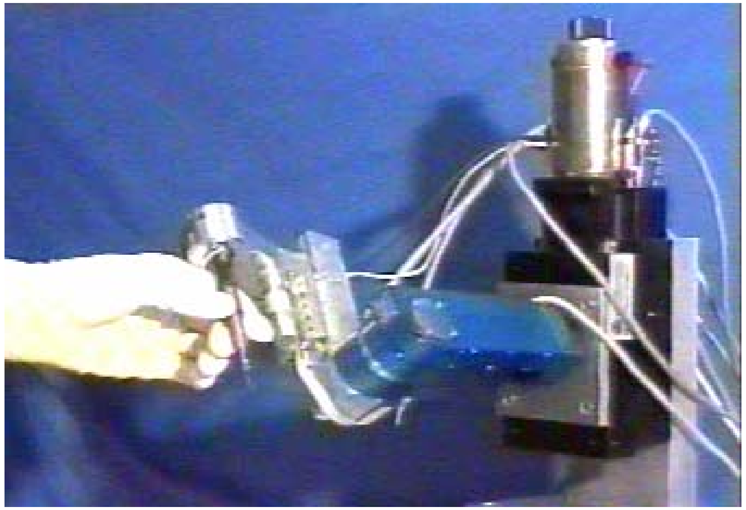
- Emergence of robot manipulator designs specifically designed for surgical applications
  - E.g., RCM, MRI compatible systems, “snake” robots, …
- Cooperative control for human skill augmentation
- Specialized systems with tissue or image sensing



S. Salcudean *et al.* (UBC)



R. Howe, *et al.* (Harvard)



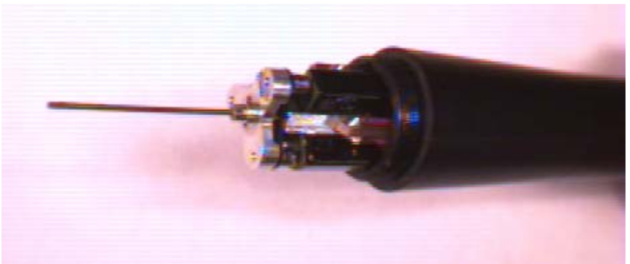
R. Taylor, *et al.* (JHU)

Micron:
Active Cancellation with Freehand Device

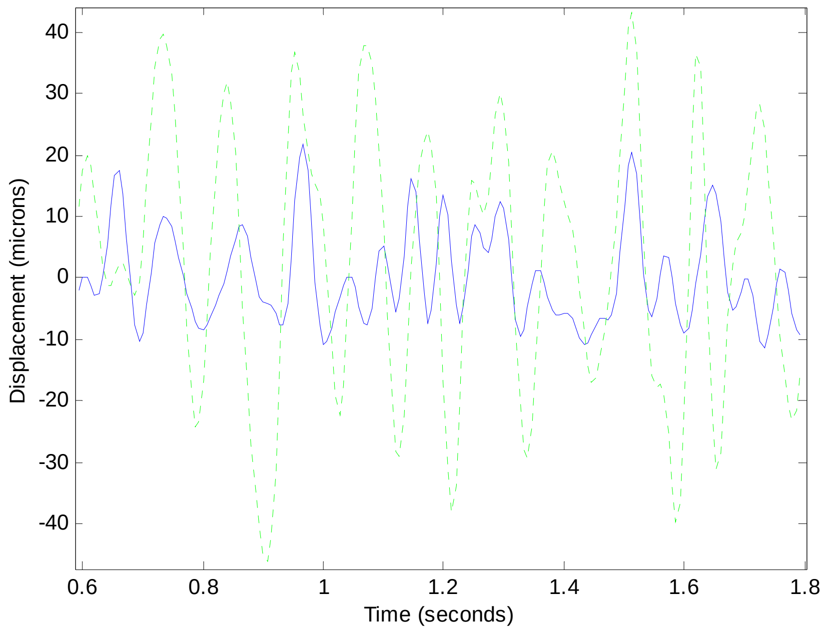
Riviere, Ang, *et al.* (CMU)

Micron incorporates motion sensing and endpoint control

- small, hand-held design
- active tremor cancellation
- new system meets goal of < 10μm rms motion



Precise control of piezoelectric actuators is needed for effective active tremor compensation.

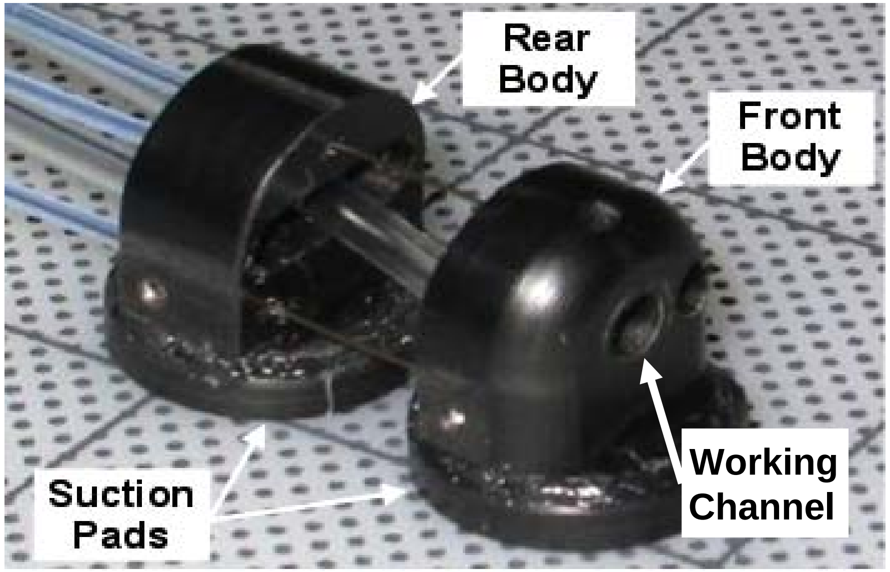


Active error compensation via Micron, displaying uncompensated (green) vs. compensated (blue) results.

Heart Lander

Riviere/Patronik/Zenati (CMU/U. Pittsburgh)

Subxiphoid approach
- attach to beating heart via suction
- maneuver to site
- perform therapy



QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

A new concept for minimally invasive surgery!

One Driving Application: MIS of upper airway

Haptic information deficiency

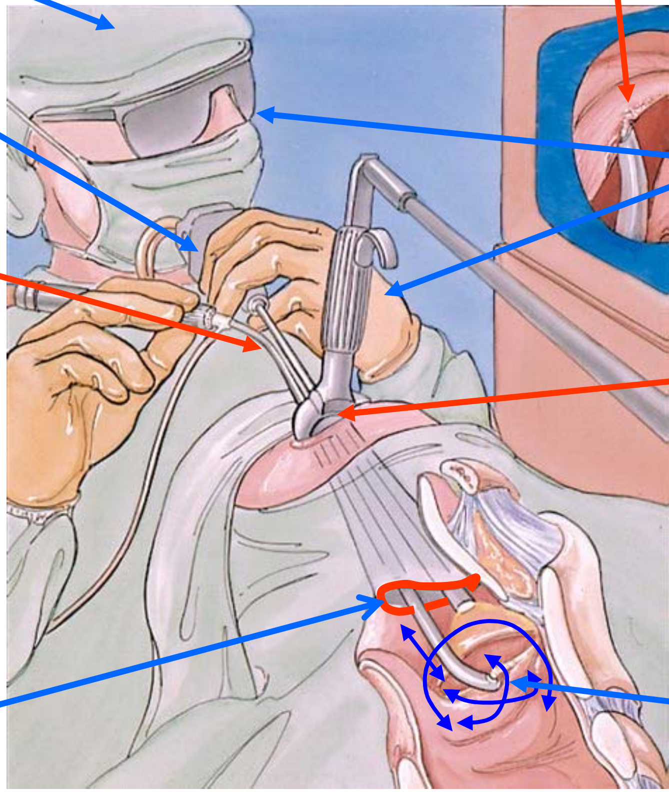
View limited by soft tissue

Multiple tools

Hand-eye coordination

Long rigid instruments

Predetermined entry port



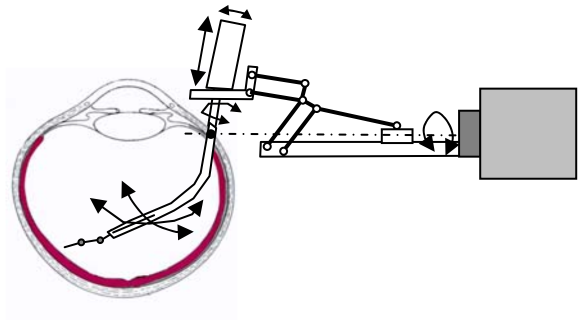
4 DoF motion constraint

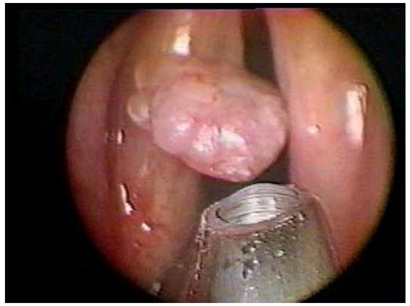
No distal dexterity

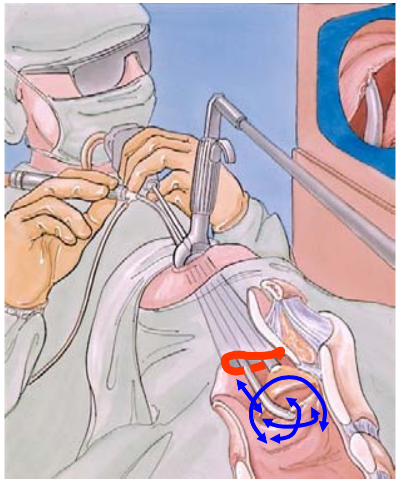
No suturing or functional tissue reconstruction capability

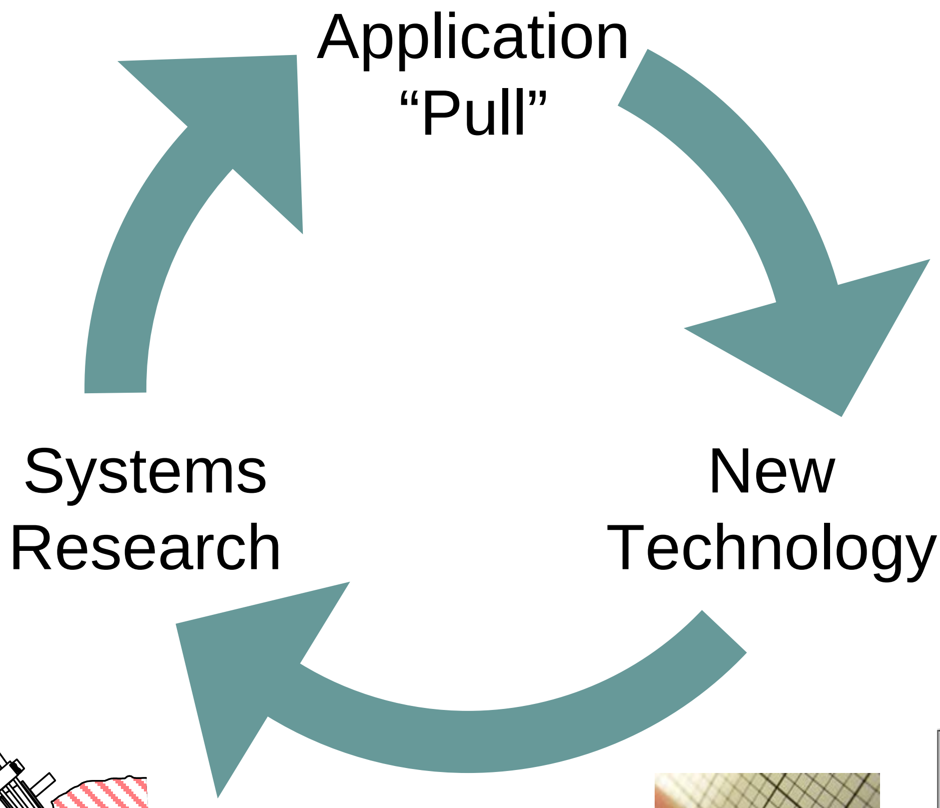
N. Simaan, R. Taylor, P. Flint

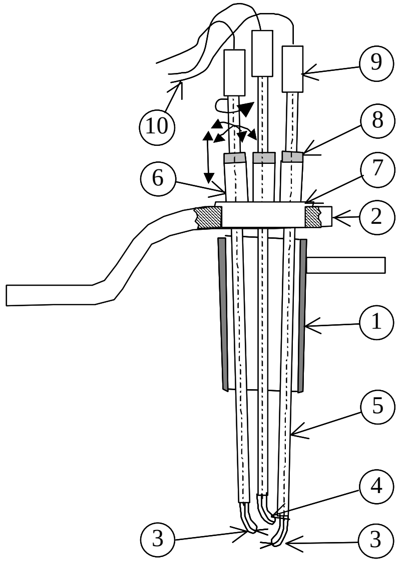
Working in constrained spaces

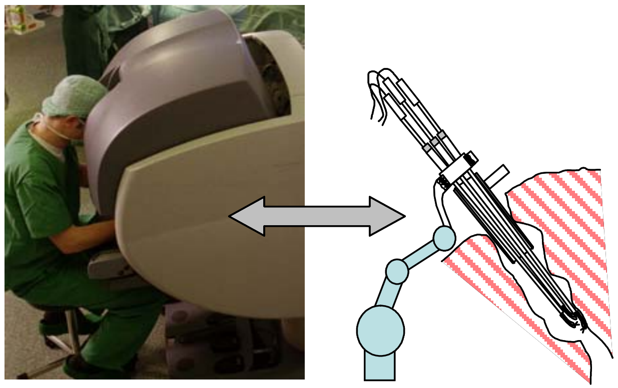


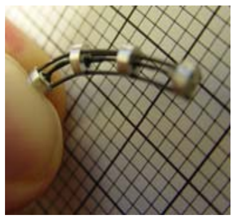


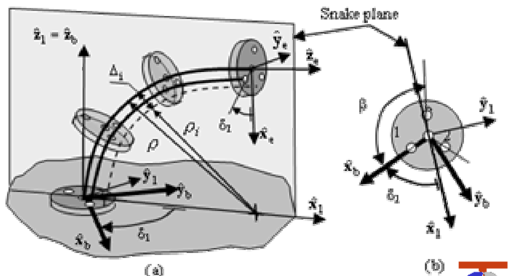




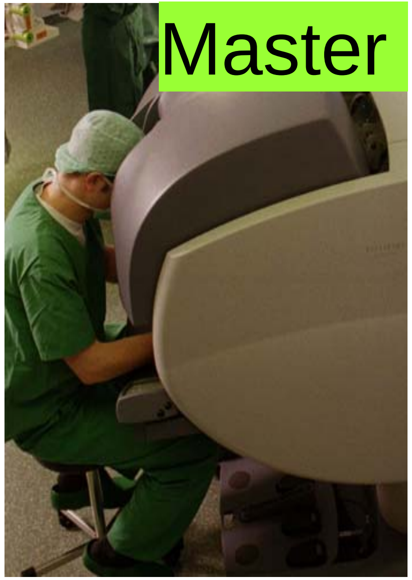




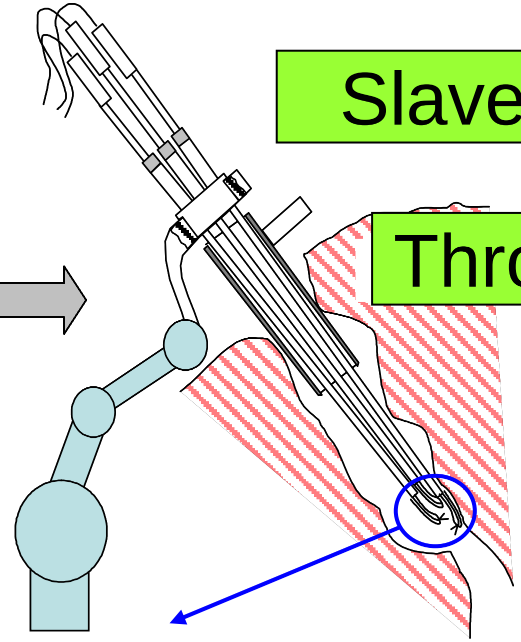




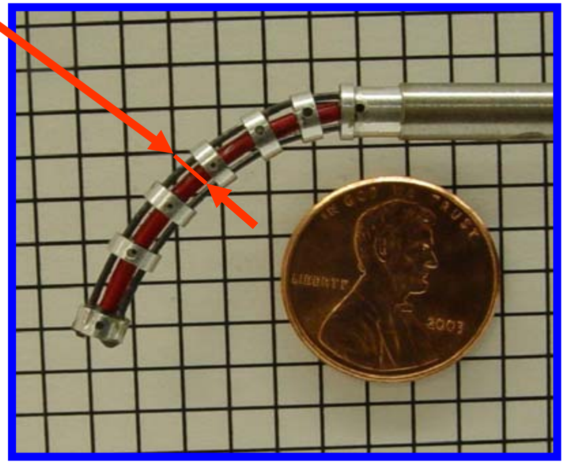
High Dexterity Robot for Confined Spaces



Controller



Ø4 mm



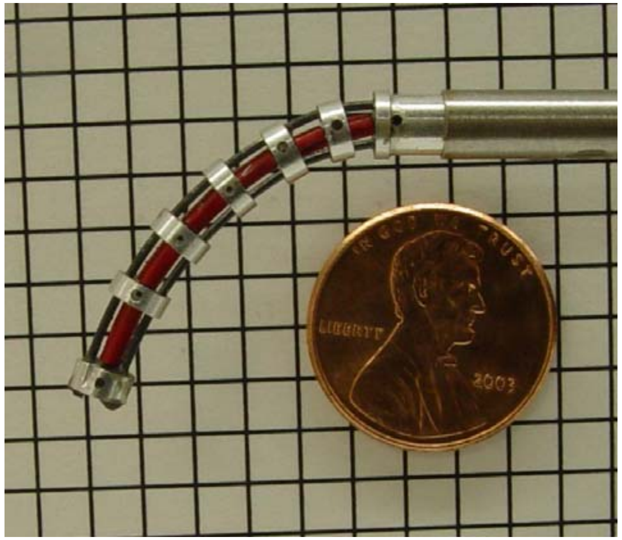
Ø4 mm Distal Dexterity Unit for
Surgical tool manipulation

N. Simaan, R. Taylor, P. Flint

Scalable robot for dexterous surgery in small spaces

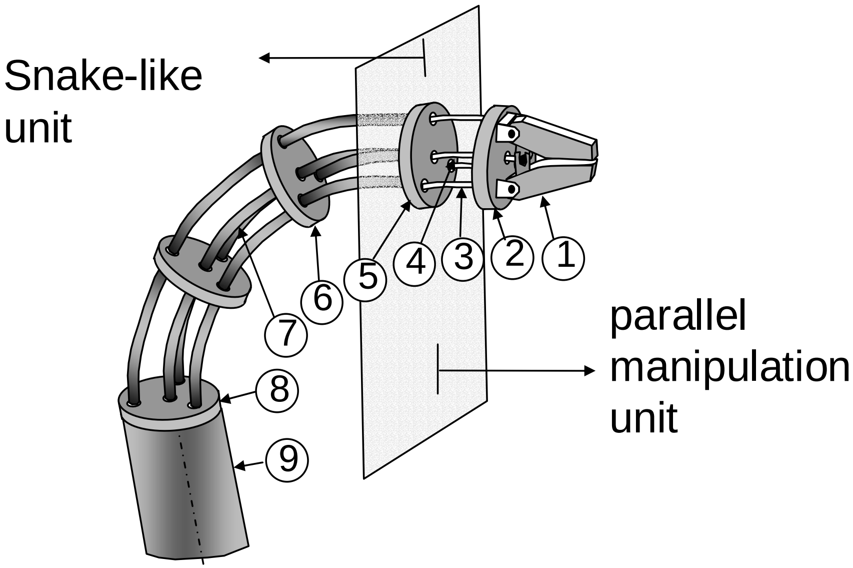
Nabil Simaan, Russell Taylor, Paul Flint, MD

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.



4.2 mm diameter

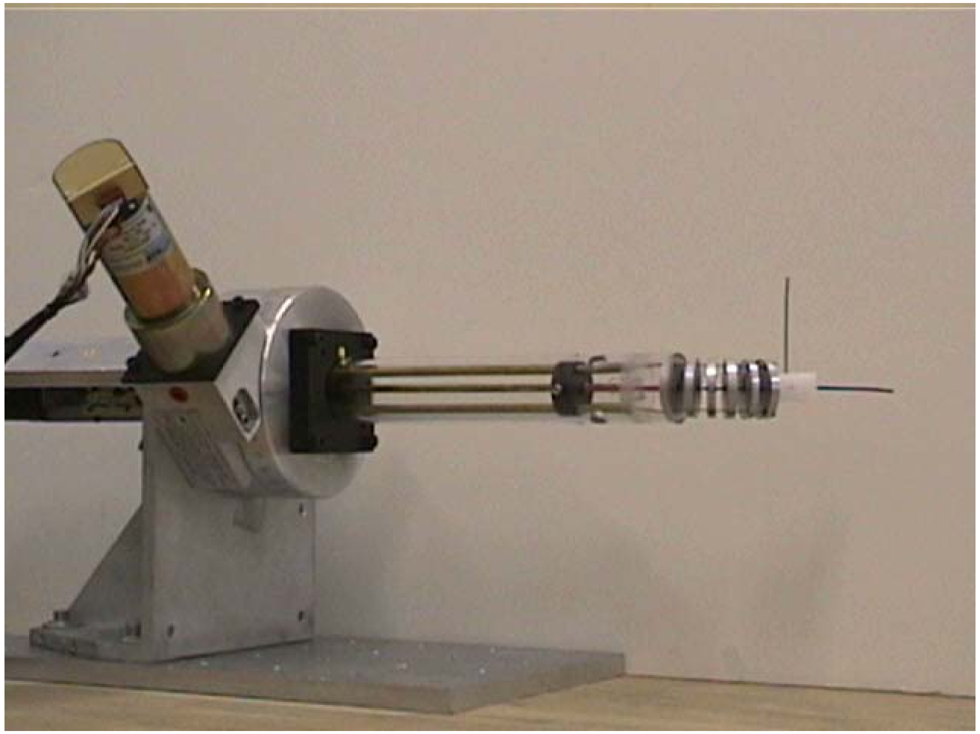
>1 N force application ability



1 gripper
2 moving platform
3 parallel stage flexible links
4 Gripper actuation link
5 end disk
6 spacer disk
7 central backbone tube
8 base disk
9 DDU holder

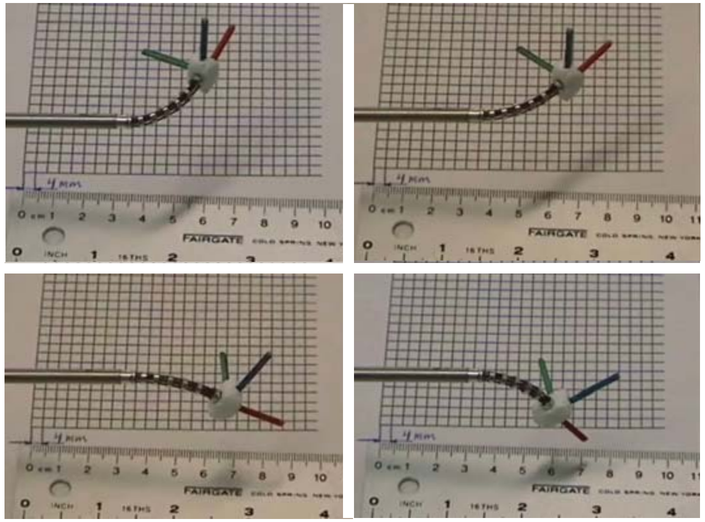
Functional Prototypes: Large and Small Scale

Large Scale



Test-bed for Suturing Application & Low Level Controllers and Debugging

Small Scale

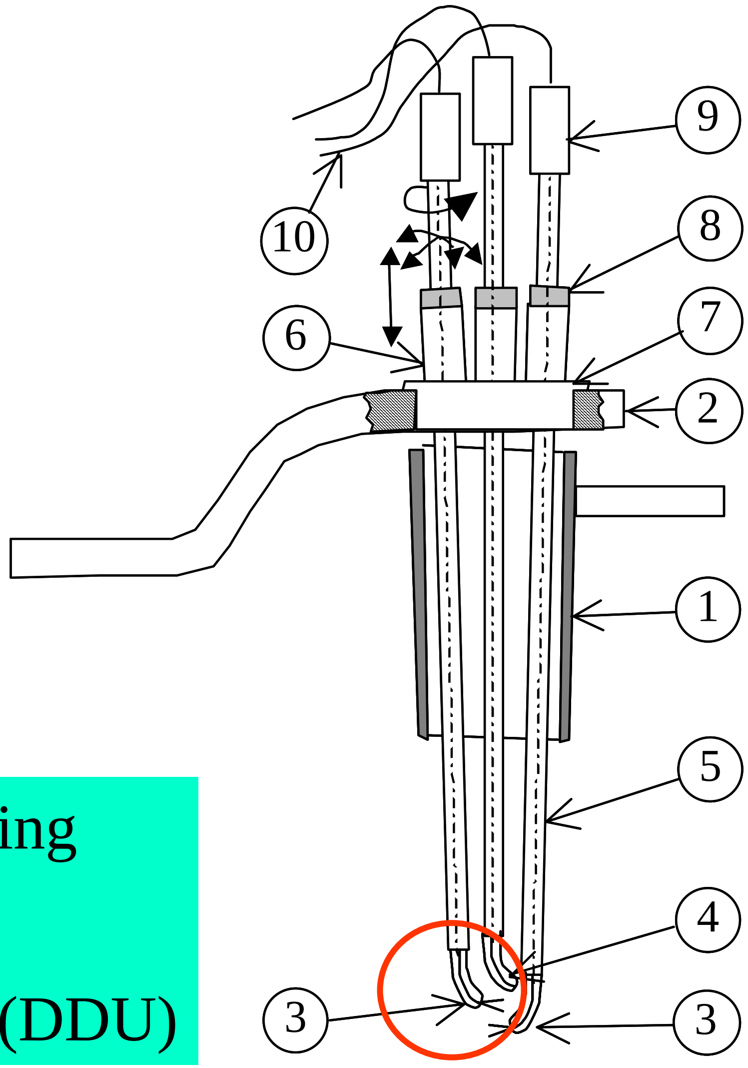


QuickTime™ and a
Cinepak decompressor
are needed to see this picture.

N. Simaan, R. Taylor, P. Flint, A. Kapoor, P. Kazanzides

Slave Robot

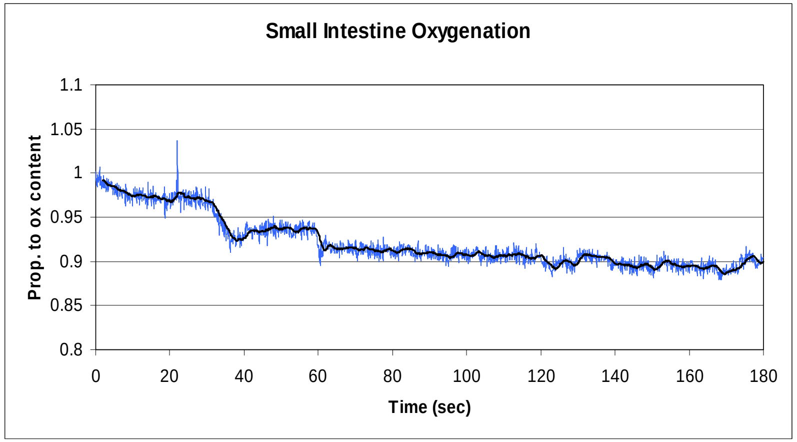
1. Laryngeoscope
2. Base link
3. Distal Dexterity Unit (DDU)
4. DDU for saliva suction
5. DDU holder
6. Tool Manipulation Unit (TMU)
7. Rotating base
8. Fast clamping device
9. Driving unit for the snake
10. Electrical supply /data lines

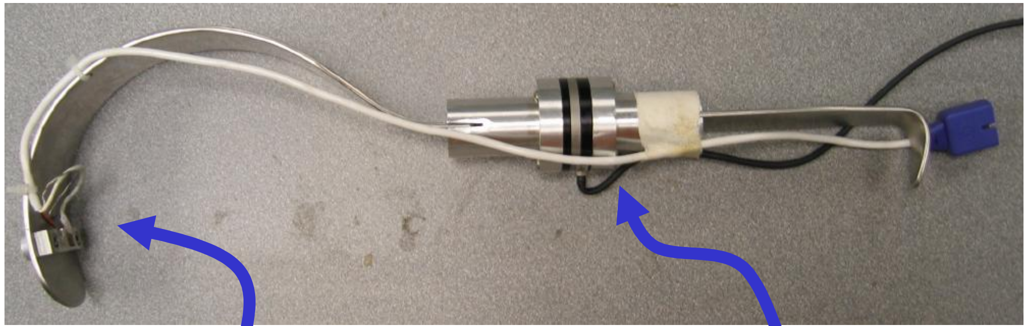


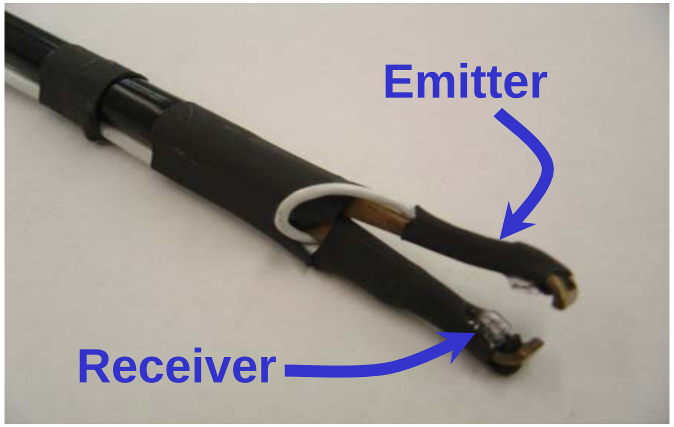
- A 34 DoF 3-armed slave robot operating through a long and narrow cannula
- Each arm has a Distal Dexterity Unit (DDU)

Sensorized Instruments

- Tool-to-tissue interaction force
- Tissue oxygenation, etc.
- Integrate with information infrastructure, process control, decision supports







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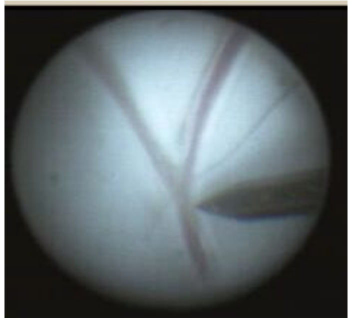
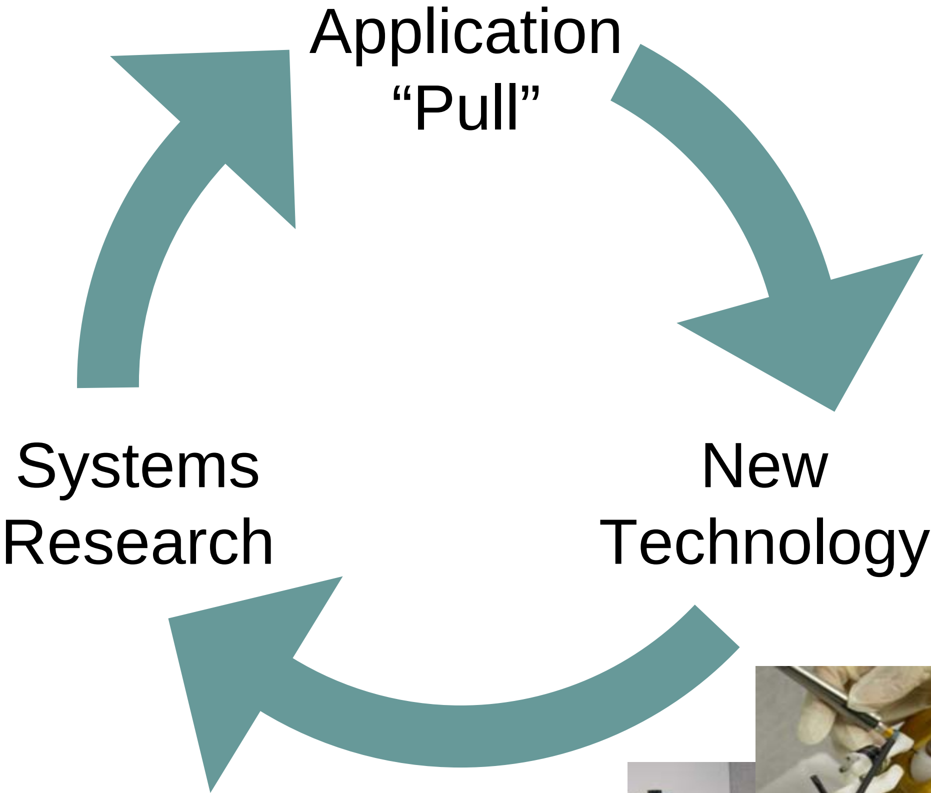
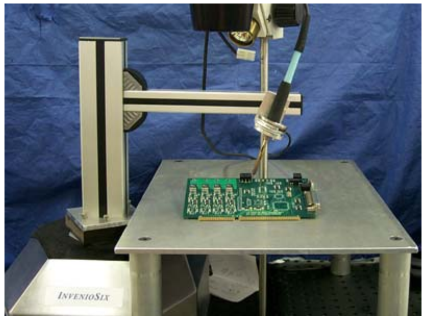
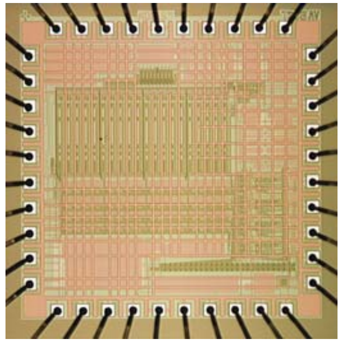
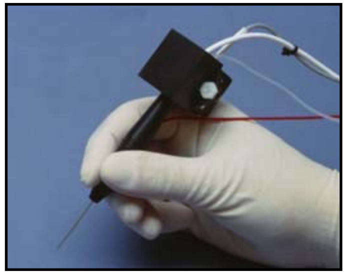
Microsurgery





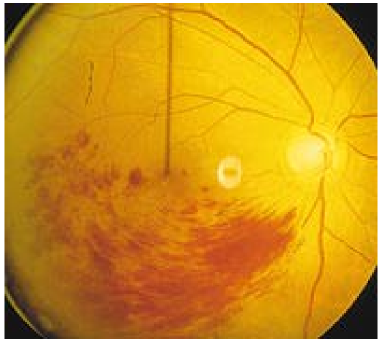




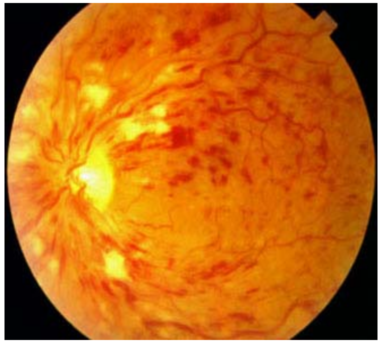


Eye Conditions: Leading Causes of Blindness

- Central Retinal Vein Occlusion (CRVO)
- Branch Retinal Vein Occlusion (BRVO)

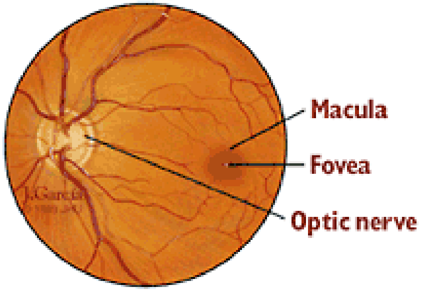


BRVO

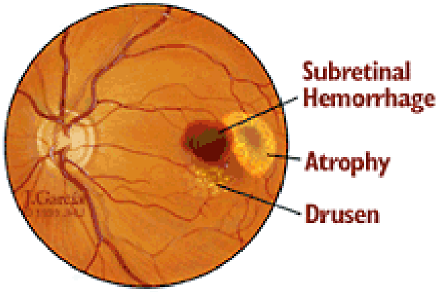


CRVO

- Age-related Macular Degeneration (ARMD)



Normal

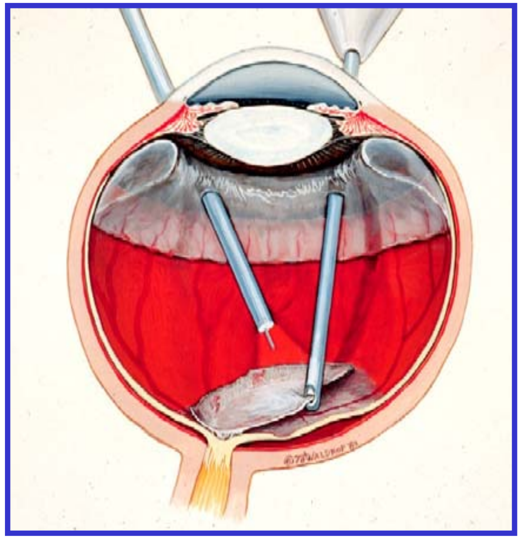


Macular degeneration

Images taken from the Wilmer Ophthalmological Institute and www.avclinic.com

Vein Cannulation - Challenges Involved ?

- Manipulation within delicate retinal structures
  - Retinal Vein (100 microns in diameter)
  - Needle (20-50 microns in diameter)



- At these micro-scales
  - Tactile feedback is practically non-existent
  - Depth perception is limited

Need for dexterity enhancement

Also the unstructured nature of the task → human needs to be directly "in the loop"

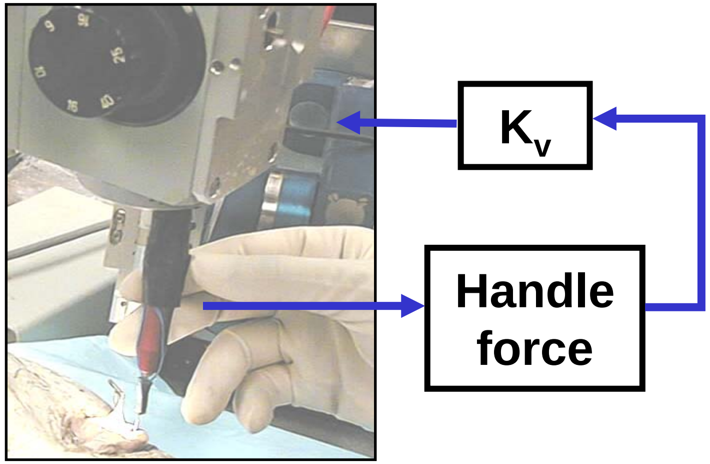
Research Objectives

Development and demonstration of vision-based guidance that provides assistance in micro-scale eye surgery, specifically retinal vein cannulation.

Implementation of the system at a resolution close to 50 microns.

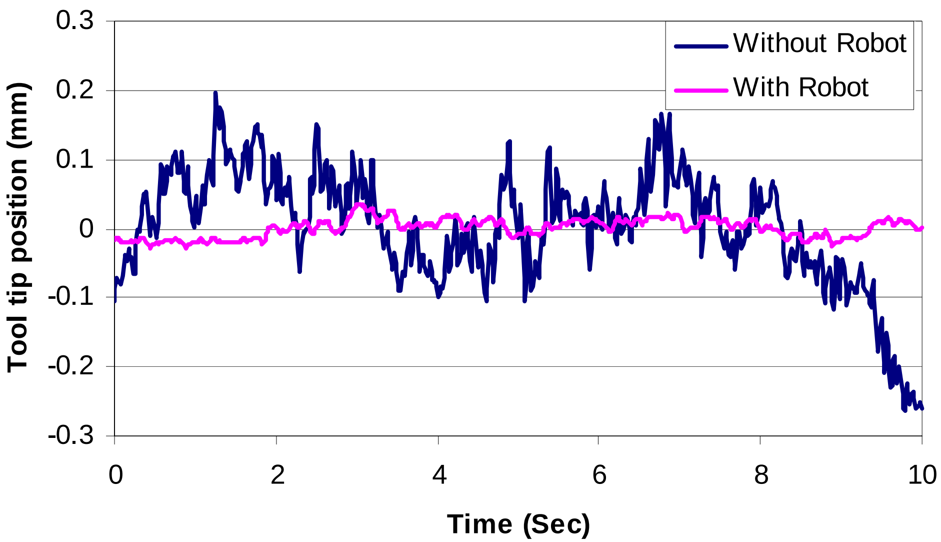
Recent work by Bettini04 has shown that under certain controlled conditions vision-guided cooperative manipulation in 2D can be done at a resolution of approx. 10 microns.

Steady Hand Guiding for Microsurgery



QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

R. Taylor & R. Kumar



2 Micron Accuracy

Force-scaling

Remote Center of Motion

How To Structure Visual Guidance?

"Classification and Realization of the Different Vision-Based Tasks" (Chaumette, Rives, Espiau, 1994)

"A Modular System for Robust Hand-Eye Coordination (Hager, 1997)

"Task Specification Languages for Uncalibrated Visual Servoing" (Dodds, 2000)

Our Problem: Design a control framework that maps traditional active (vision-based) control systems into admittance controls with a similar geometric interpretation

Virtual Fixtures: Basic Idea

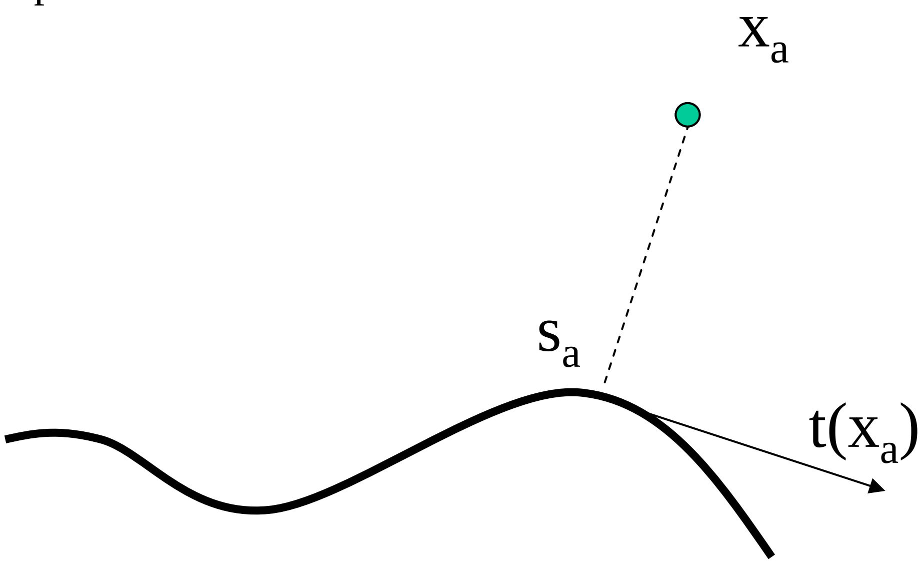
Consider

- curve p(s)
- tool tip x_a
- closest point $p(s_a)$ to x_a

The preferred direction δ_p is the normalized tangent

$$t(x_a) = \tfrac{d}{ds}\, p(s)\,\big|_{s=s_a}$$

$$\delta_p(x_a) = \frac{t(x_a)}{\|t(x_a)\|}$$



Virtual Fixtures: Basic Idea

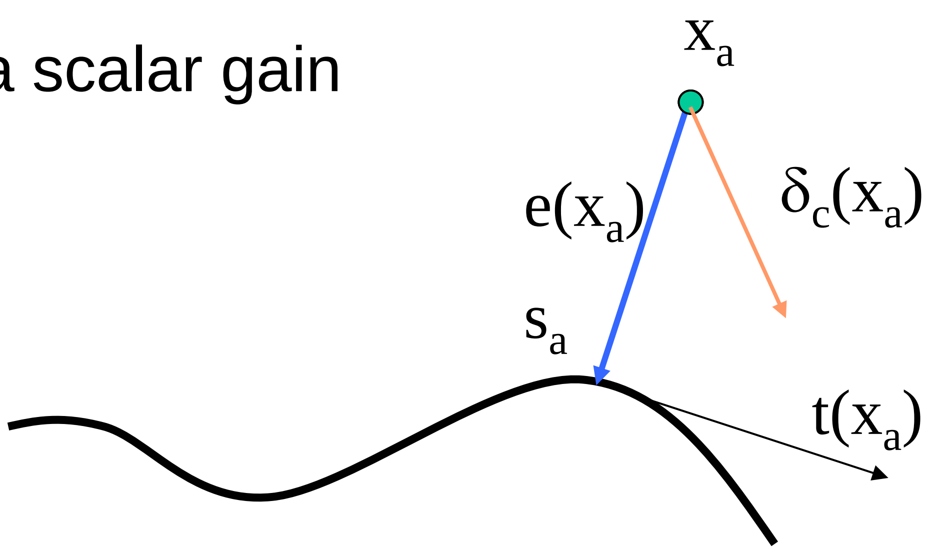
Now, define an error that returns tool to p

$$e(x_a) = p(s_a) - x_a$$

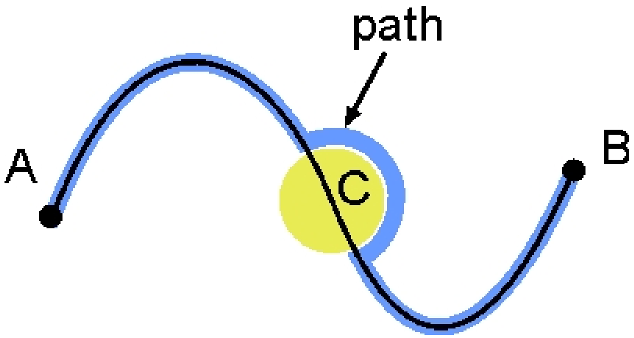
Define a new reference direction with this error term

$$\delta_c(x_a) = \delta_p(x_a) + k_d e(x_a)$$

where $k_d > 0$ is a scalar gain



Effect of Varying Compliance



QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

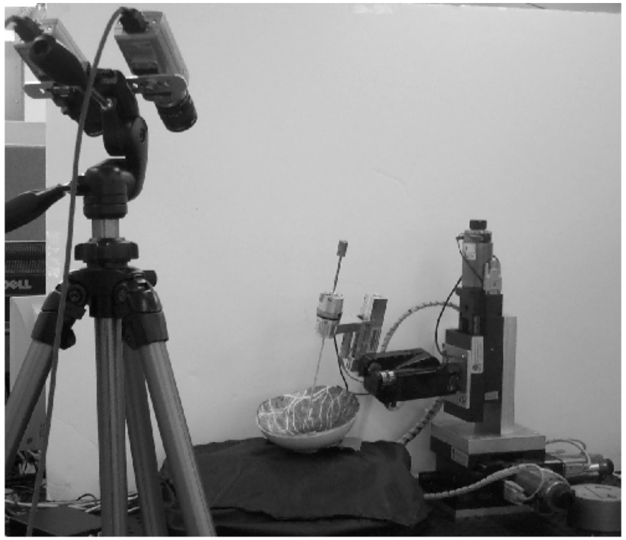
c_τ	Average error (pixels)	Execution time (sec)	Obst. avoidance time (sec)
0	0.59	16.38	N/A
0.3	0.84	21.16	8.71
0.6	2.08	17.49	4.36
1 (fast)	7.06	19.55	4.58
1 (precise)	2.25	39.29	7.85

Micro Scale: Varying Compliance

c_τ	Average error (pixels)	Execution time (sec)
0	3.20	26.86
0.3	4.97	34.85
0.6	7.64	45.66
1	8.15	55.75

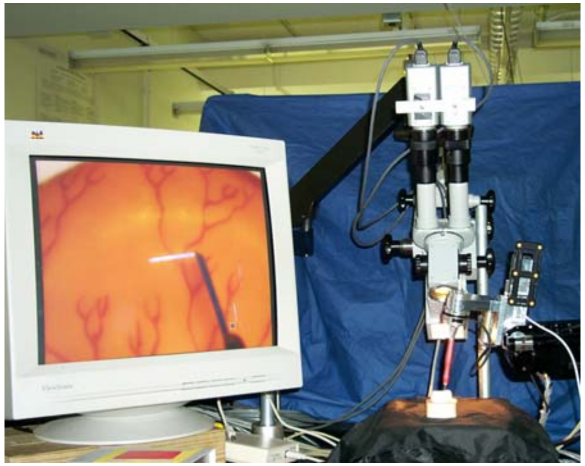
QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

The Eye TestBed

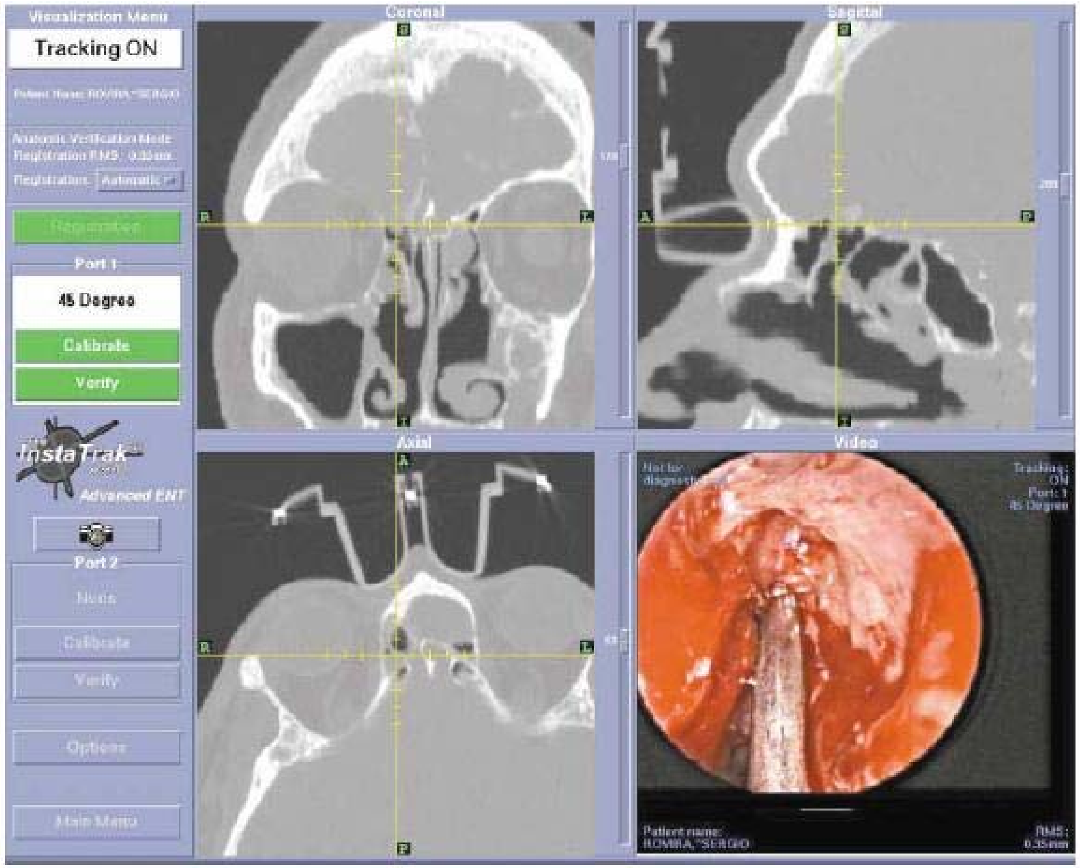


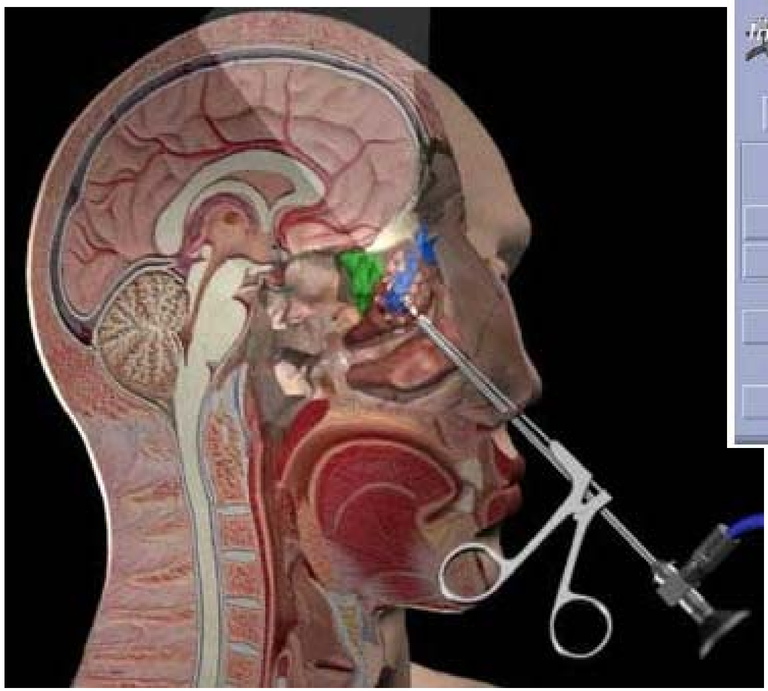
- Preliminary testbed (scaled version) for application of virtual fixtures to real surgery. Steady Hand robot with stereo cameras.
- Fully calibrated system – robot to camera calibration and stereo calibration. Average robot to camera transformation error is 2 mm +/- 1.5mm.
- Resolution of the system ~ 3mm/pixel.

- Current System: Zeiss stereo surgical microscope, steady-hand robot, stereo display
- Minimal Calibration: direct image-based formulation
- Resolution of the system ~ 100μ/pixel.



Example: Endoscopic Sinus Surgery



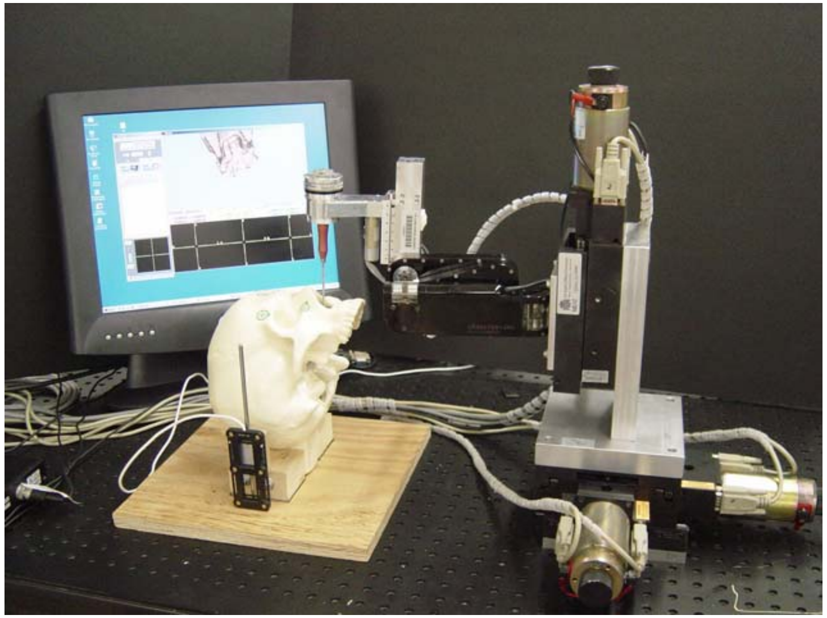


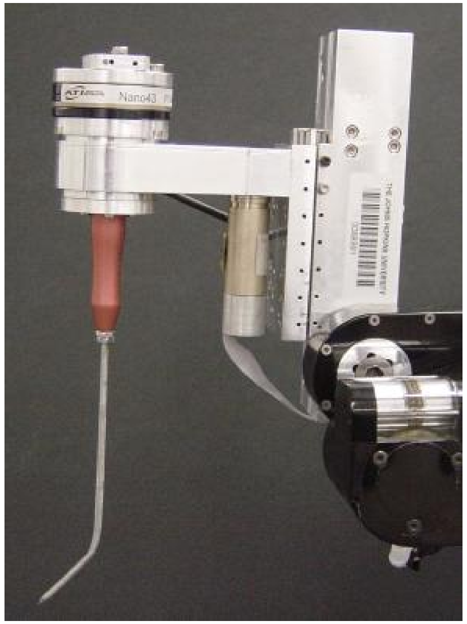
D. W. Kennedy, W. E. Bolger , and S. J. Zinreich

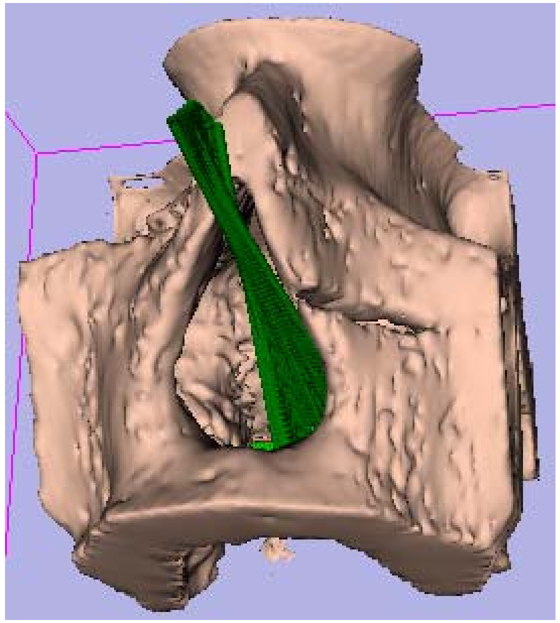
Diseases of the Sinuses: Diagnosis and Management. 2001.

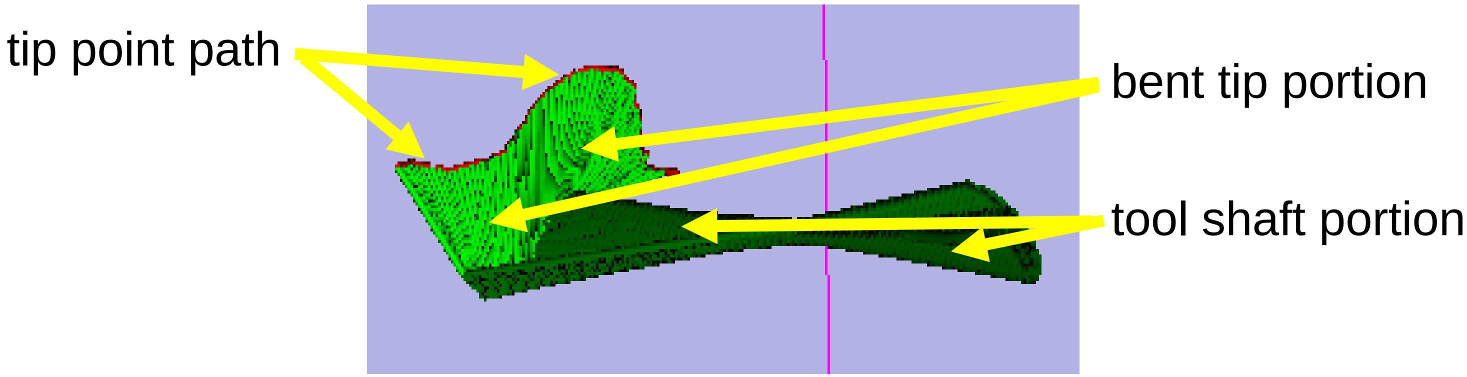
Steady-hand sinus surgery with virtual fixtures derived from CT models

Ming Li, Russell Taylor

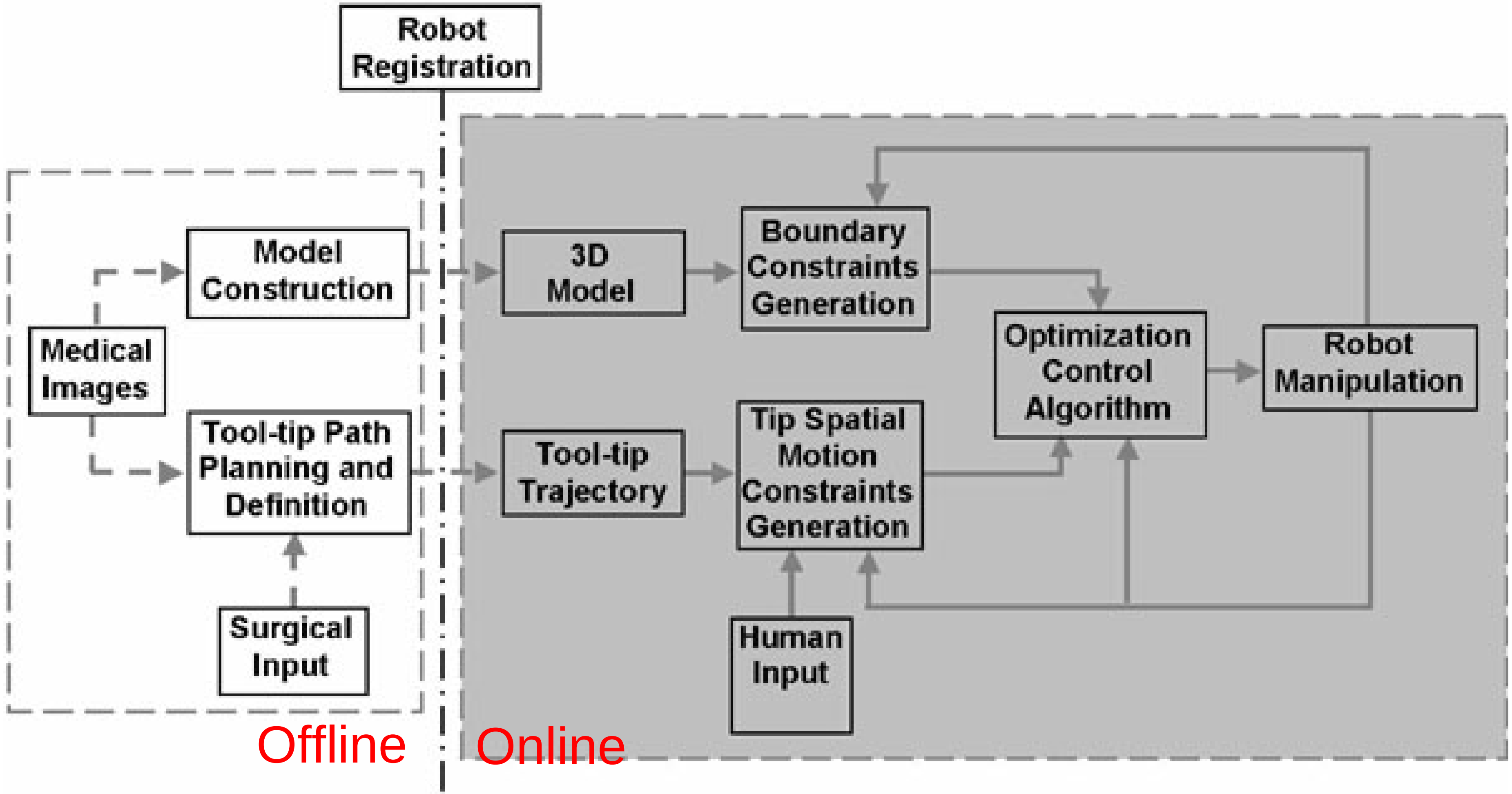






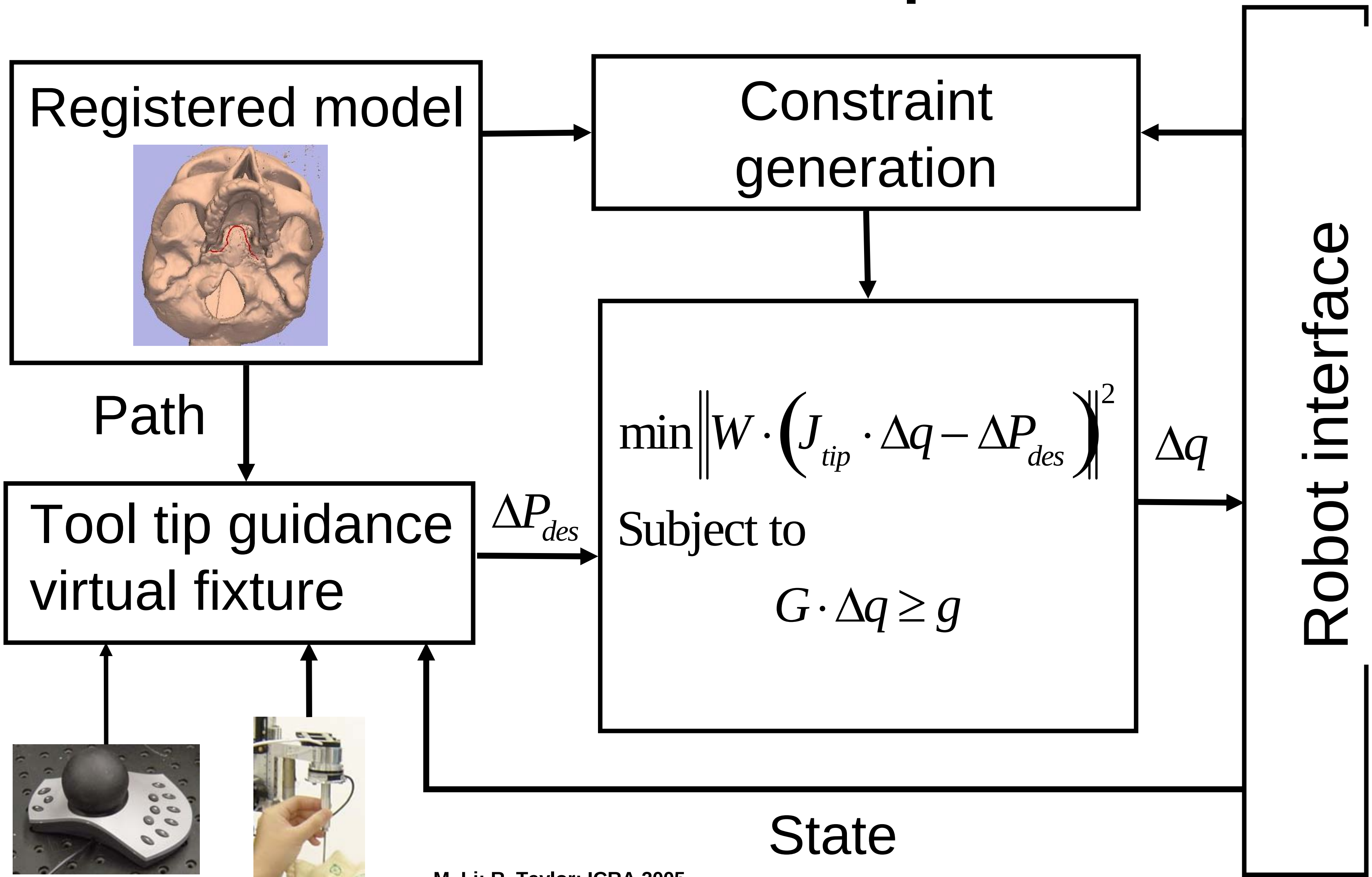


Virtual Fixture Generation System



M. Li; R. Taylor; ICRA 2005

Virtual Fixture Online Implementation



M. Li; R. Taylor; ICRA 2005

Cooperative
control guiding

3D mouse guiding

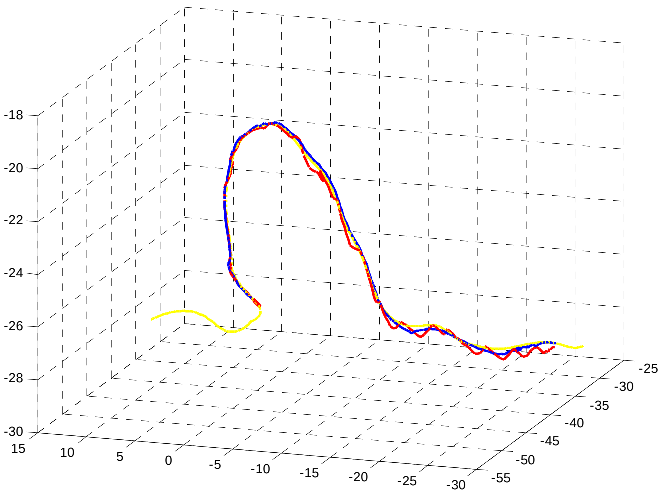
QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

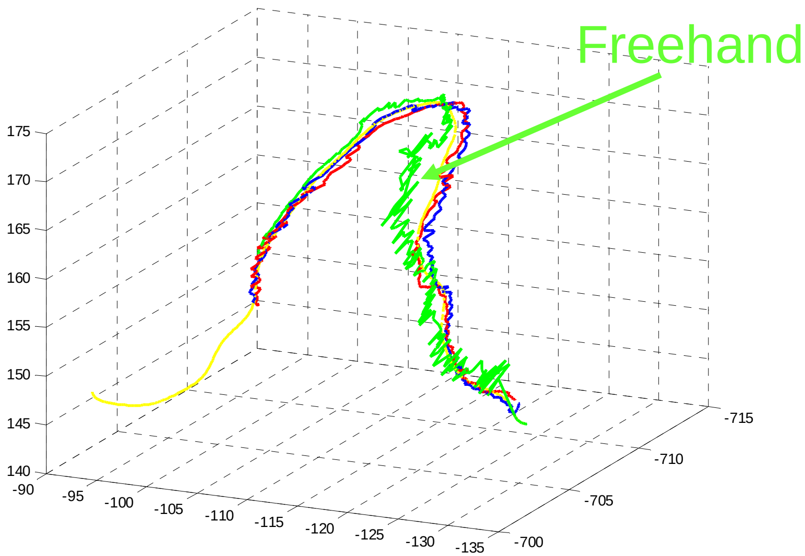
View of path & tool

M. Li; R. Taylor; ICRA 2005

Performance of Teleoperation *vs* Cooperatively Hands-on Operation

Trajectory of the path



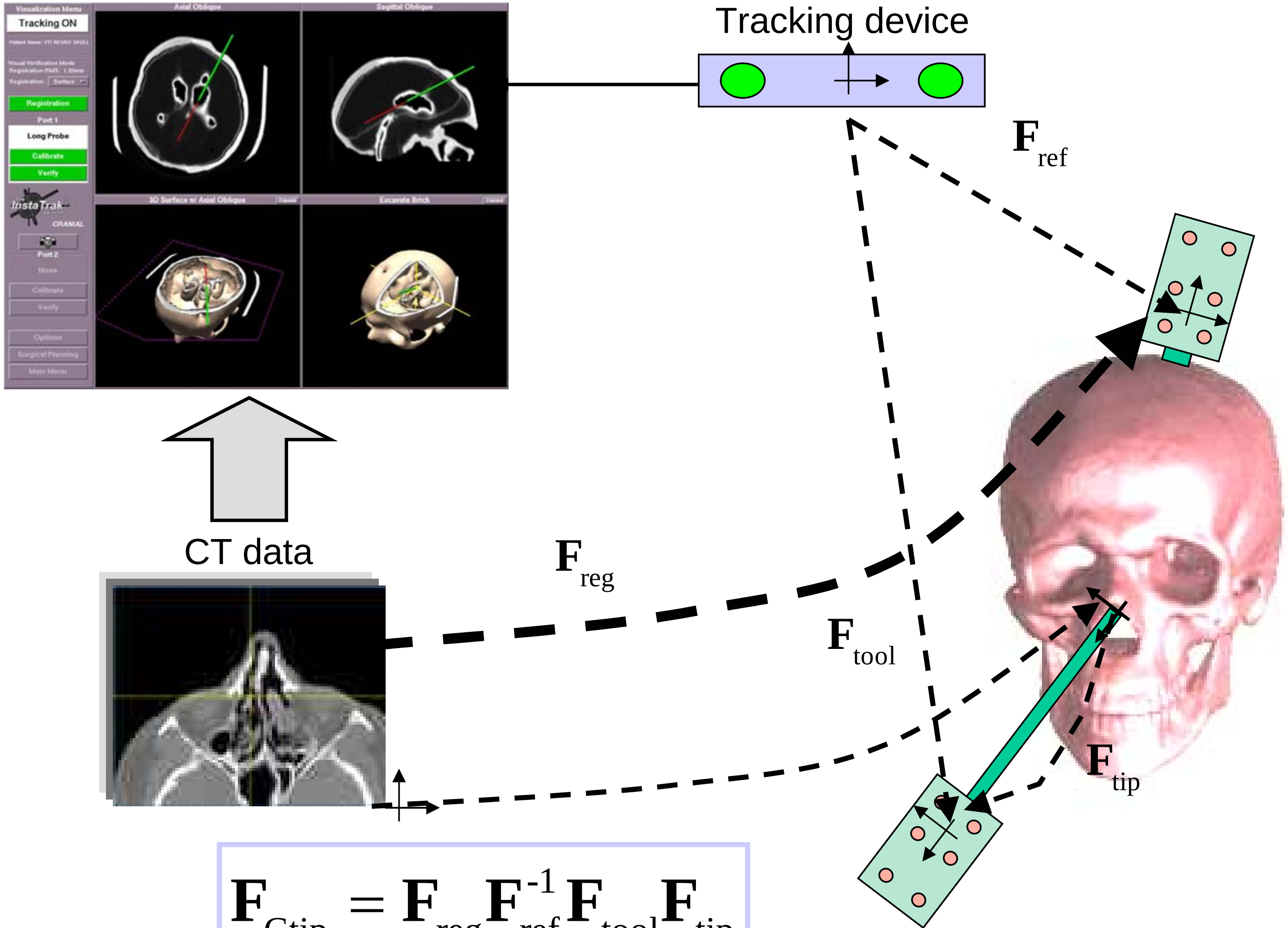


Yellow: given path; Red: remote; Blue: hands-on

Robot context | Optical Tracking context

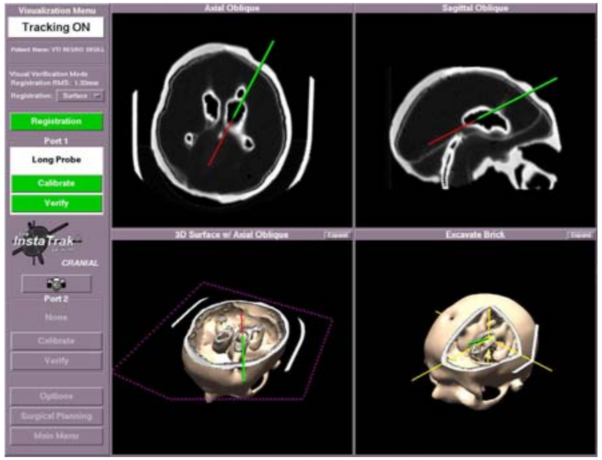
M. Li; R. Taylor; ICRA 2005

Canonical Navigation System

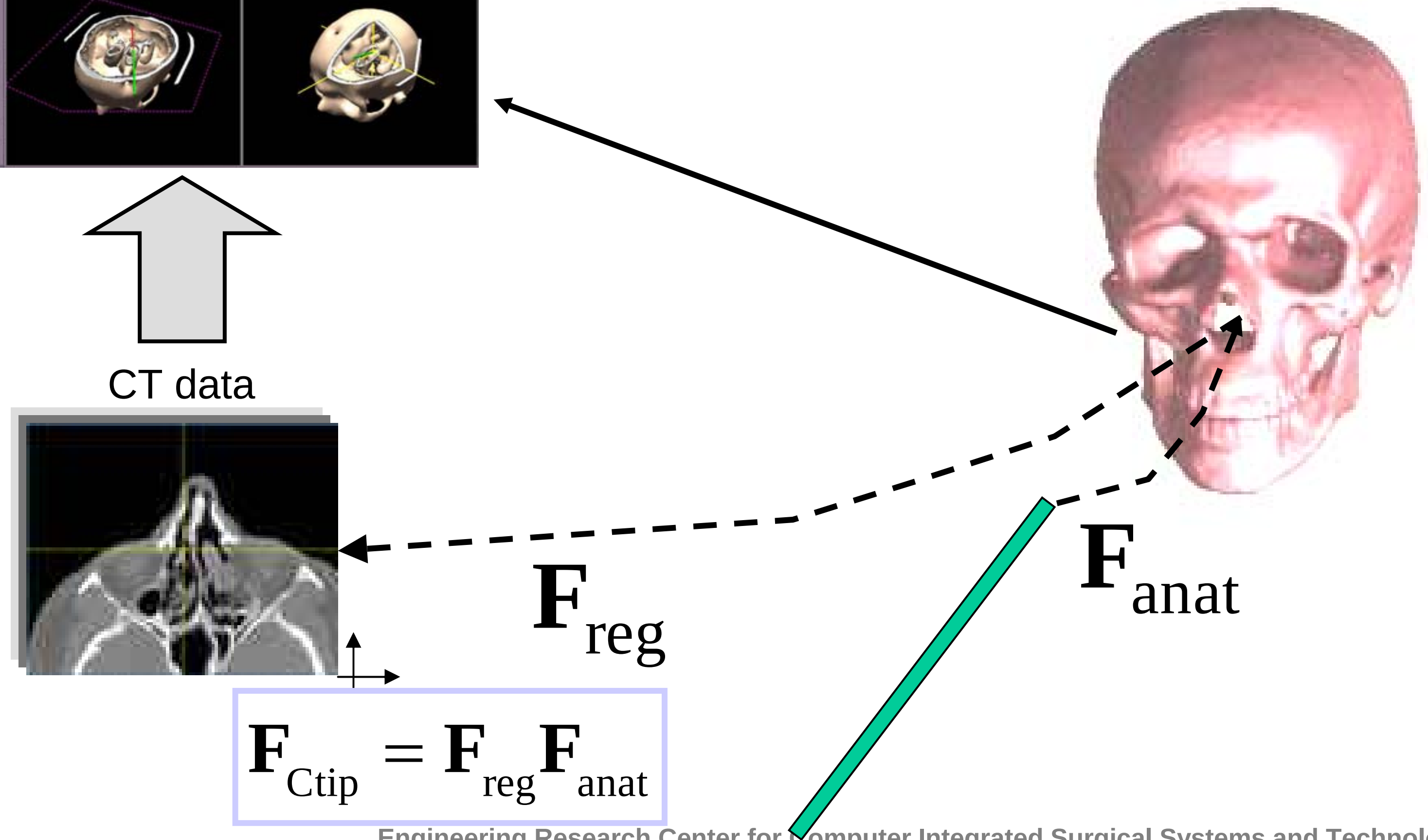


$$F_{Ctip} = F_{reg} F_{ref}^{-1} F_{tool} F_{tip}$$

Our Goal: Direct Registration



From a sequence of endoscope images, compute registration to CT and endoscope position



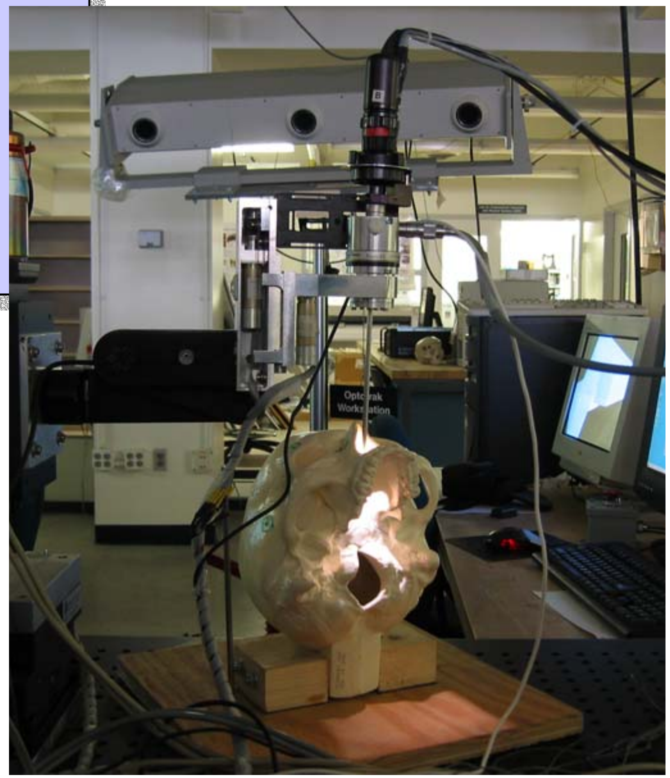
$$\mathbf{F}_{\mathrm{Ctip}} = \mathbf{F}_{\mathrm{reg}}\mathbf{F}_{\mathrm{anat}}$$

Scale-Invariant Registration of Monocular Images to CT-Scans for Sinus Surgery

Darius Burschka, Ming Li,
Russell Taylor, Gregory D. Hager

Proc. MICCAI 2004
St. Malo, France

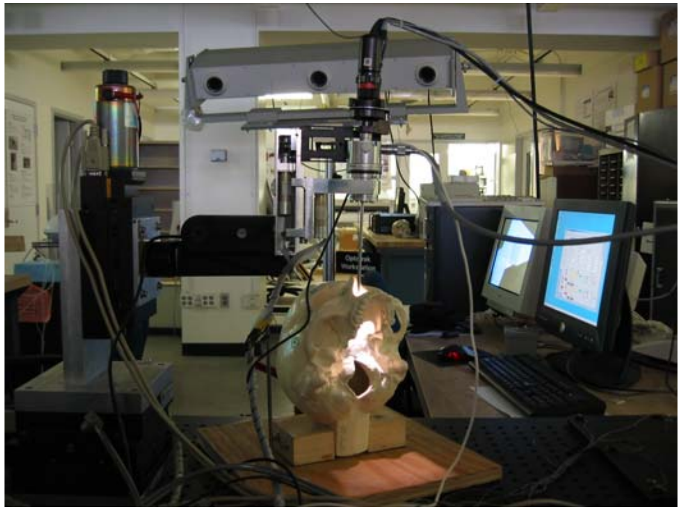
QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

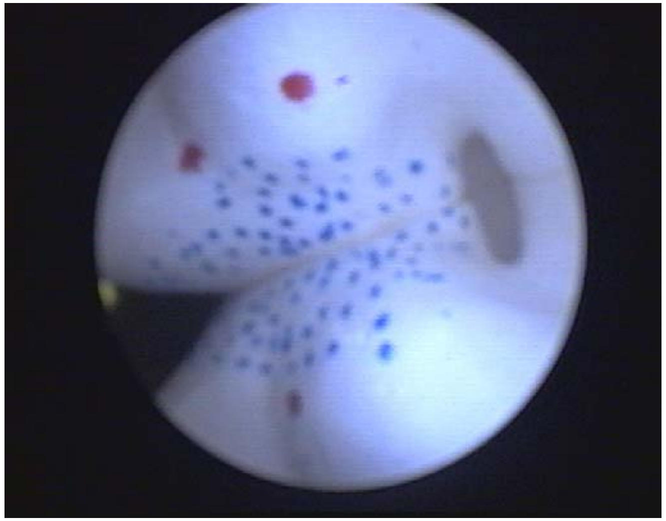


- Accuracy Experiments
  - Plastic skull phantom
  - Surface reconstruction ~ 0.5 mm
  - Registration ~0.5 mm

Validation: Phantom Results

- Surface Reconstruction accuracy ~ 0.5 mm
- Registration accuracy ~0.5 mm





Burschka, Li, Taylor, Hager

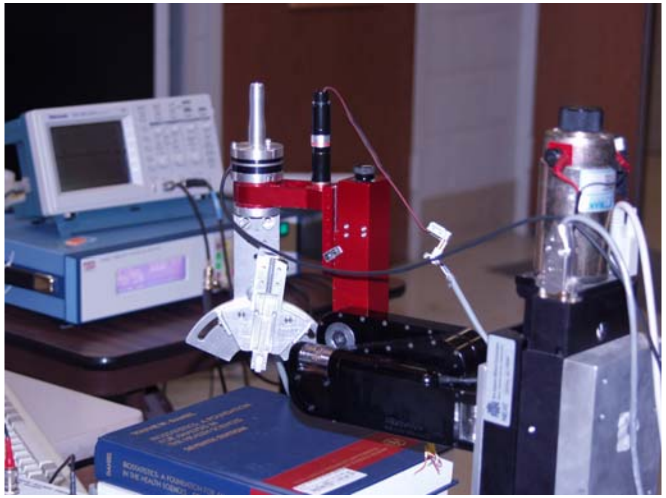
Cadaver Validation

- Porcine model with modified anatomy
- Embedded CT fiducials
  - again "gold standard" registration
- Hand-held endoscope

Burschka, Li, Taylor, Hager

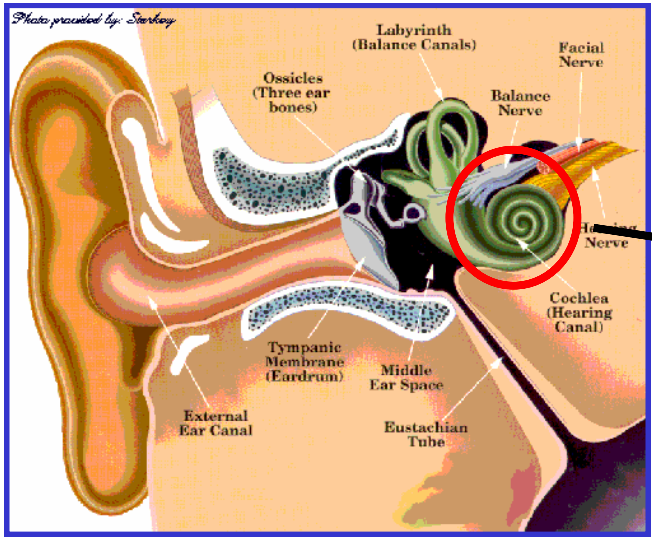
High Precision Ultrasound Guided Needle Placement

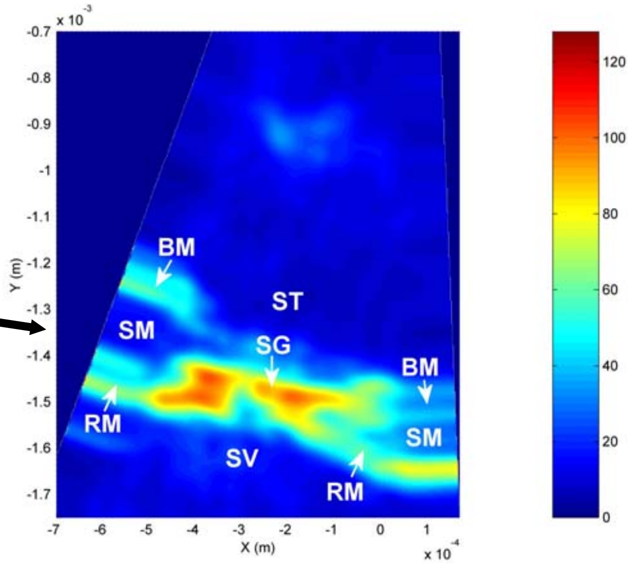
Rothbaum/Roy/Mustafa/Niparko/Francis/Whitcomb



Goal: to access the scala-media under ultrasound guidance

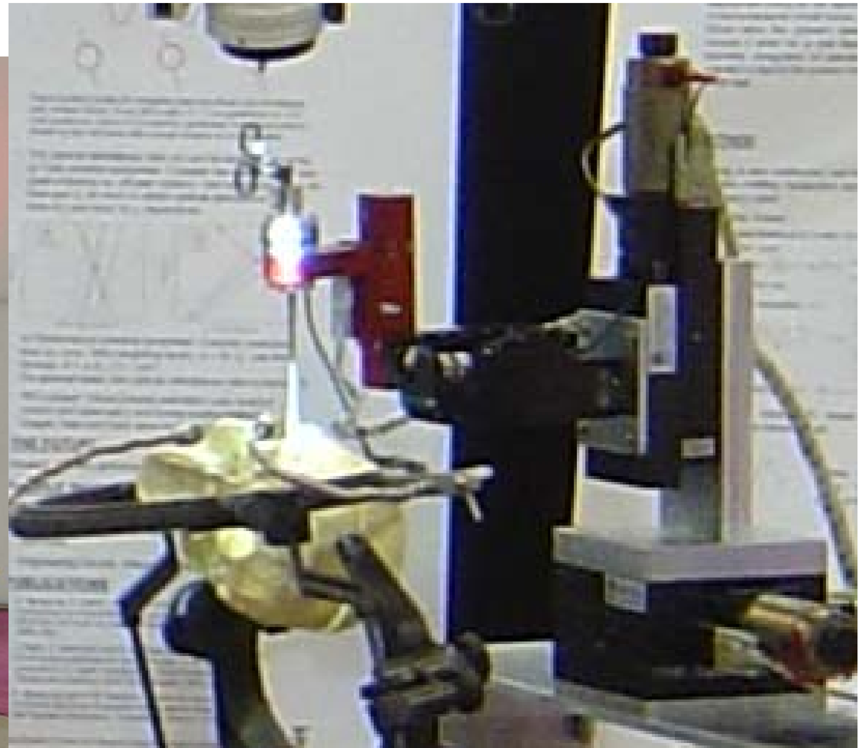
- Novel high resolution US device (collaboration with K. Shung and the Biomedical Ultrasonics Laboratory at USC)
- <30 μm resolution





NeuroSurgery

Kazanzides/Clatterbuck - JHU/Synergetics, Inc



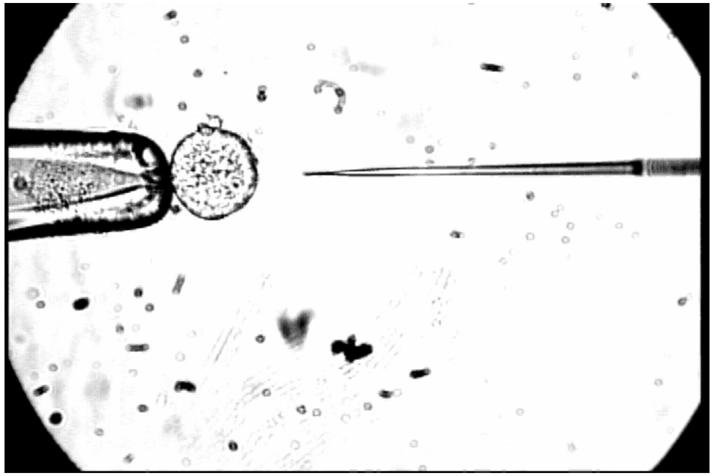
Collaborative demonstration of JHU Steady-Hand technology for neuro application at CNS "OR of the Future"

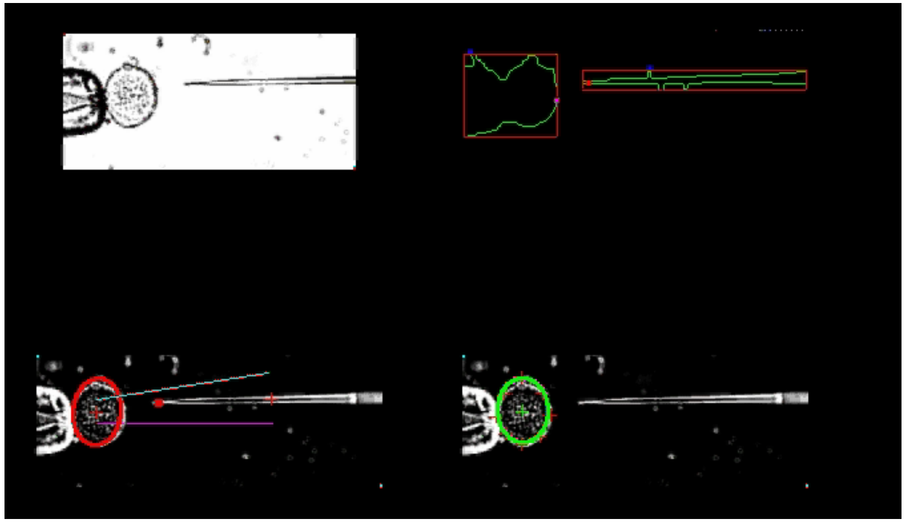
Two weeks from conception to completion!!

Biomanipulation with a steady hand robot

Rajesh Kumar(1), Ankur Kapoor(2), Russ Taylor(2)

- Cooperatively controlled robot for single-cell scale biomanipulation tasks
- Multiple control modes
  - Simple compliant guiding
  - “Augmented” compliant guiding
  - Shared/supervised autonomy
- Future work includes:
  - Next generation system
  - Visual “virtual fixtures”

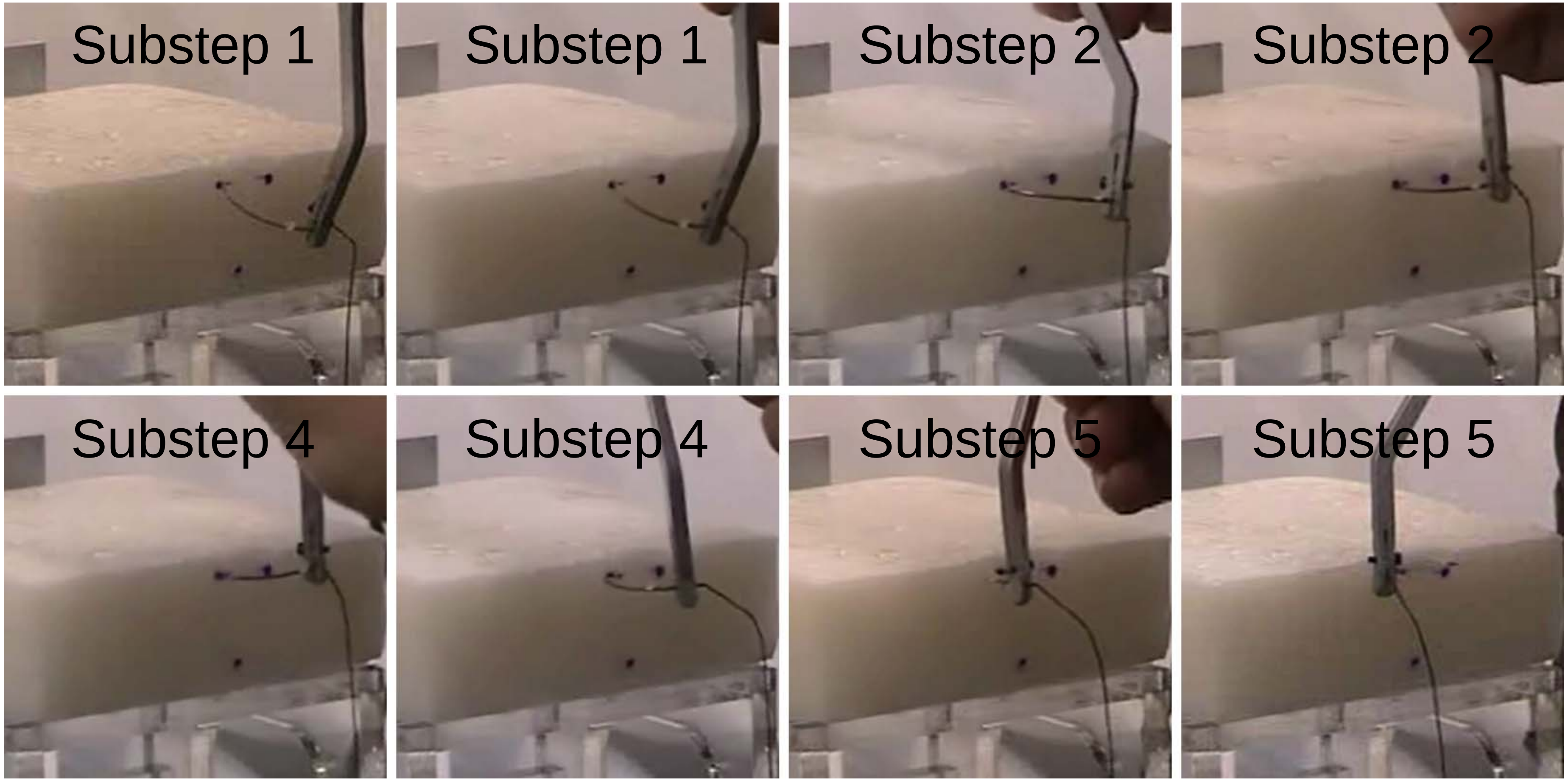




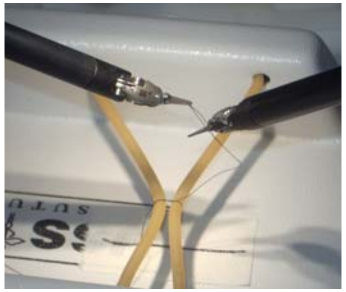
(1) Foster-Miller; (2) CISST ERC, JHU

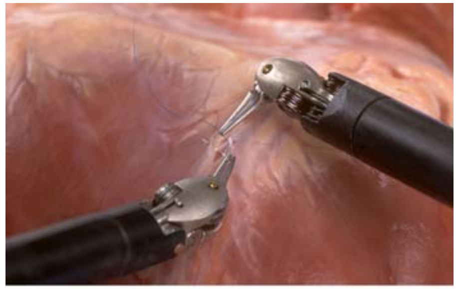
Virtual Fixtures for Suturing

Ankur Kapoor, Ming Li, Russ Taylor

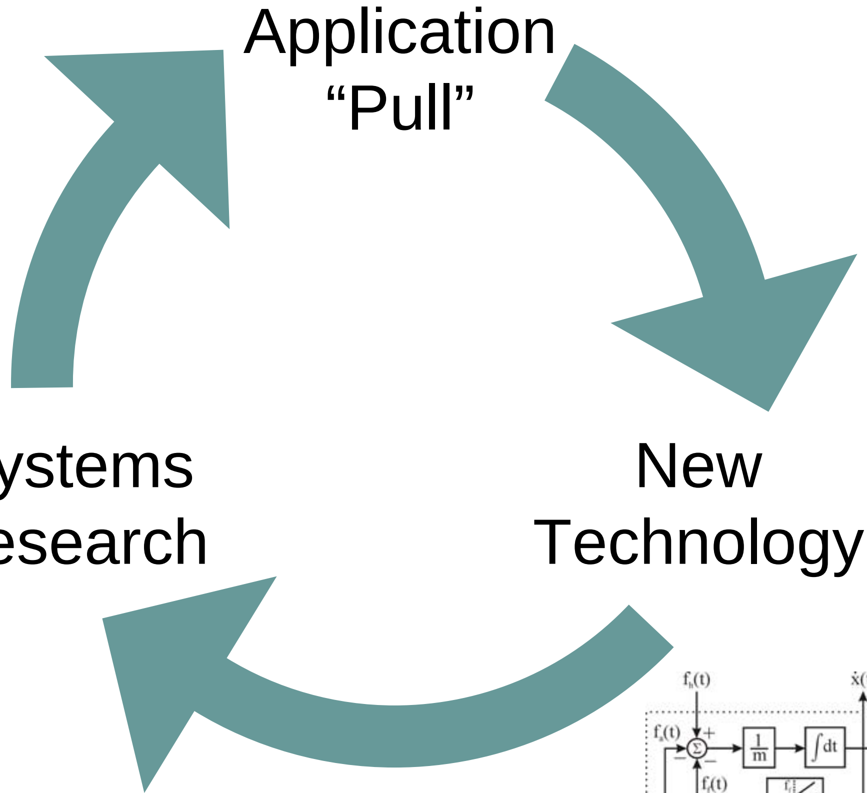


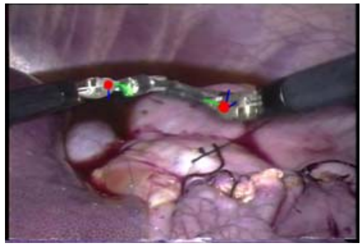
Teleoperation

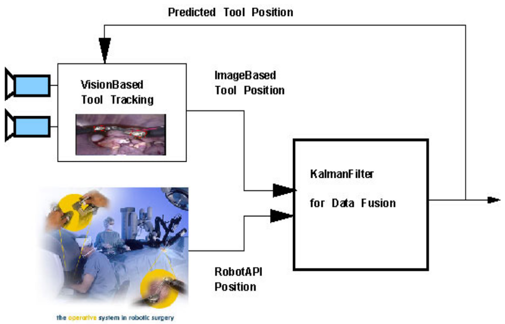


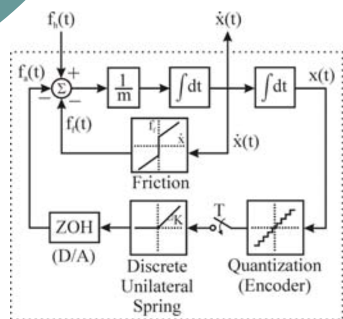


QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.





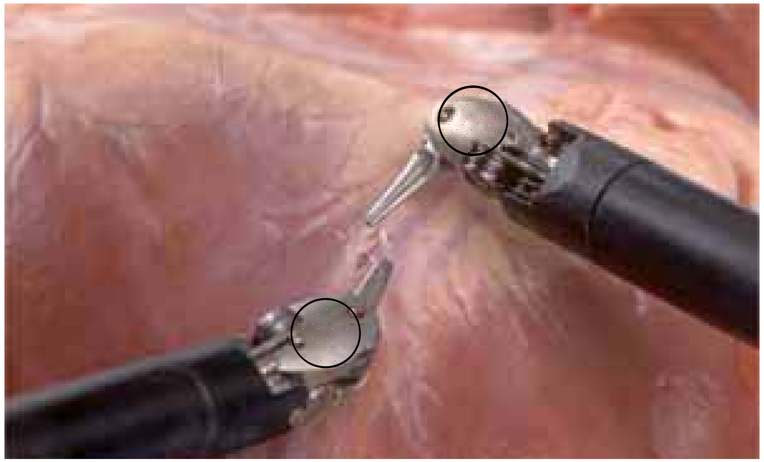




Augmented Reality for Surgeon Assistance

T. Akinbiyi, A. Okamura, D. Yuh

- Force sensors in robotic surgical instruments
- Computer display of warning when force is too high
- Pilot study for suturing
  - 3:1 reduction in broken sutures



Pilot Study

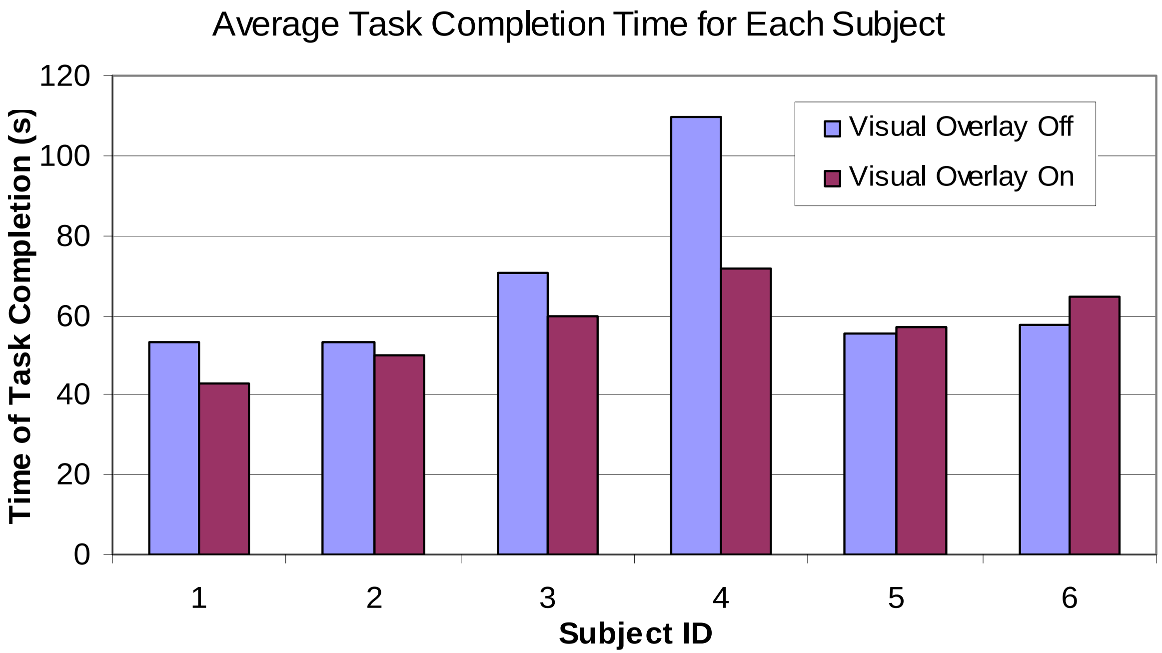
Ideal Trial

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

Excessive Force

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

Results



- Number of Broken Sutures
  - Visual overlay on: 1
  - Visual overlay off: 3
- 5 out of 6 users preferred task with visual overlay

Video tracking of surgical tools

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

Akinbiyi, Okamura & Yuh; Burschka & Hager

Real-time Video Registration Techniques

Hager/Thakor/Yuh/Lau (JHU)

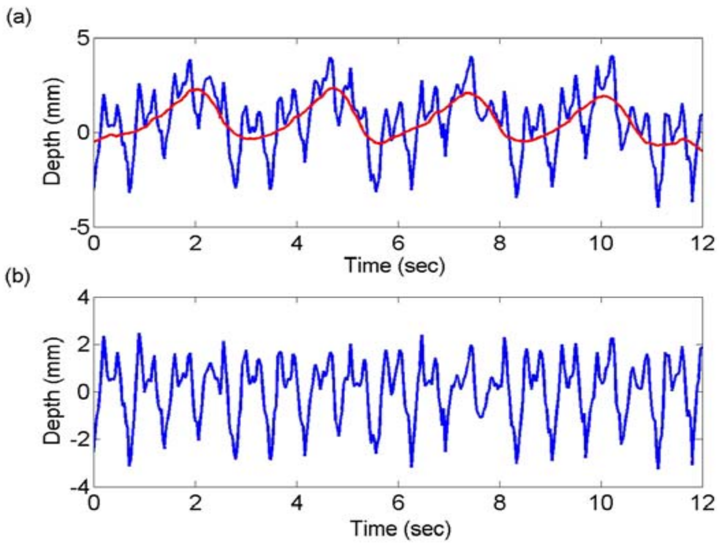
QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

Problem: Construct dynamically tracked models of deformable surfaces

Solution: Optimize a parametric surface from stereo imagery

Results: Real-time tracking of a beating heart with:

1. Real-time performance
2. Extremely high accuracy (< 1/10 pixel)
3. Generalization to many imaging devices and applications



Stereo tracking of in-vivo beating heart using Intuitive Stereo Endoscope

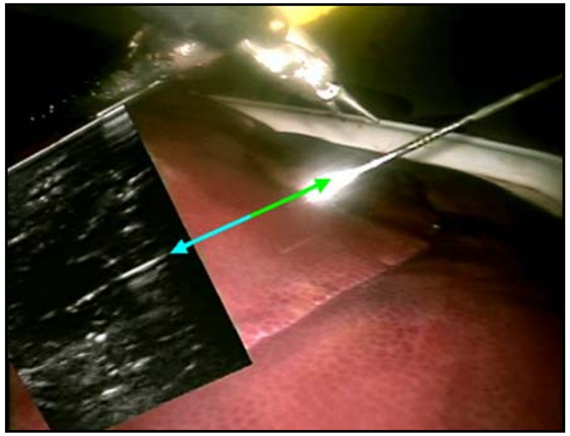
Telemanipulation with Integrated Laparoscopic Ultrasound for Hepatic Surgery

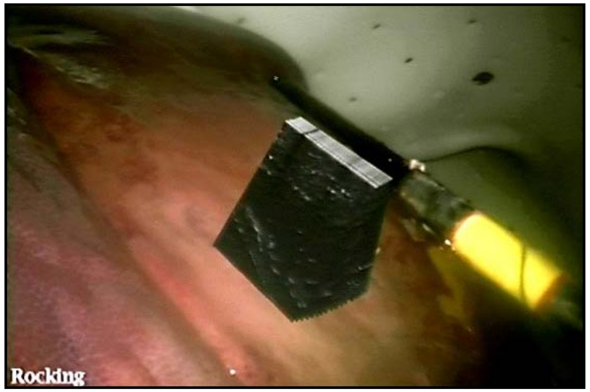
Collaboration between JHU and Industrial Partner

Presented by Christopher J. Hasser, Director of Applied Research, Intuitive Surgical, Inc.

Ultrasound probe examining artificial lesion in porcine liver with registered 2D ultrasound overlay

Needle insertion demonstrates alignment



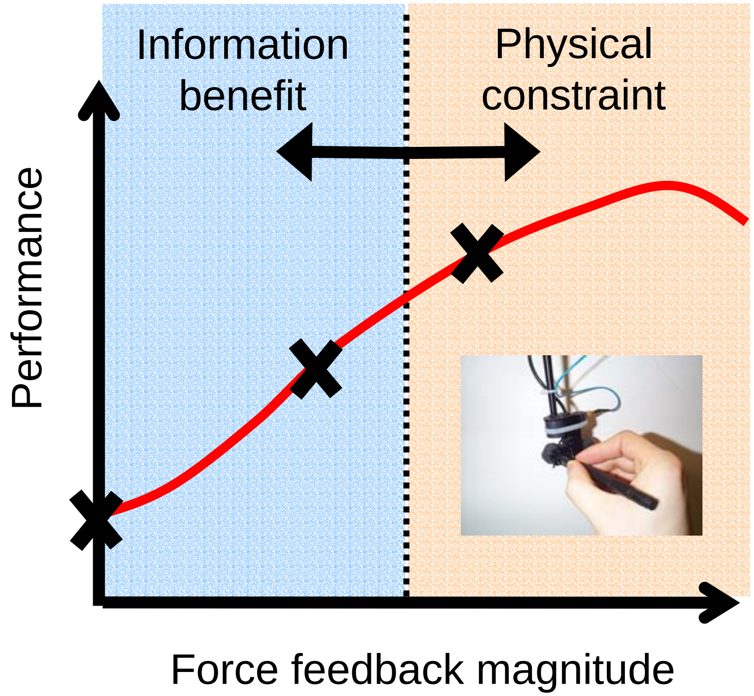


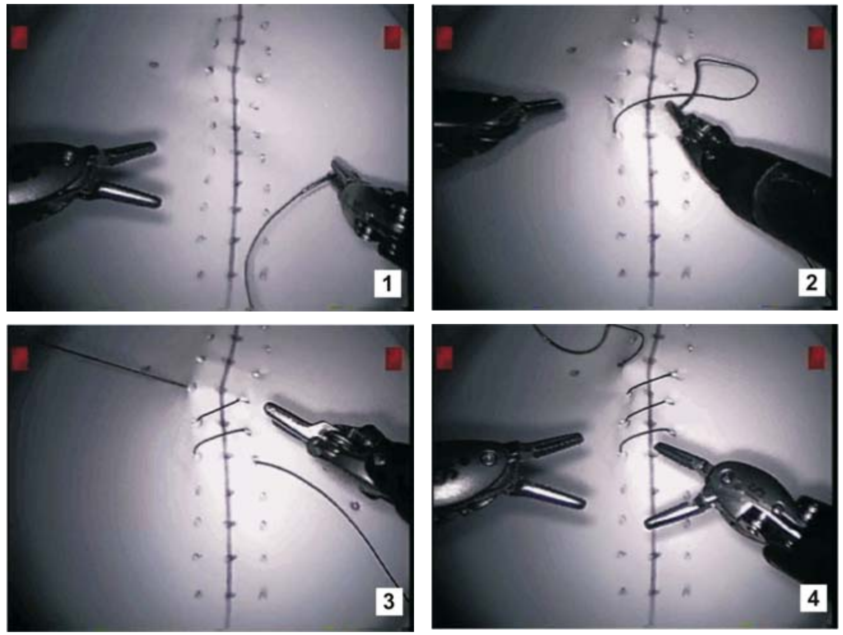
Registered 3D ultrasound volume swept w/autonomous robot motion

Human Modeling

Fundamental research on human modeling for learning and effectiveness is needed

Increased force feedback provides increasing performance benefit

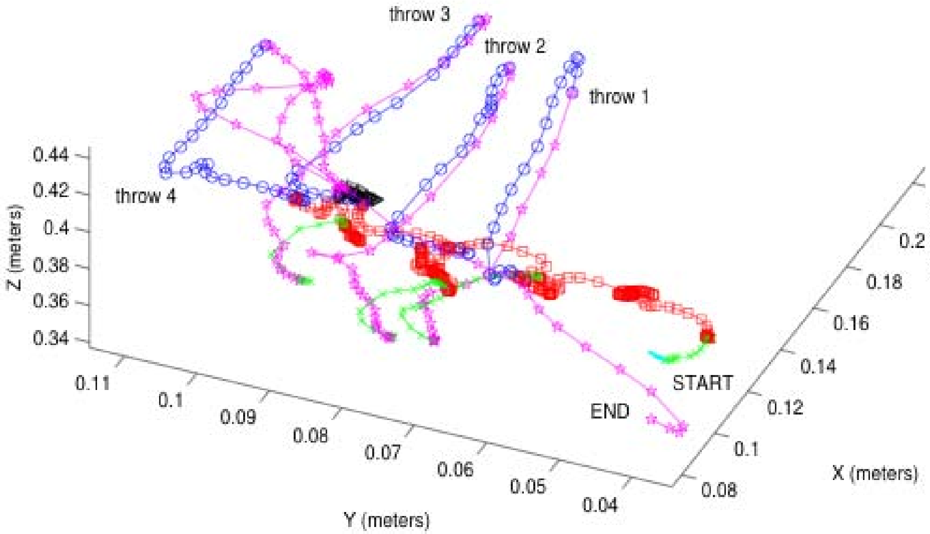


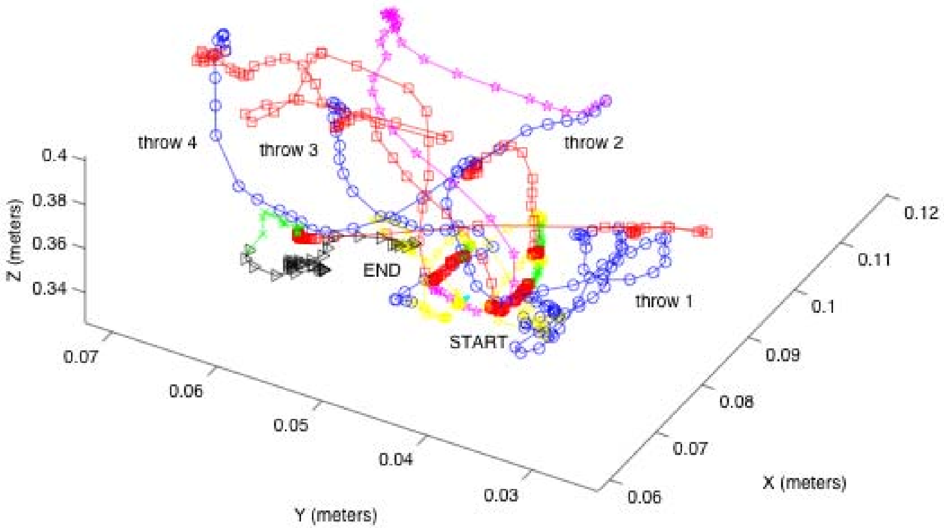


Studies of surgical learning curves require task modeling and human motion recognition

Context Aware Surgical Assistant (CASA)

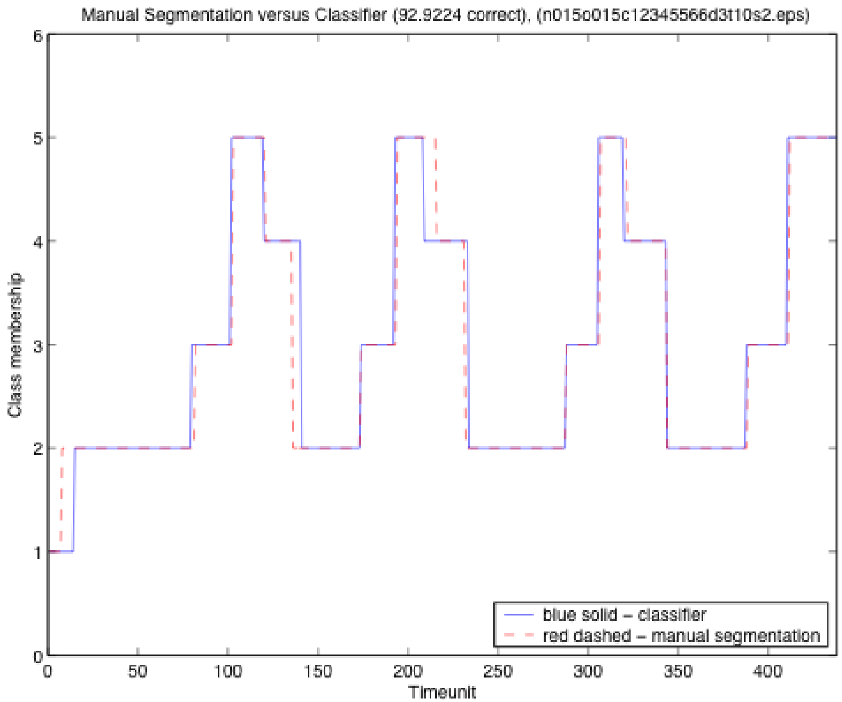
- Develop methods for observing and understanding surgery and surgical technique



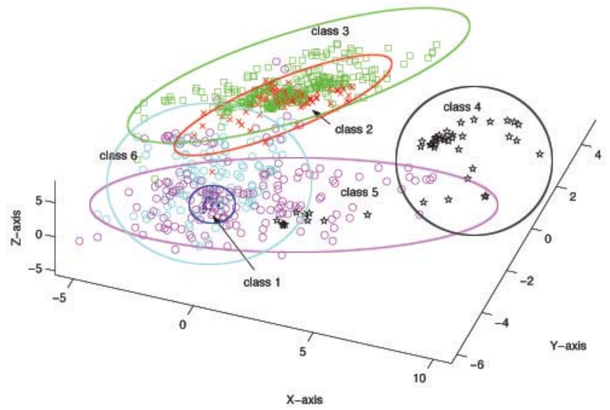


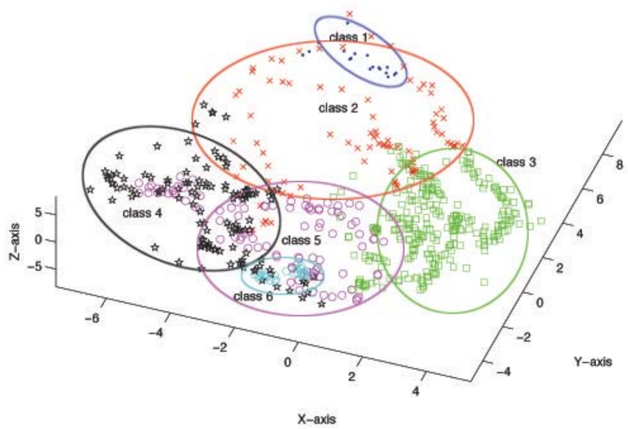
Two examples of a 4-throw suture

Other Views of the Same Data



HMM-based segmentation





LDA Projections

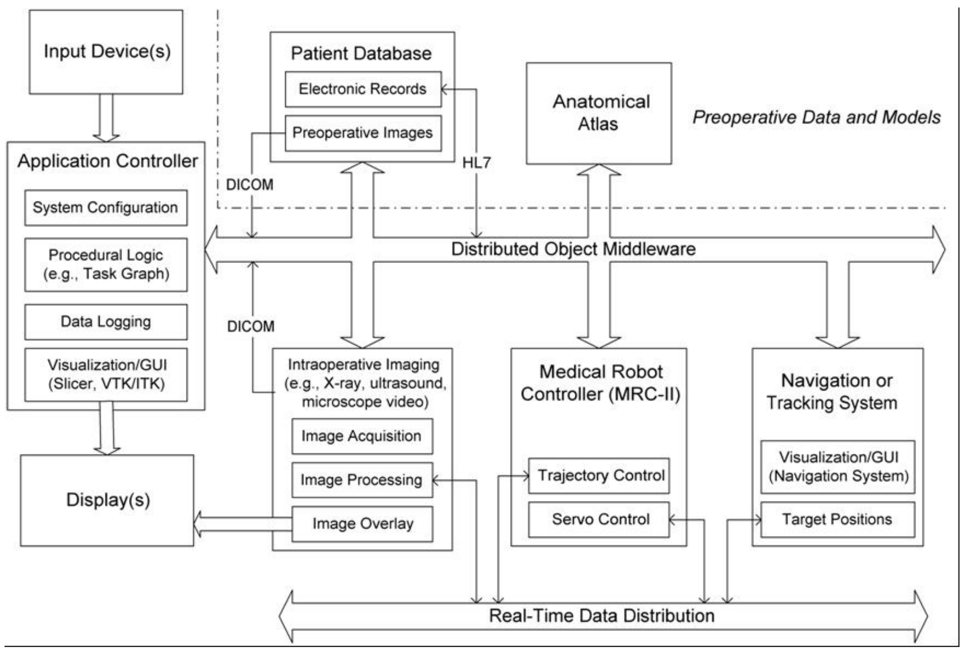
Our Objective: To Observe, Interpret, and Diagnose Surgical Gestures

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

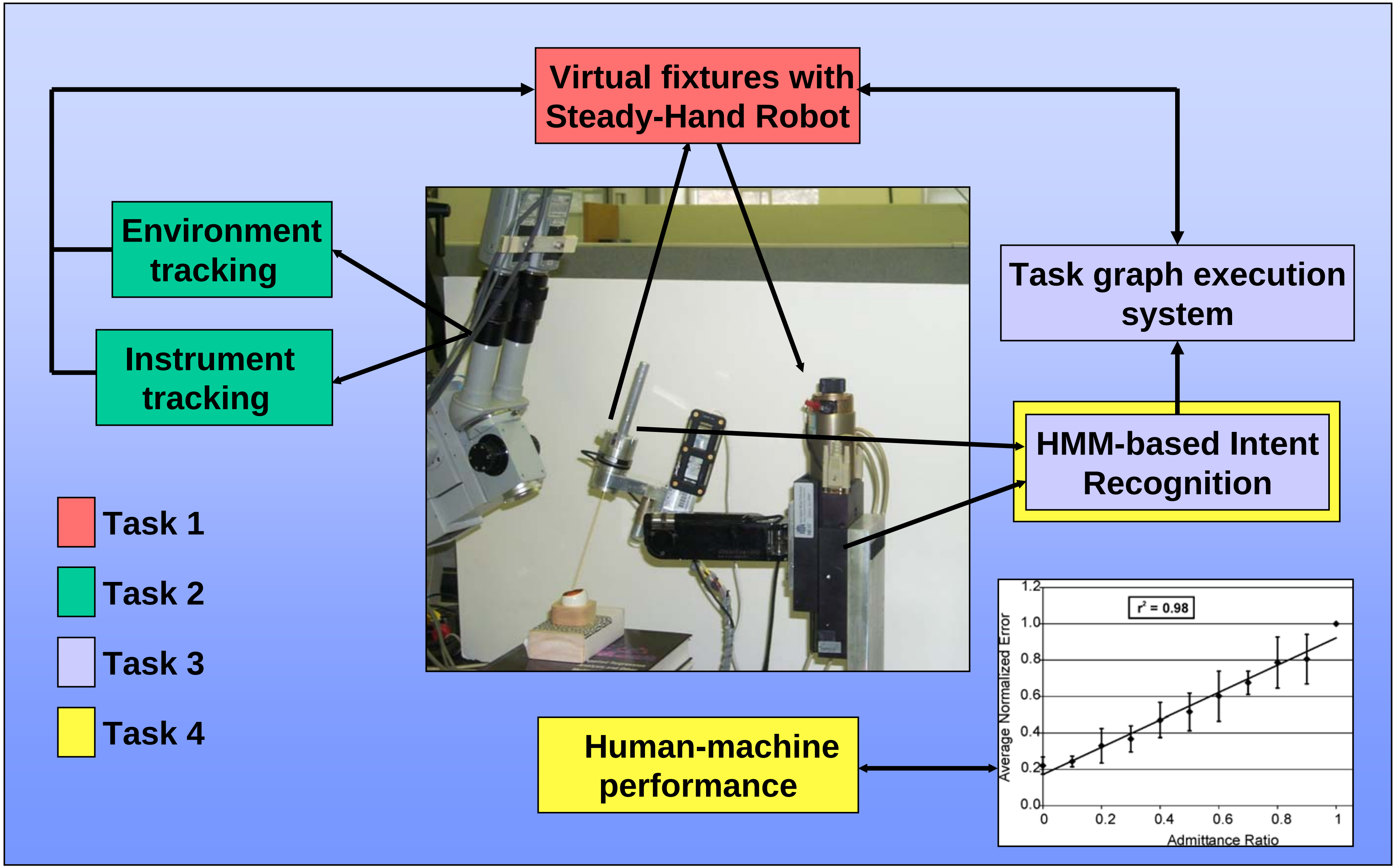
A Final Comment: Systems Science

Core Challenge: Develop architectures, building blocks, and analysis techniques that facilitate rapid development and validation of versatile CIS systems & processes with predictable performance

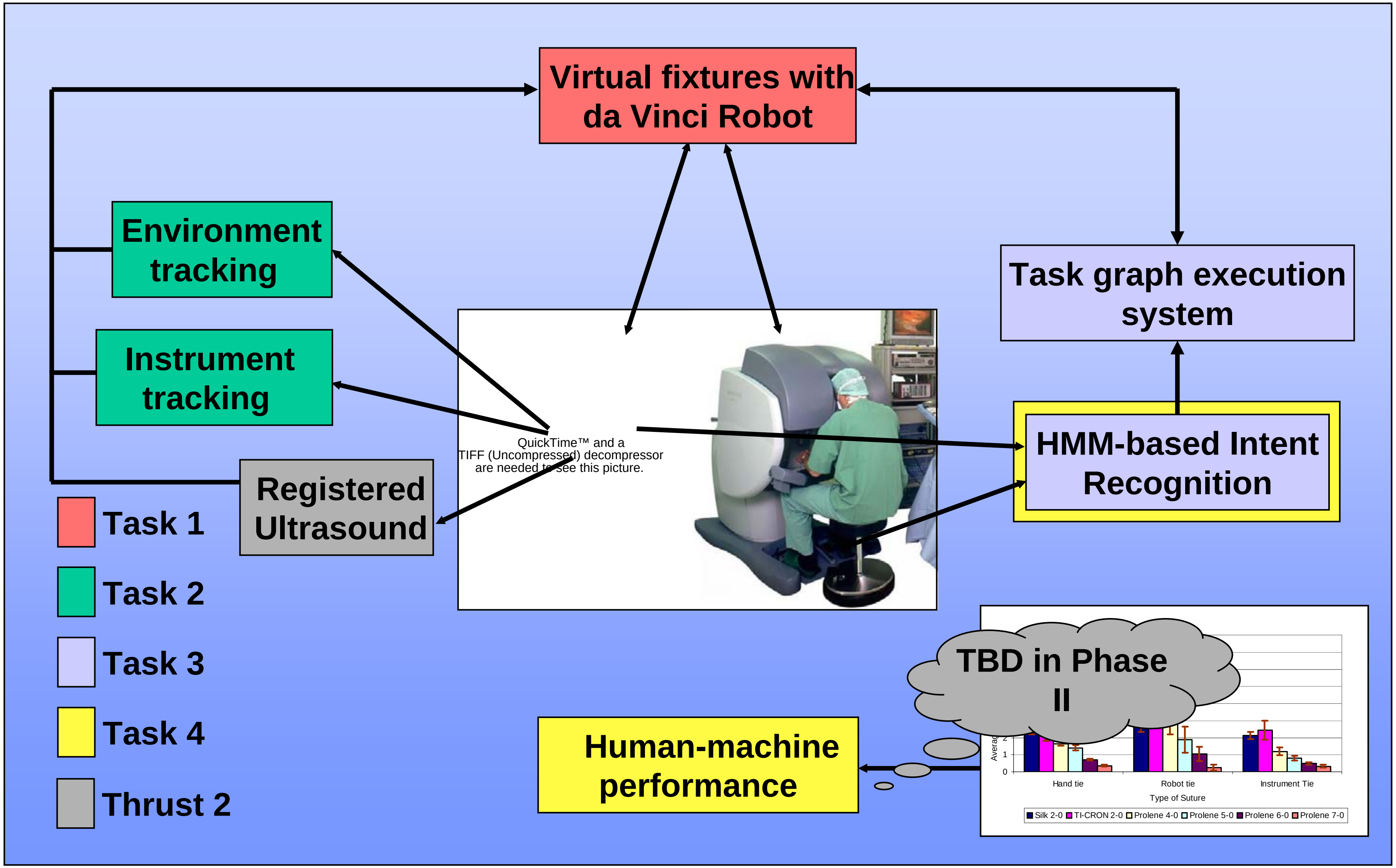
- Modularity & standards
- Robustness & safety
- Customization
- Validation
- Information management



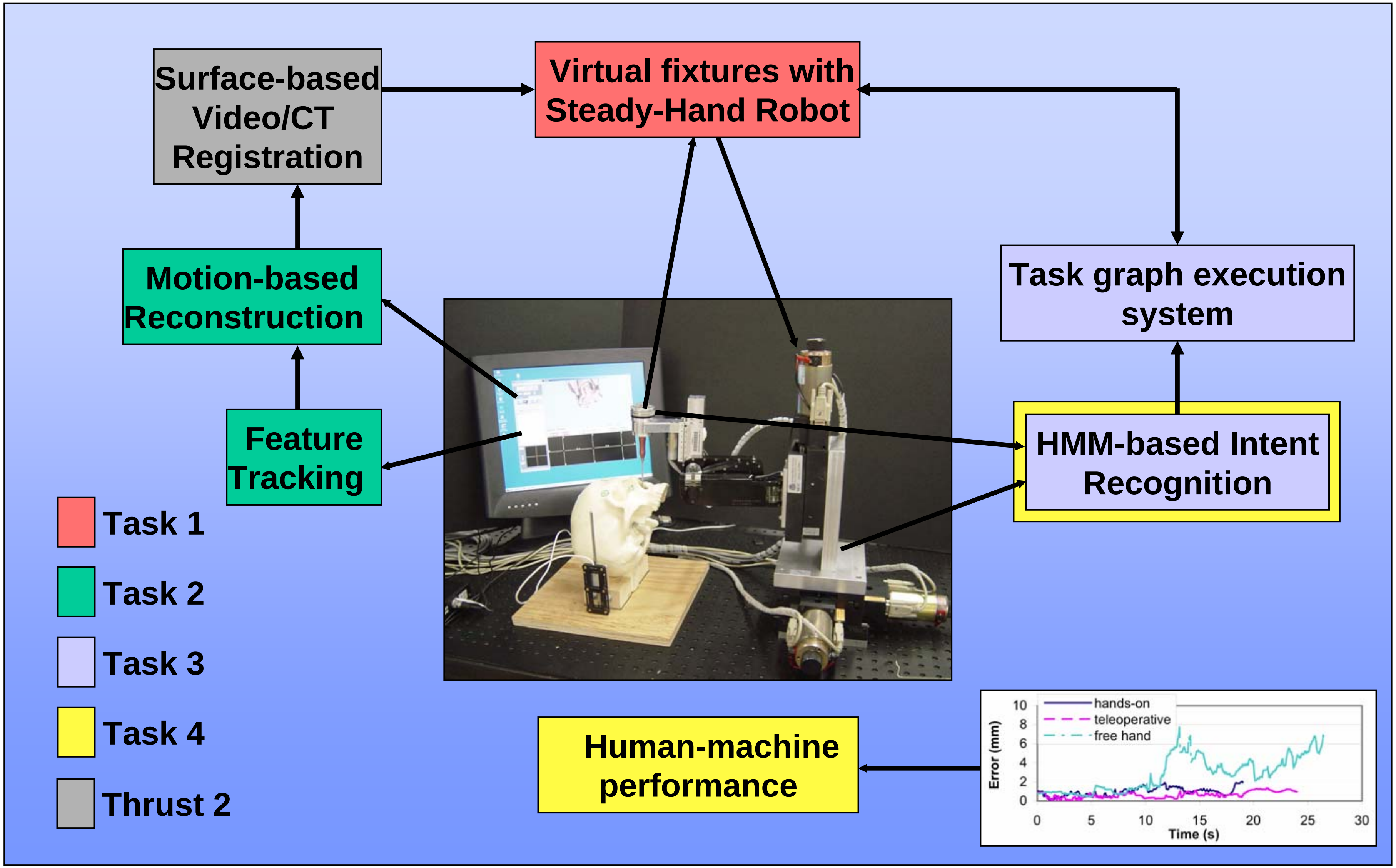
Microsurgical Workstation Architecture



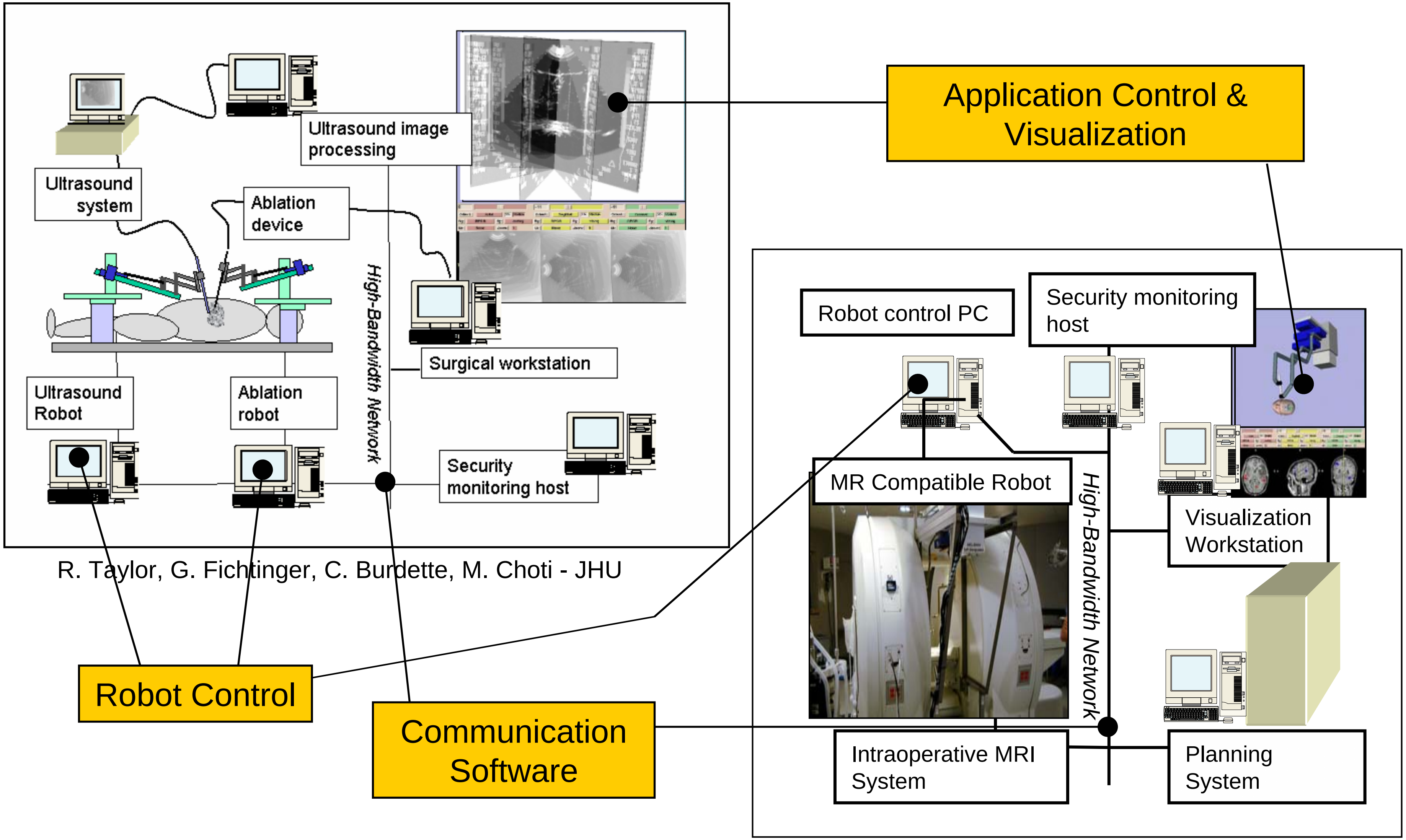
Teleoperation Workstation Architecture



Sinus Surgery Workstation Architecture



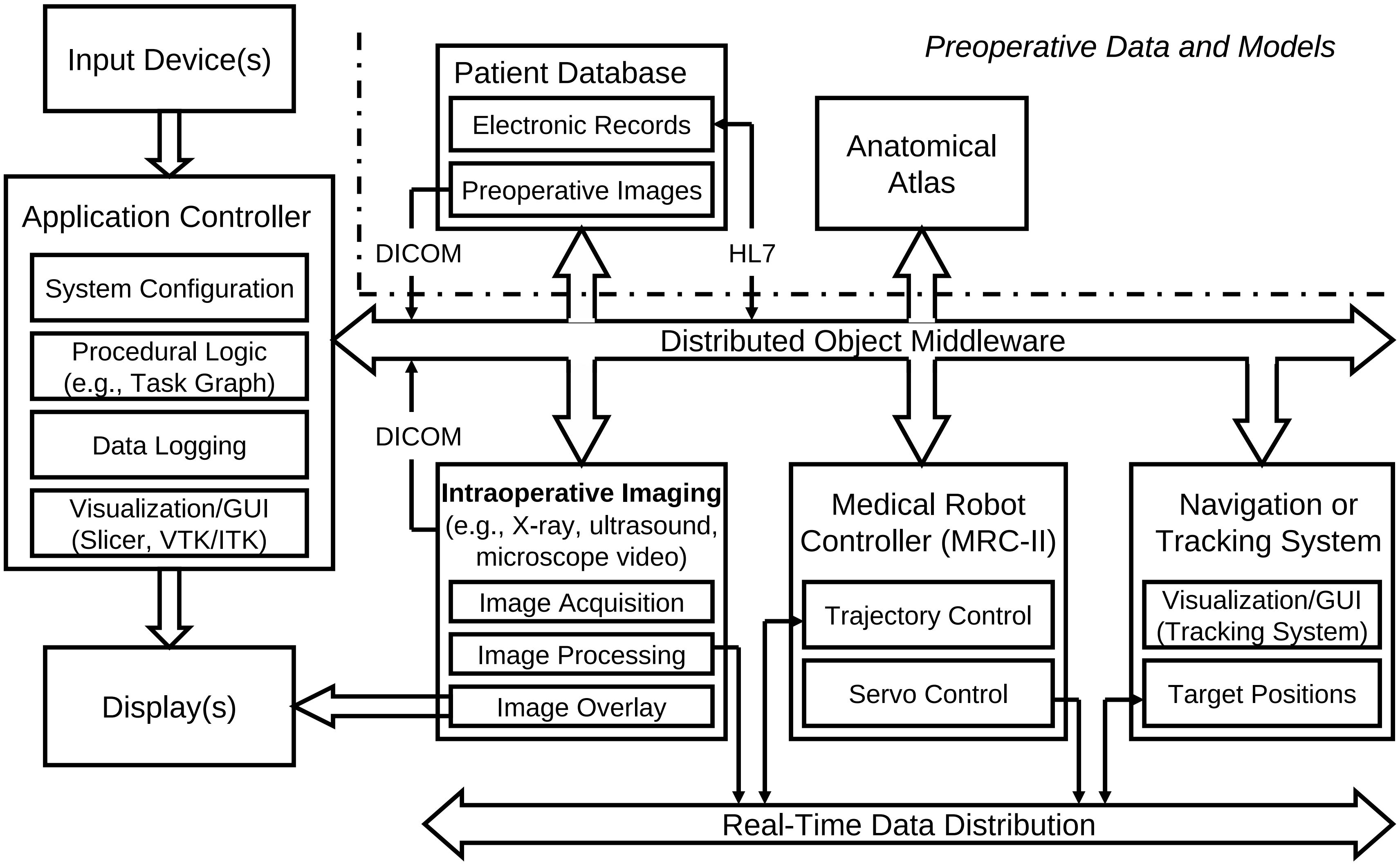
Crucial need: common architecture & infrastructure



R. Taylor, G. Fichtinger, C. Burdette, M. Choti - JHU

Ron Kikinis, Kiyo Chinzei, Clare Tempany - BWH

CISST Architecture (physical view)



Software Development Process

Software Development Plan (SDP)

Software Quality Assurance Plan (SQAP)

Requirements

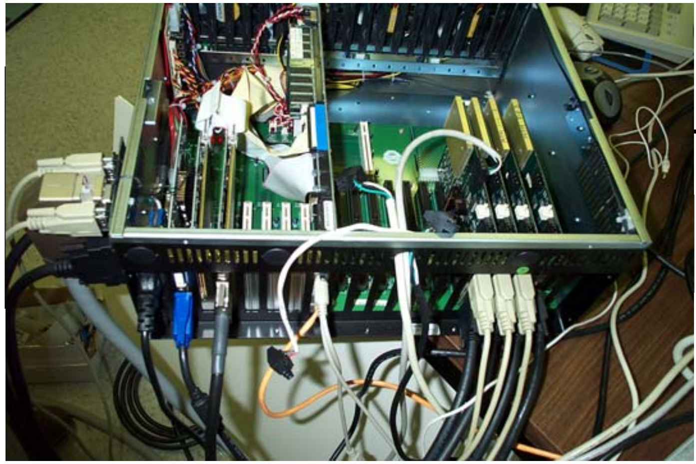
Design

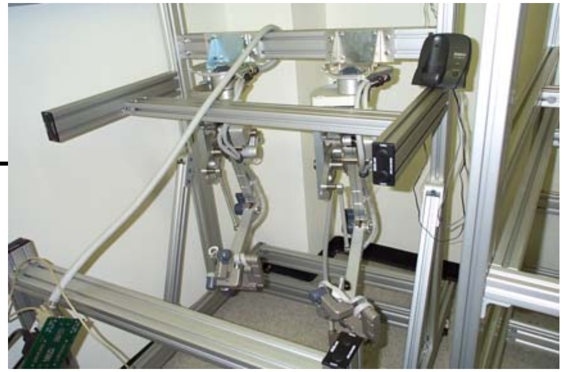
Implementation

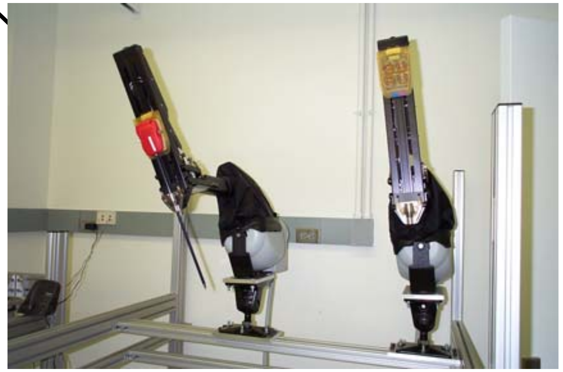
Testing

"ISO 9000 – Lite"

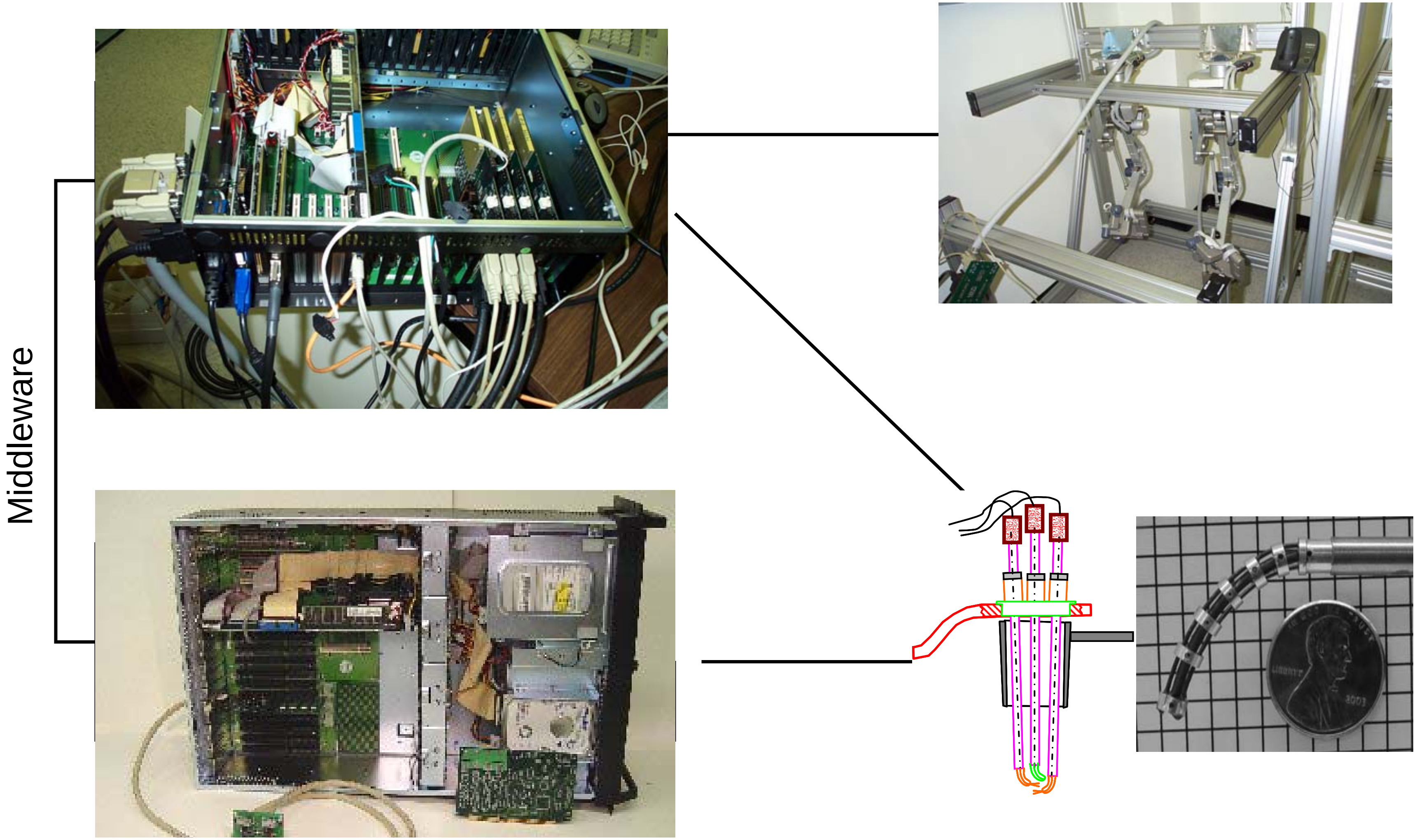
Example: Teleoperation (daVinci)







Example: Teleoperation (Snake)



Example: Image-Guided Robot (Animal Res.)

PC

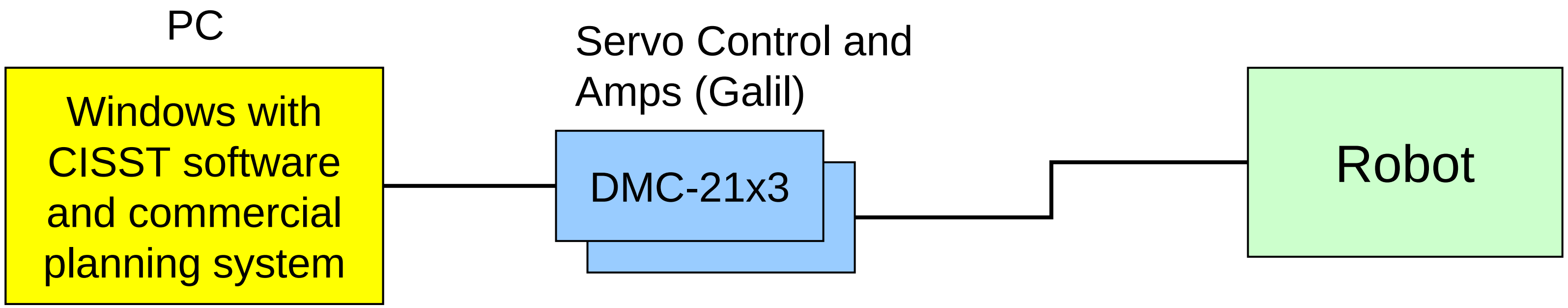
Windows with CISST software and 3D Slicer

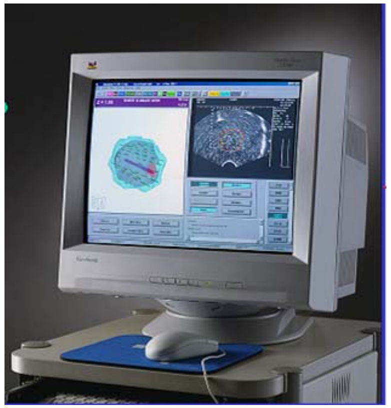
Servo Control and Amps (Galil)

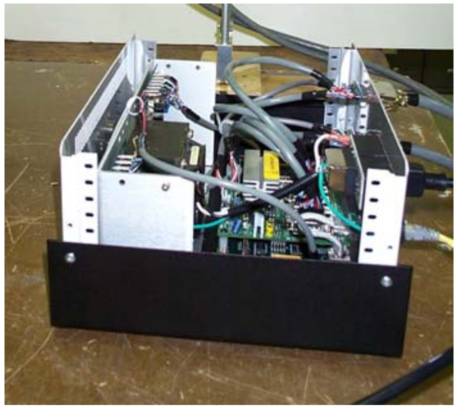
DMC-21x3

Robot

Example: Image-Guided Robot (Prostate)





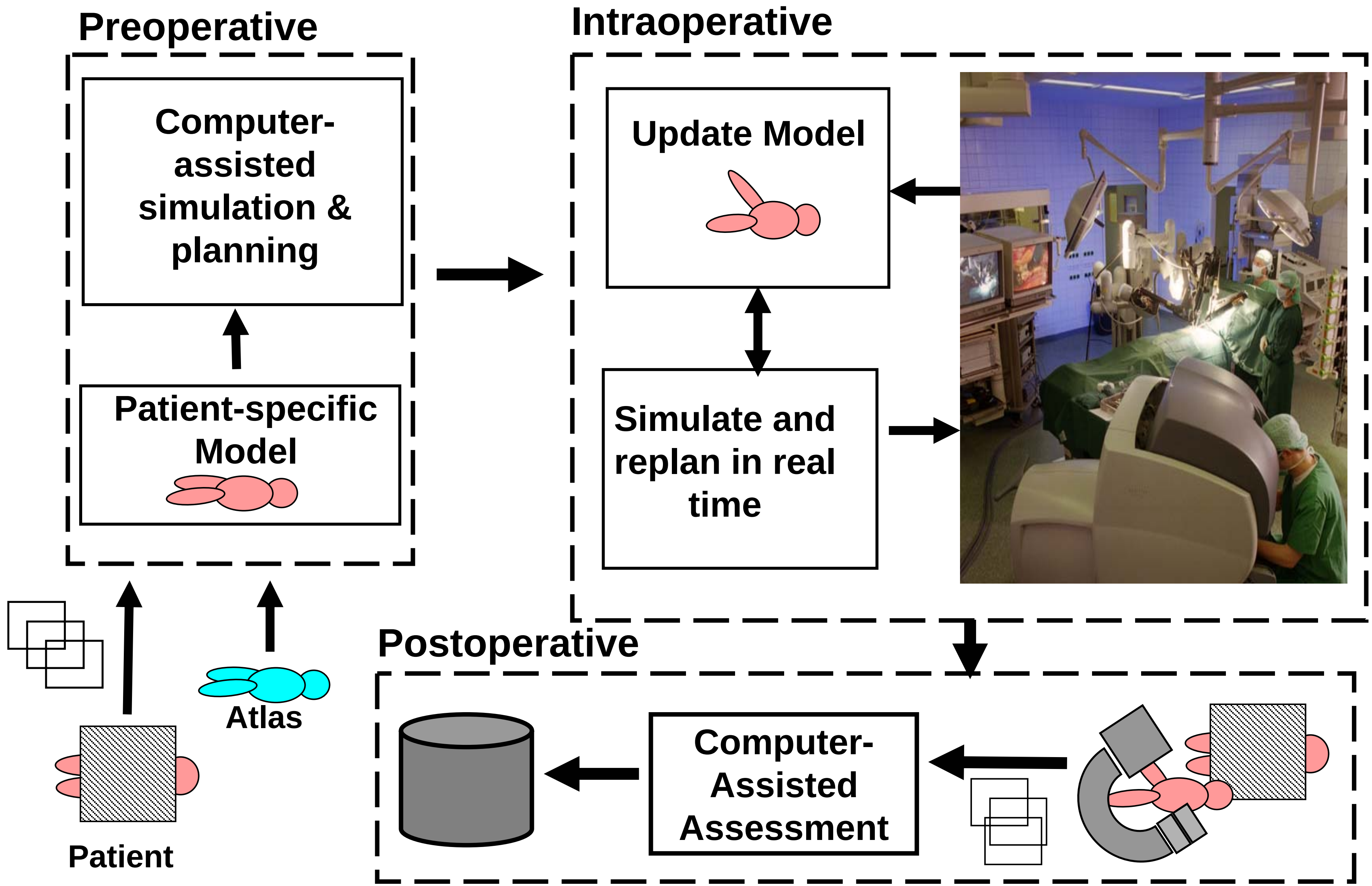


The Big Question

When Will it Happen?

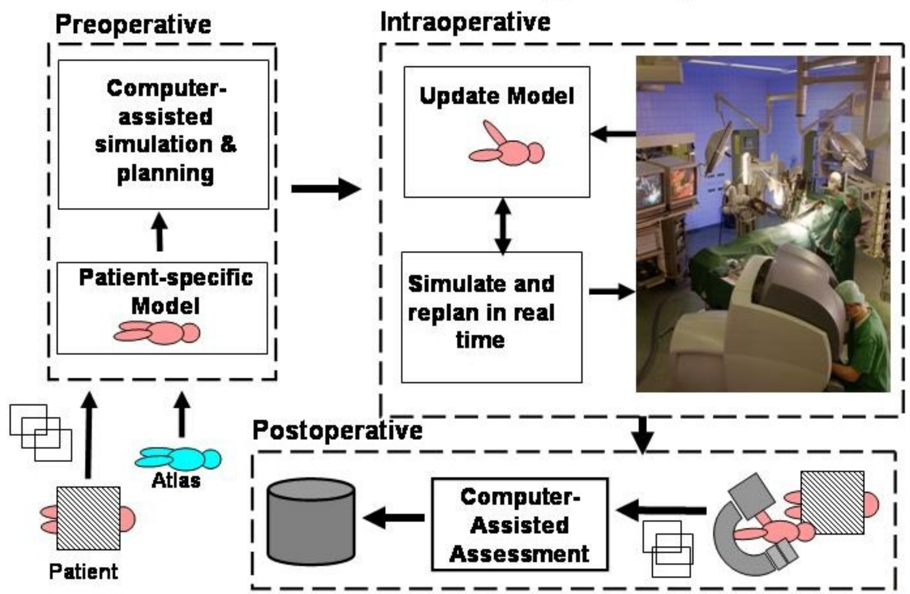
What is the “killer” app?

The Computer-Integrated OR



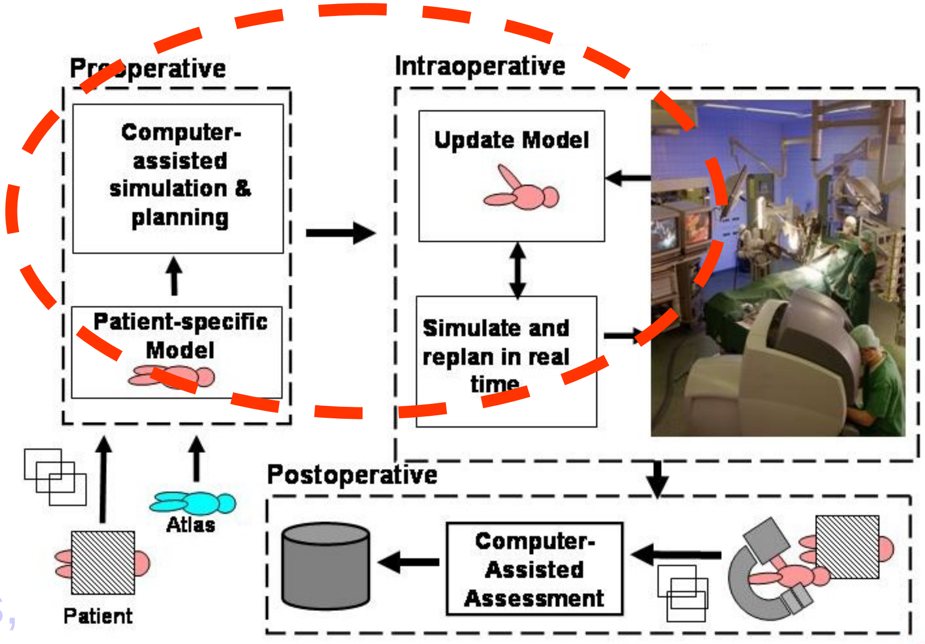
Drivers for Adoption

- **Improved quality**
  - Reduce surgical errors
  - Lower morbidity
  - Greater consistency
- **Enable new interventions**
  - Transcend human limits
  - Minimize invasiveness
  - Process feedback
- **Cost Effectiveness**
  - Supply / workflow control
  - “Do it once”
  - Time



Key elements

- **Comprehensive real time computer models**
  - Patient
  - Surgical task
  - Operating room
- **Computer-driven technology**
  - Robotics, visualization aids
  - Imaging equipment
  - Anesthesia, therapeutic devices, logistics systems
- **Comprehensive information capture and analysis**
  - Error & "near miss" analysis
  - Outcomes & indications
- **Integration with broader hospital information system**



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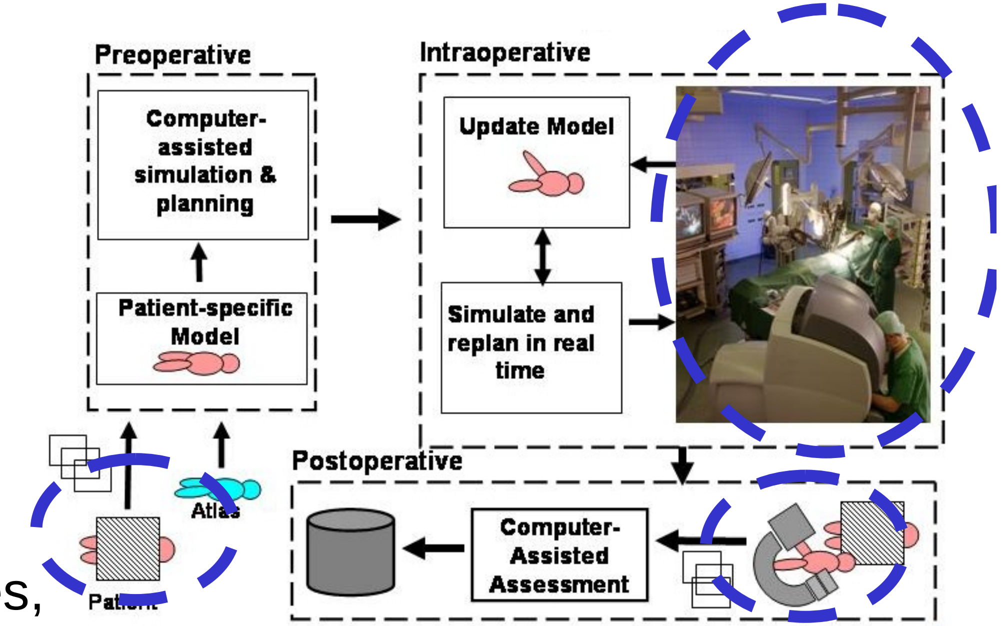

Key elements

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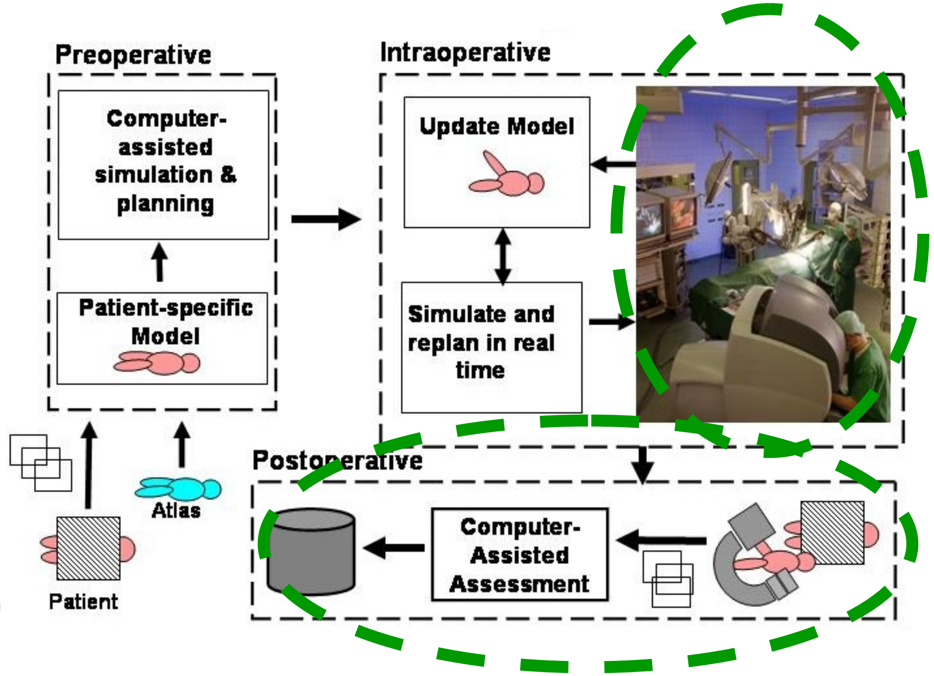

The whole is greater than the sum of parts

- **Comprehensive real time computer models**
  - Patient
  - Surgical task
  - Operating room
- **Computer-driven technology**
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  - Imaging equipment
  - Anesthesia, therapeutic devices, logistics systems
- **Comprehensive information capture and analysis**
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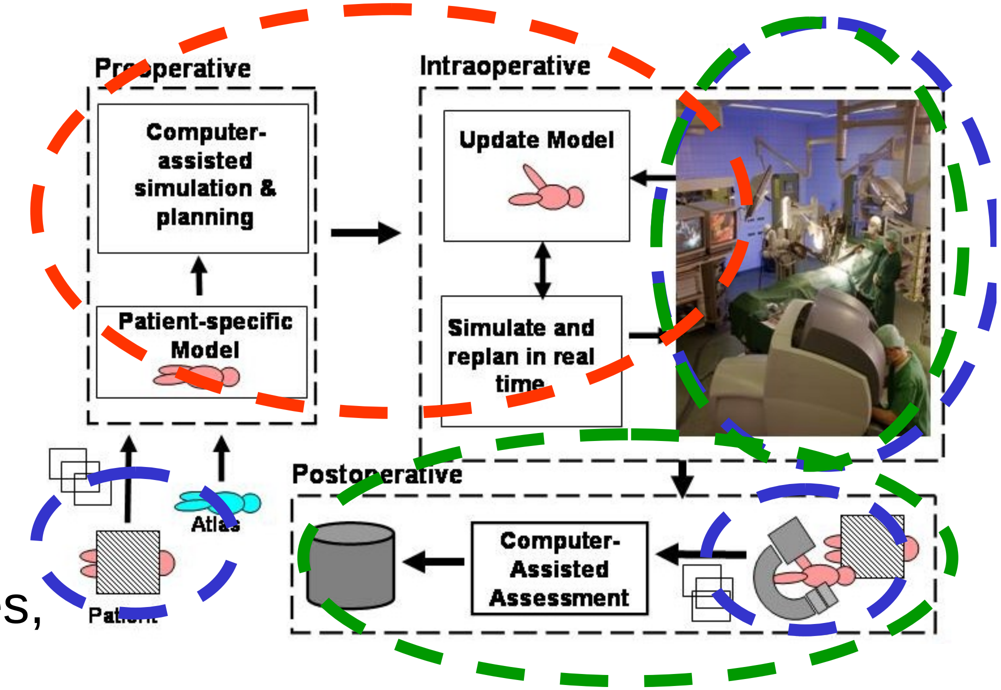

Drivers for adoption

- **Error-free surgery**
  - Designs & systems to make things safer
  - Integration of imaging, computer assistance, etc.
- **Enablers for otherwise infeasible interventions**
  - Superhuman capabilities (access, precision, …)
  - Delivery systems for novel image-guided therapies
- **Enablers for research & development**
  - Consistency, capability & data gathering
- **Capture of information about cases**
- **Use of robots as training tools**
  - Mentoring
  - Simulation integrated with robotics

* From Turf Valley Workshop (March 2003)

“Six Sigma Surgery”

- Goal: Eliminate errors in interventional medicine.
  - 44,000-98,000 hospital patients die each year as a result of errors (*Institute of Medicine, Dec. 1999)*
  - *Over 50% of “should never happen” events are surgery related (Minnesota Report on Adverse Health Events, Jan. 2005).*
  - *What actually happens in the OR is poorly documented and variations in surgical technique are not well controlled in outcome studies*
- *Significant attention from Congress, DoD, NIH, …*
- *Solution inherently requires systems approach integrating process information management, human factors, technology.*

Suggested Approaches to OR Safety
Stephen Schimpff, MD*

- **HUMAN FACTORS**
  - LEADERSHIP
  - MANAGEMENT
  - TEAMWORK
  - COMMUNICATION
  - TRAINING
  - INFORMATION TRANSFER
  - MANDATES

- **TECHNOLOGY**
  - INFORMATION SYSTEMS
  - IDENTIFICATION DEVICES
  - VIDEO
  - SIMULATORS
  - ROBOTICS

** Former CEO of U. Md. Hospital, presentation based on study on OR patient safety commissioned by TATRC*

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Human factors and technology are synergistic elements of any comprehensive approach!

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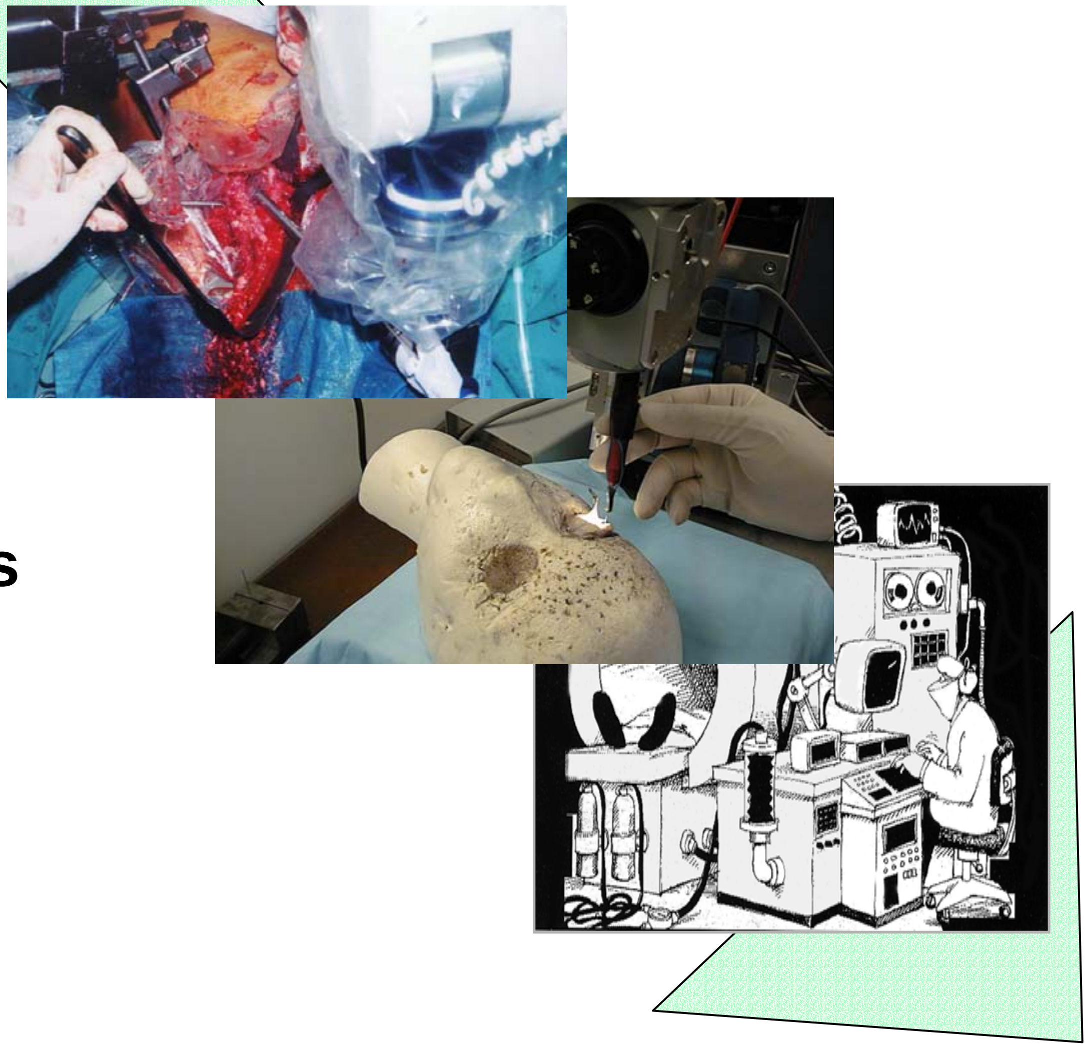
How can we get there?

Strong and committed teams
- Surgeons
- Engineers
- Industry



Focus on systems that address important needs

Rapid iteration with measurable goals

Have fun!

The real bottom line: patient care

- Increase **consistency and quality** of surgical treatments
- Provide new capabilities that **transcend human limitations** in surgery
- Promote **better outcomes** and more **cost-effective** processes in surgical practice