NSF Engineering Research Center
for Computer Integrated Surgical
Systems and Technology

Computer-Integrated Interventional Medicine:

Integrating Imaging, Intervention, and Informatics to Improve Patient Care

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WHITING SCHOOL OF ENGINEERING
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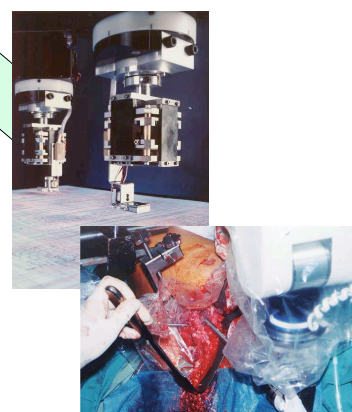
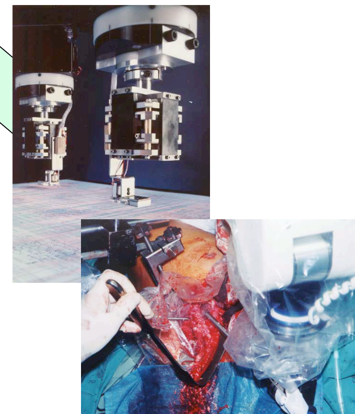
Prediction

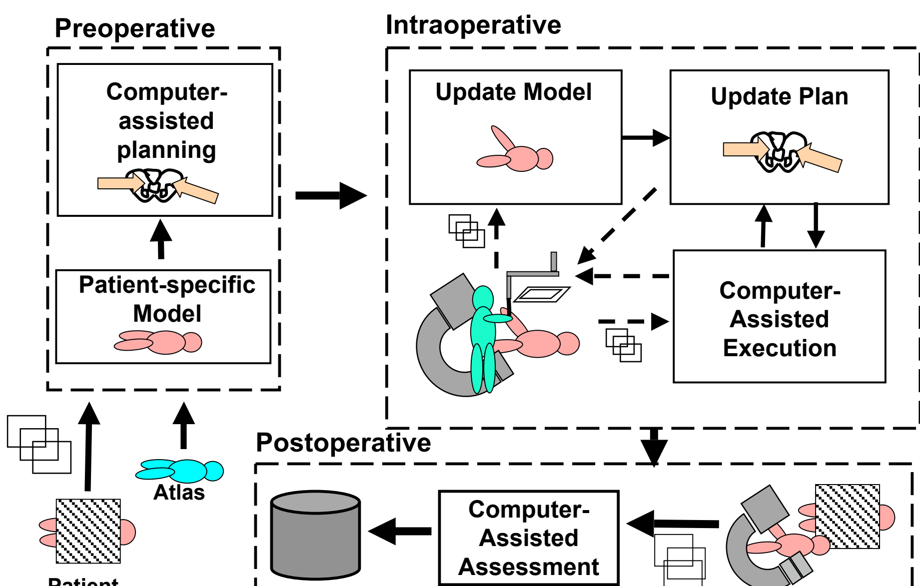
A partnership between human clinicians and computer-based technology will fundamentally change the way surgery and interventional medicine is performed in the 21st Century, in much the same way that computer-based technology changed manufacturing in the 20th Century

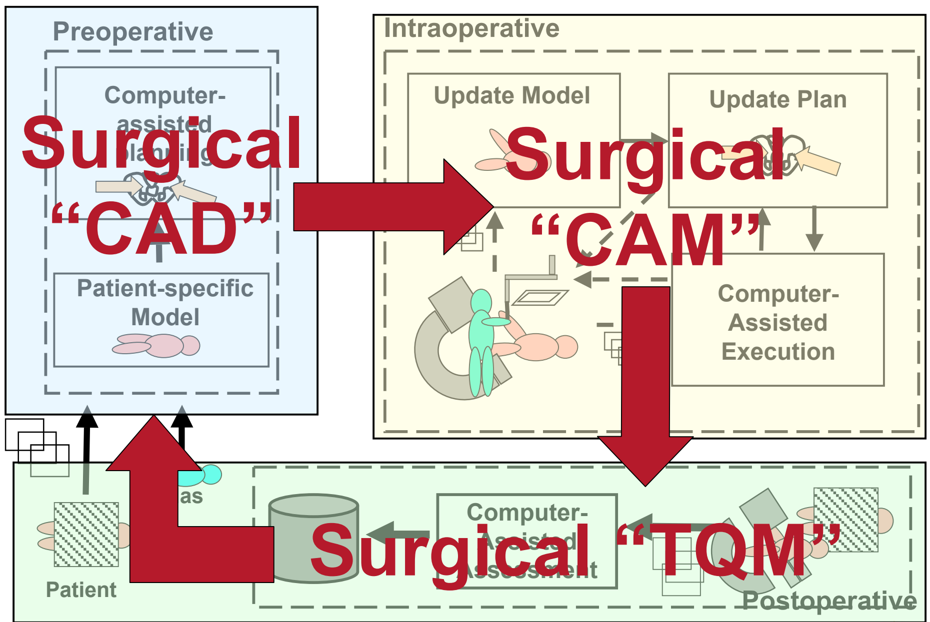


What will drive this change?

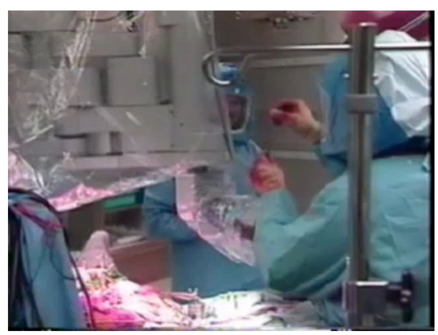
- New capabilities that **transcend human limitations** in surgery
- Increased **consistency and quality** of surgical treatments
- **Better outcomes** and more **cost-effective** processes in surgical practice

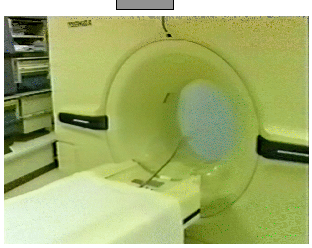


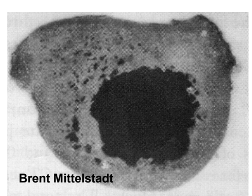




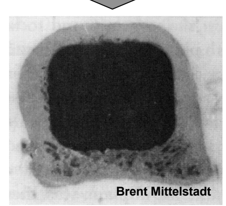
Example: Robotic Joint Replacement Surgery







Manual Surgery



Robotic Surgery

Taylor, Kazanzides, Paul, Mittelstadt, *et al.*

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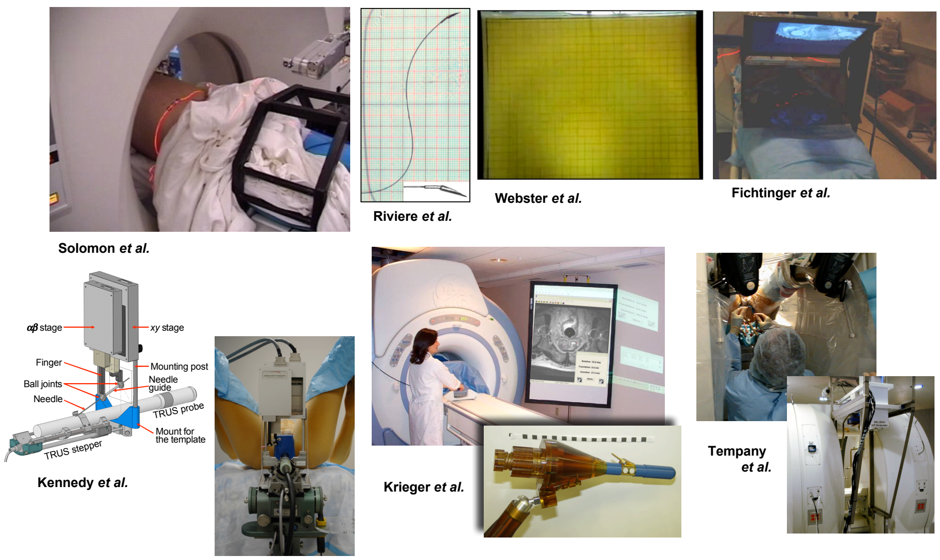
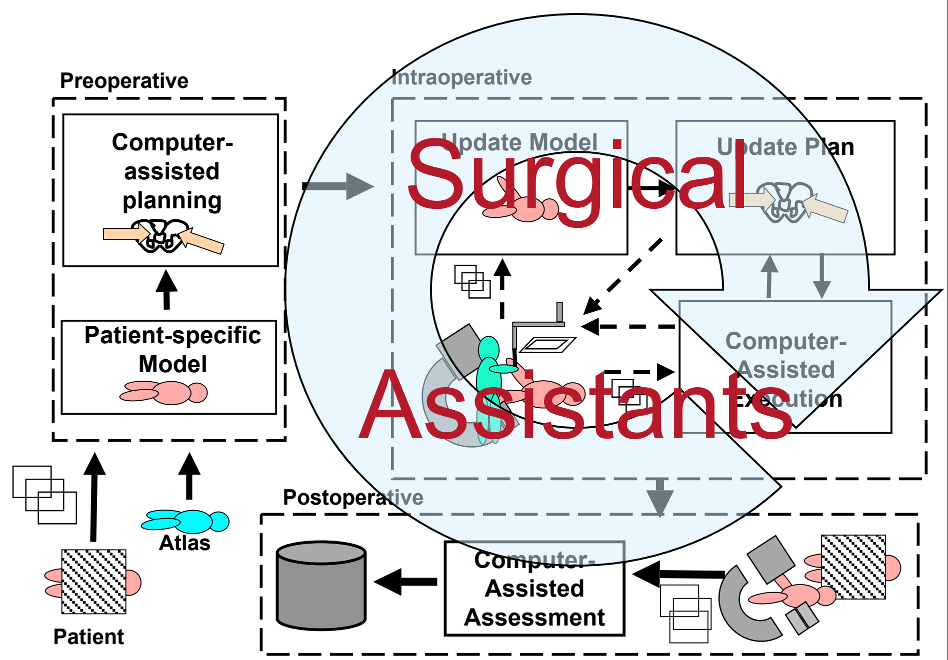
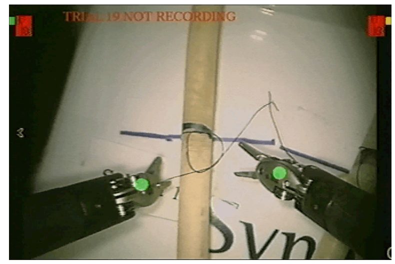
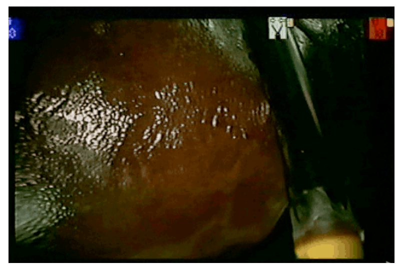
Example: In-imager Needle Placement





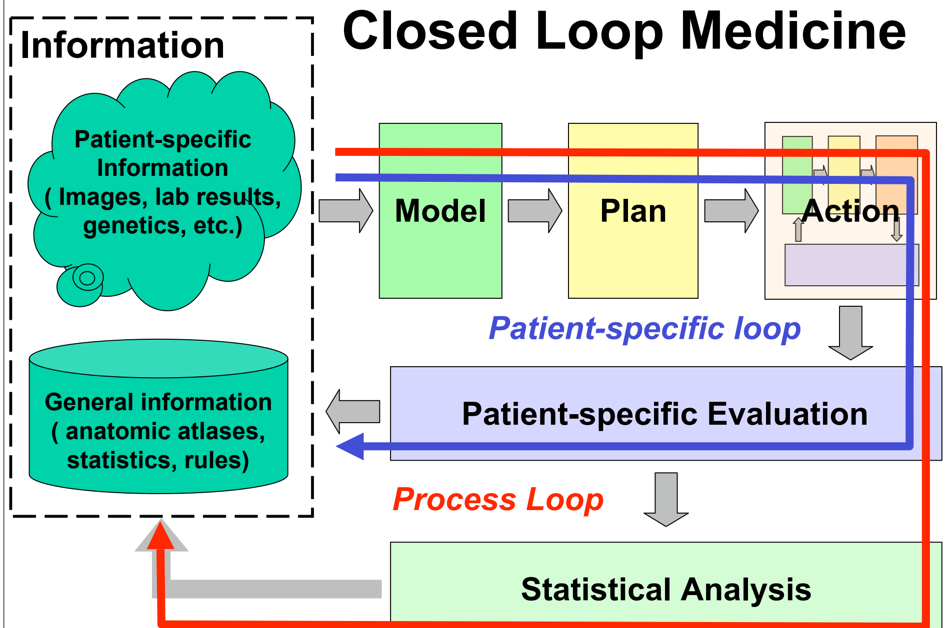
Example: Augmented Reality in Robot-Assisted Surgical Systems





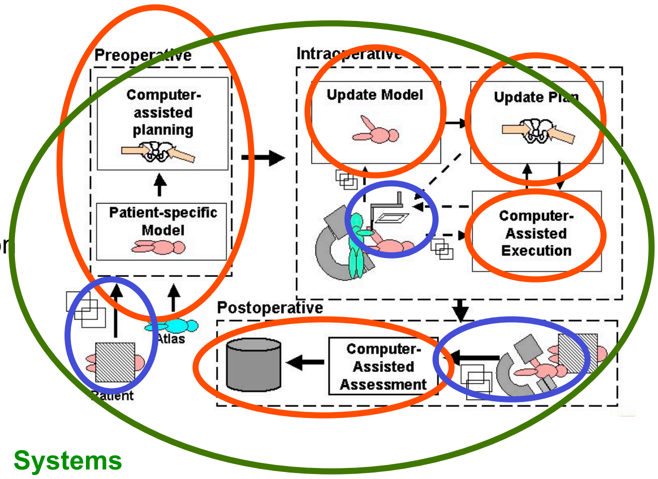
Clockwise from upper left: daVinci surgical robot; Information overlay of force information on daVinci display (Okamura *et al.);* Real time overlay of ultrasound images on daVinci display (Taylor *et al.*)

Closed Loop Medicine



Multidisciplinary Integration is Crucial

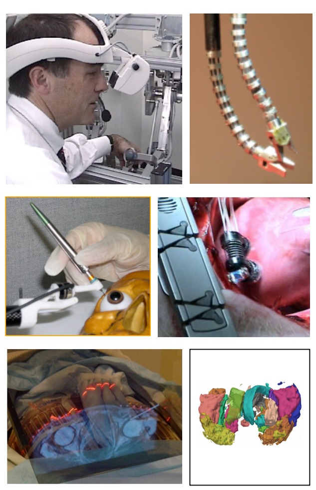
Modeling & analysis
- Segmentation
- Registration
- Atlases
- Optimization
- Visualization
- Task characterization
- *etc.*



Interface Technology
- Sensing
- Robotics
- Human-machine interfaces

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

Engineering Research Center for Computer Integrated Surgical Systems and Technology (CISST ERC)



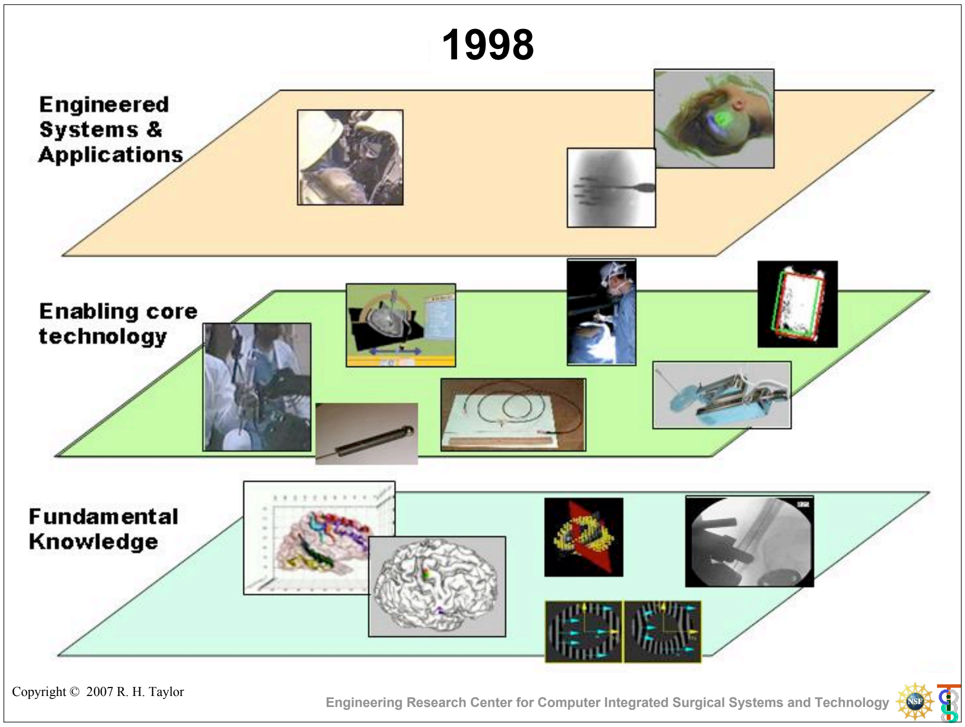
cisstweb.cs.jhu.edu

The CISST ERC is developing a family of surgical systems that combine innovative algorithms, robotic devices, imaging systems, sensors, and human-machine interfaces to work cooperatively with surgeons in the planning and execution of surgical procedures.

Areas of Research

- Robotic surgical assistants
- Image-guided interventional systems
- Focused interdisciplinary research in algorithms, imaging, robotics, sensors, human-machine systems

Institutions
- Johns Hopkins, MIT, CMU, BWH, Harvard, Penn, Morgan State, Columbia


1998
Engineered Systems & Applications
Enabling core technology
Fundamental Knowledge
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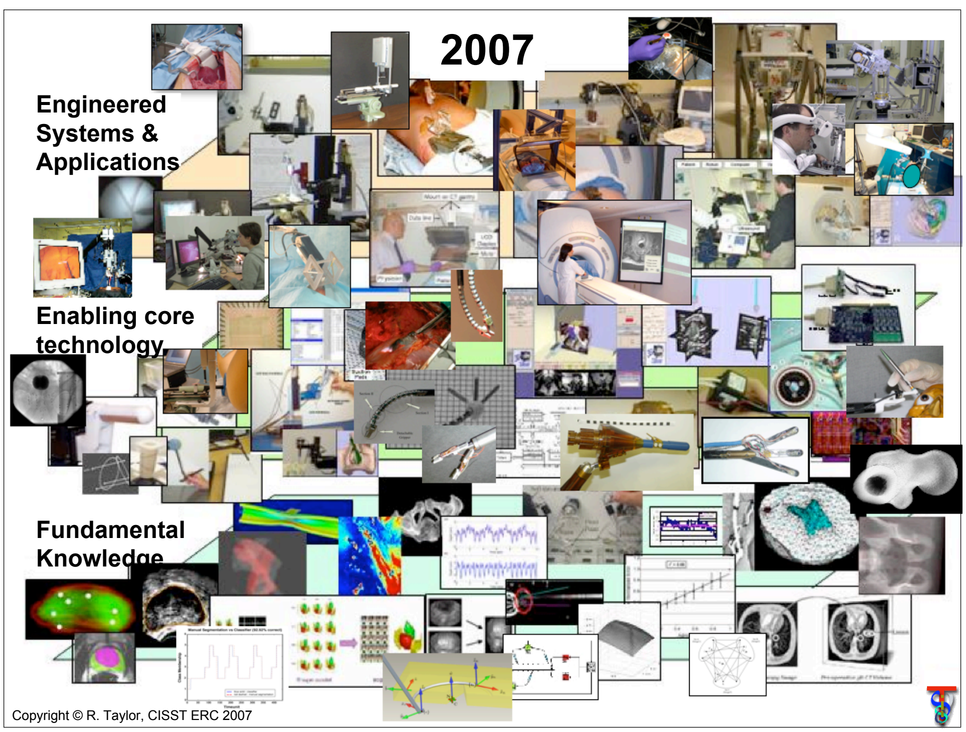
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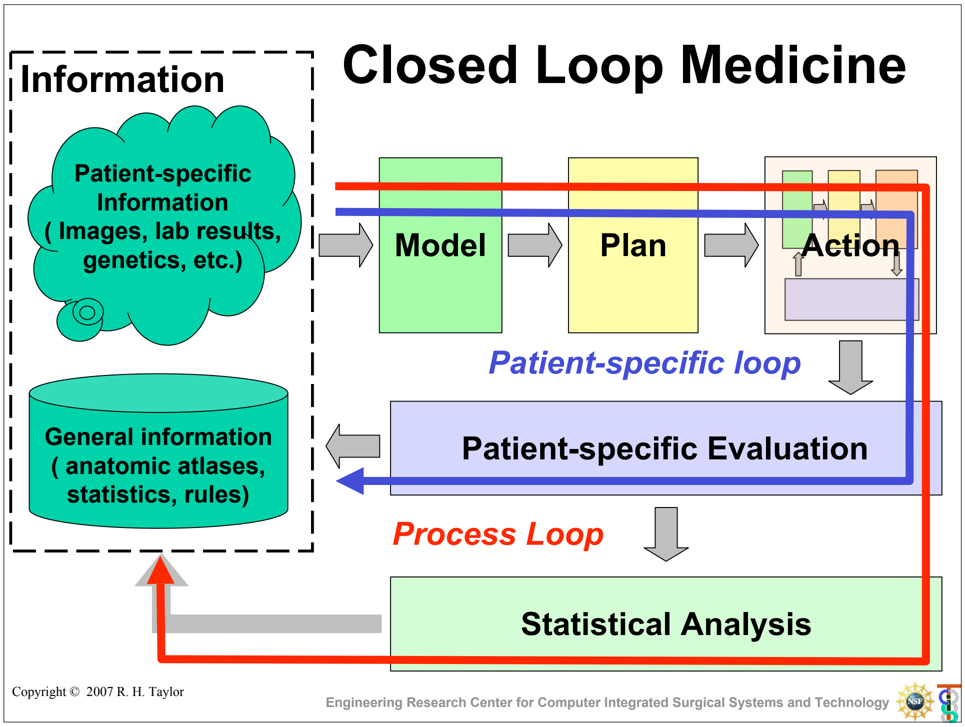
Closed Loop Medicine
Information
Patient-specific Information (Images, lab results, genetics, etc.)
General information (anatomic atlases, statistics, rules)
Model
Plan
Action
Patient-specific loop
Patient-specific Evaluation
Process Loop
Statistical Analysis
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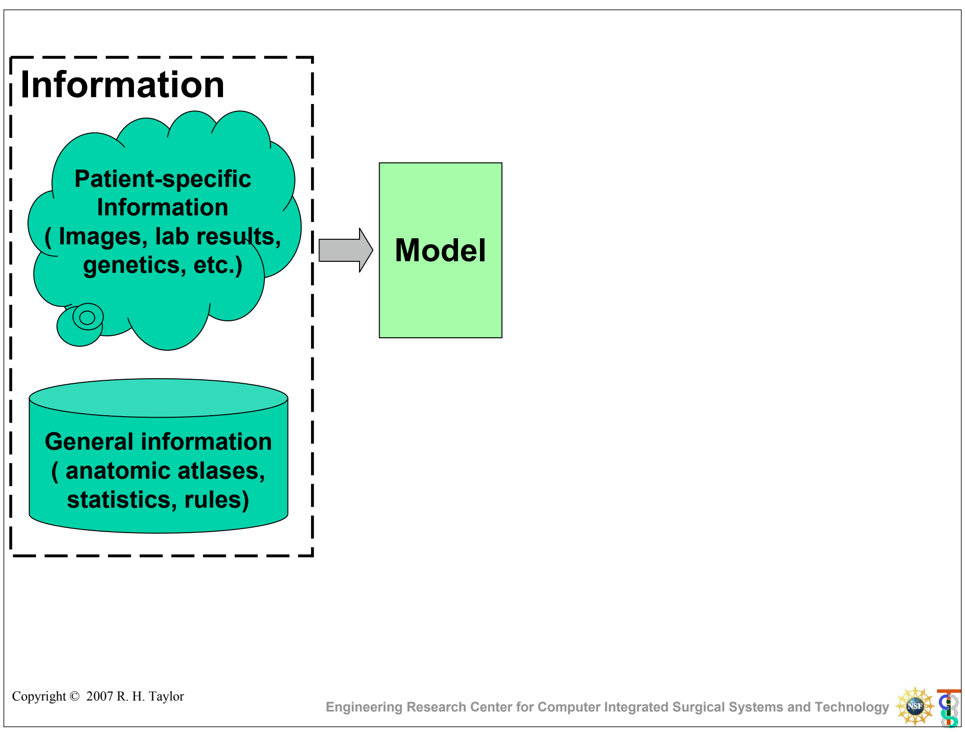
Information
Patient-specific Information (Images, lab results, genetics, etc.)
General information (anatomic atlases, statistics, rules)
Model
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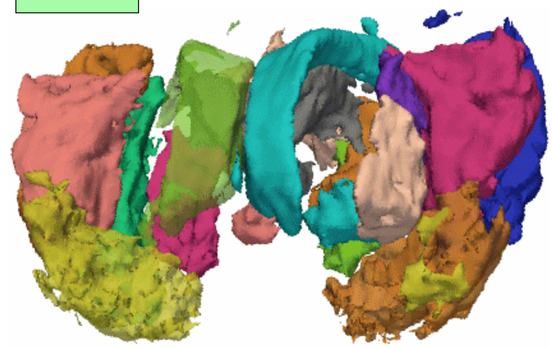
Engineering Research Center for Computer Integrated Surgical Systems and Technology

Information

Patient-specific Information (Images, lab results, genetics, etc.)

General information (anatomic atlases, statistics, rules)

→ **Model**



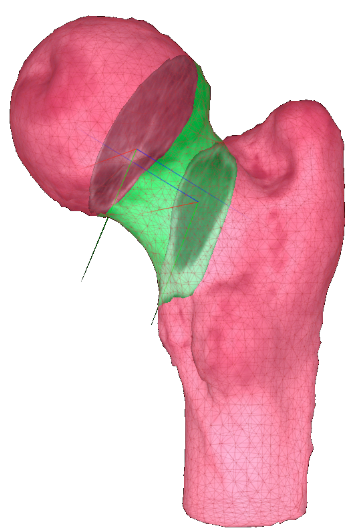
Killian, Pohl, Timoner, …

Information

Patient-specific Information (Images, lab results, genetics, etc.)

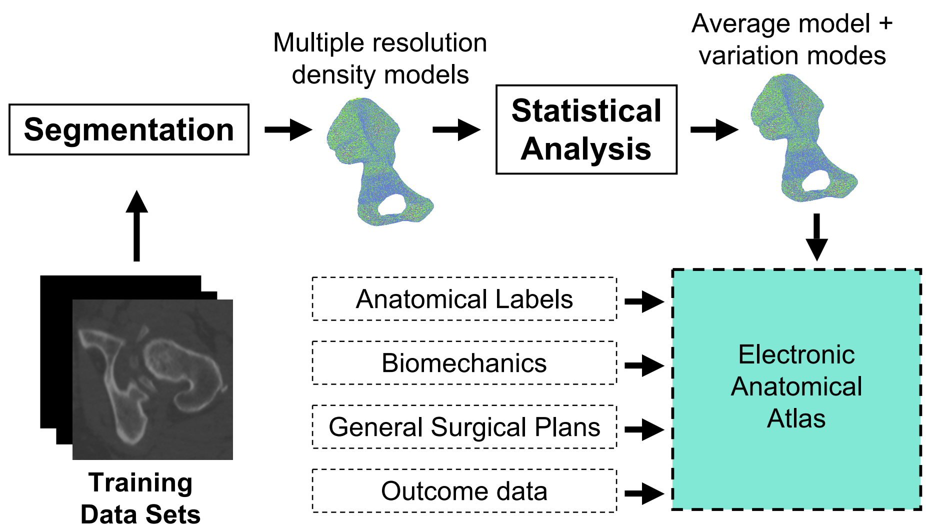
General information (anatomic atlases, statistics, rules)

→ **Model**



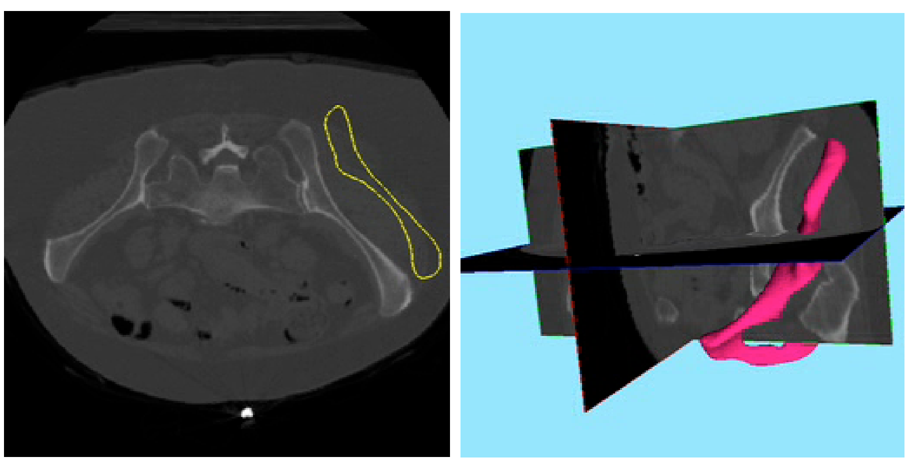
Model rendering: O. Ahmad

Statistical Atlases of Patient Anatomy

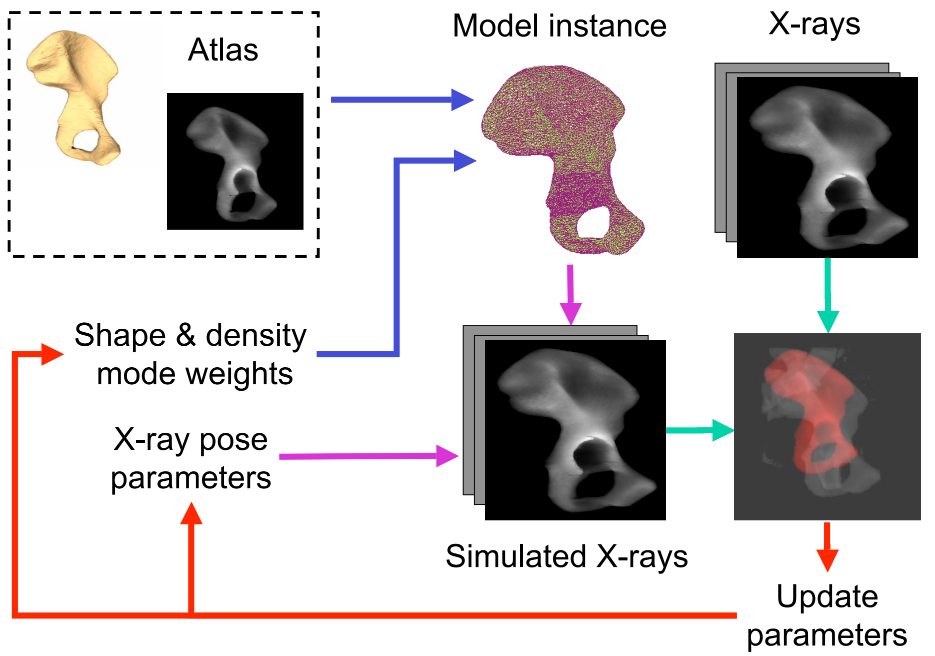


R. Taylor & J. Yao

Deformable Atlas-to-CT Registration (3D-3D)

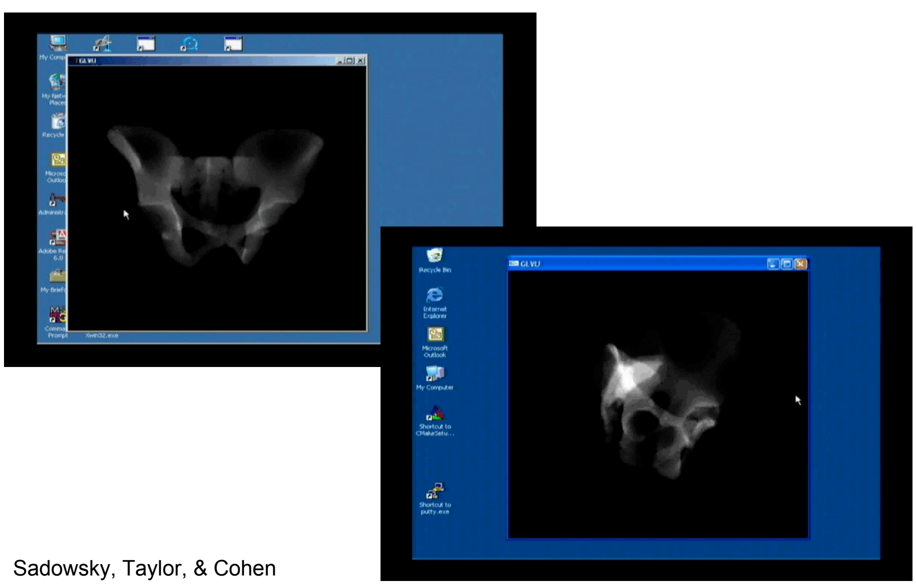


Jianhua Yao



R. Taylor & J. Yao

Fast simulated x-rays from deforming model



Sadowsky, Taylor, & Cohen

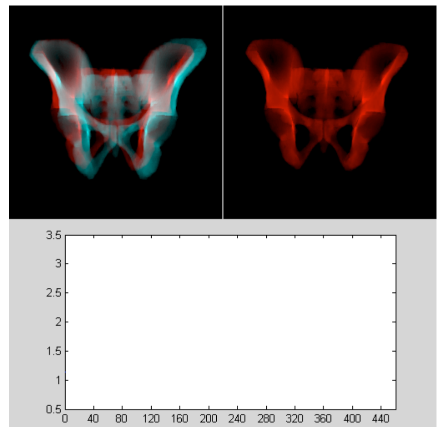
Example: 3D model of patient's pelvis from three 2D x-ray images and prior statistical atlas

Information

Patient-specific Information (Images, lab results, genetics, etc.)

General information (anatomic atlases, statistics, rules)

Model



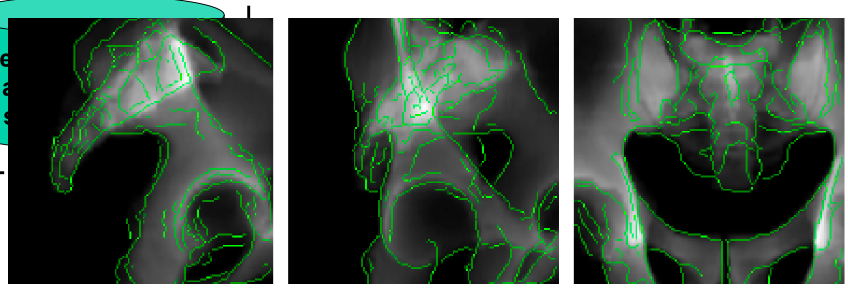
O. Sadowsky, J. Yao, R. Taylor

Example: 3D model of patient's pelvis from limited field of view x-ray images and atlas

Information

Patient-specific Information (Images, lab results, genetics, etc.)

Model



O. Sadowsky, R. Taylor

Example: 2D-3D Reconstruction from 3 DEXA Images+Atlas

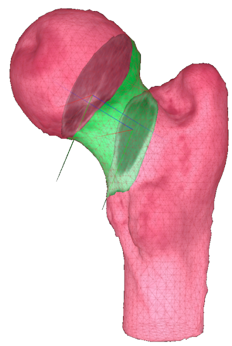
Information

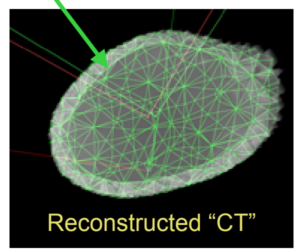
Patient-specific Information (Images, lab results, genetics, etc.)

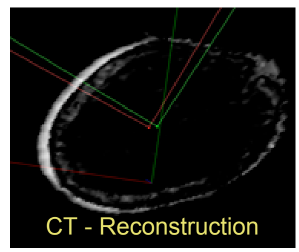
General information (anatomic atlases, statistics, rules)

Model

Reconstructed Mesh (Green)

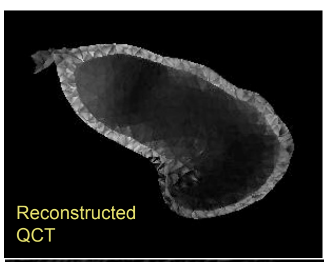


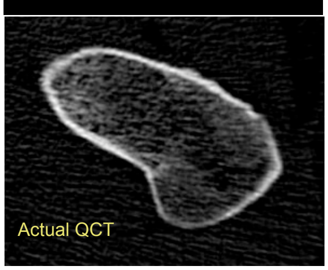


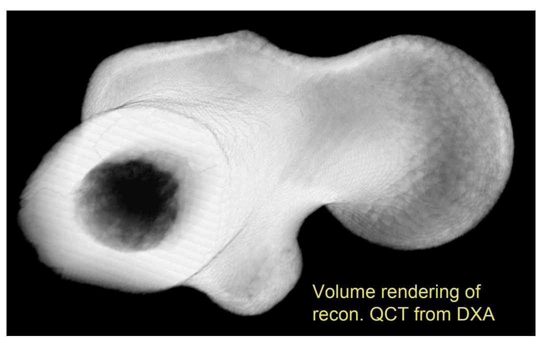


JHU: Omar Ahmad, Ofri Sadowsky, Russell Taylor
U. Erlangen: Klaus Engelke
BIDMC, Boston: Mary Bouxsein
Inst. of Aging Research, Boston: David Karasik
Hologic, Inc.: Krishna Ramamurthi, Kevin Wilson

Results







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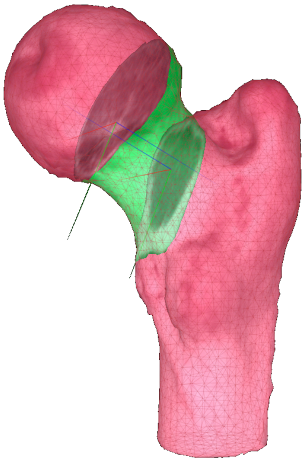
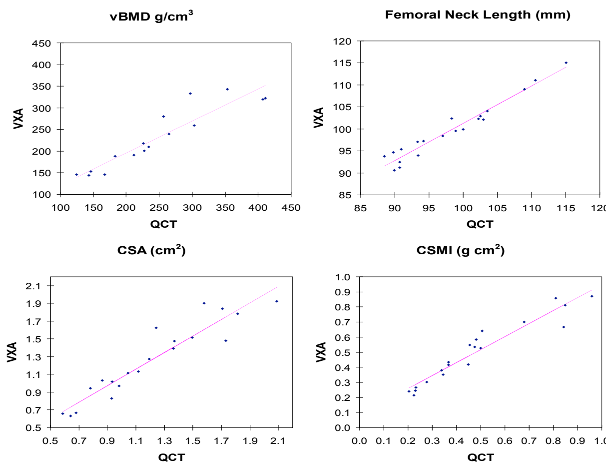
Comparison VXA to QCT





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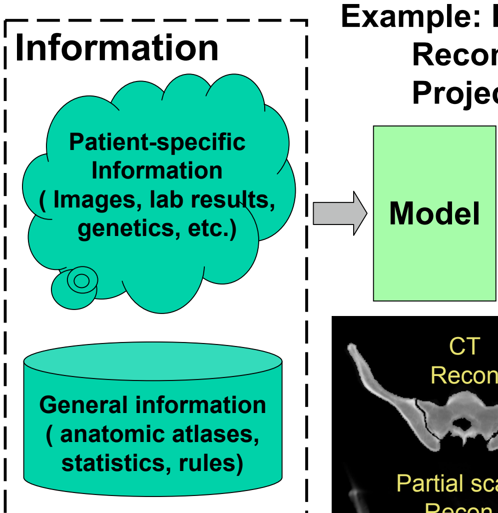
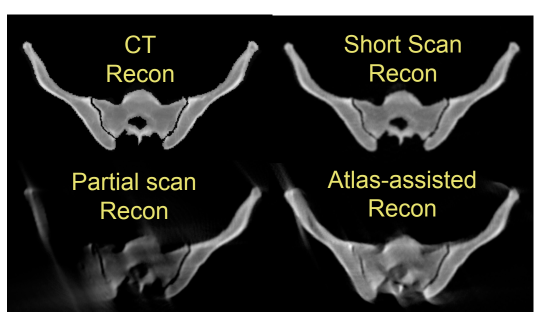
BIDMC, Boston: Mary Bouxsein
Inst. of Aging Research, Boston: David Karasik
Hologic, Inc.: Krishna Ramamurthi, Kevin Wilson

Example: Hybrid Cone Beam Reconstruction from Incomplete Projection data & Atlas

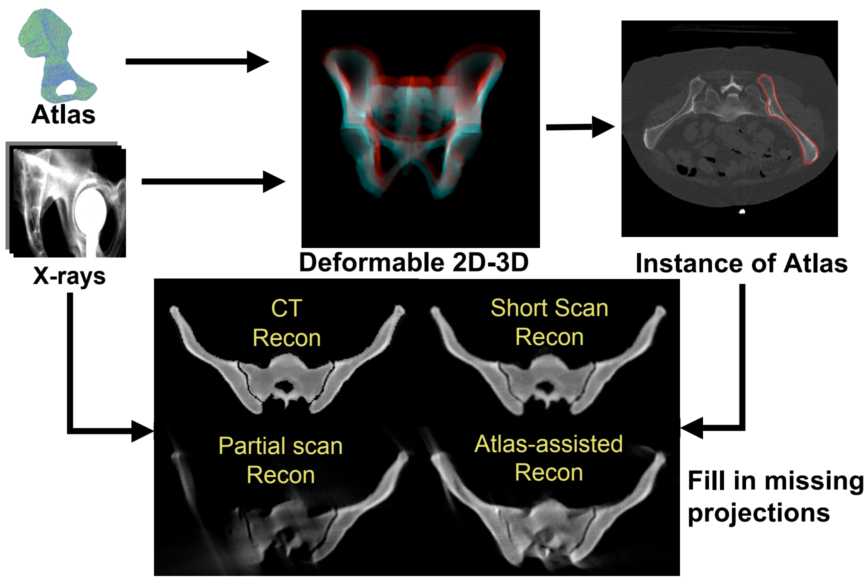




O. Sadowsky, K. Ramamurthy, J. Yao, J. Prince, R. Taylor

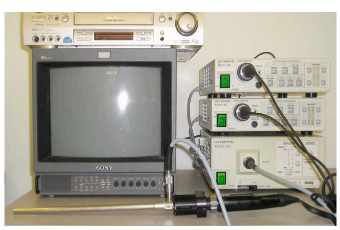
Atlas-augmented X-ray Reconstruction

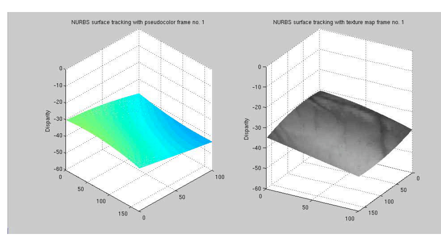
Taylor, Prince, Yao, Sadowsky, Ramamurthi



Real-time Video Techniques

Hager/Thakor/Yuh/Lau (JHU)



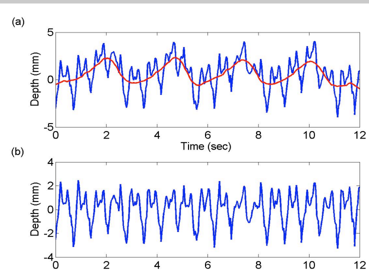


Problem: Construct dynamically tracked models of deformable surfaces

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

Information

Patient-specific Information (Images, lab results, genetics, etc.)

General information (anatomic atlases, statistics, rules)

Model → Plan

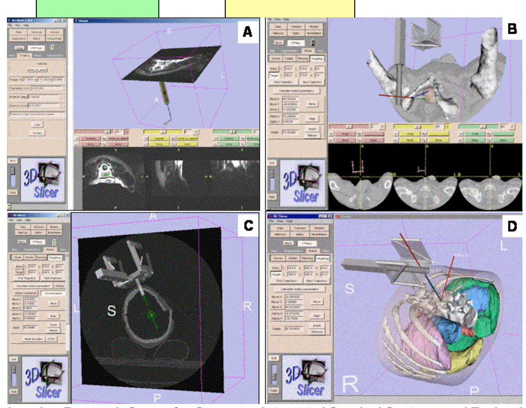
Example: Integrated environment for image-based planning, visualization, & intervention (SLICER)

Information

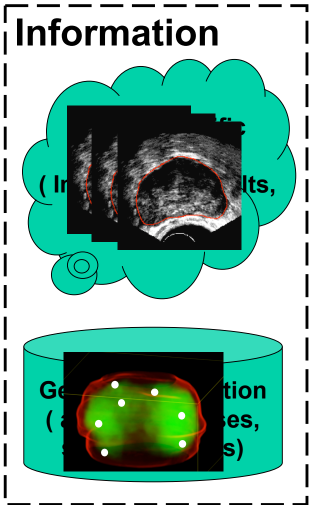
Patient-specific Information (Images, lab results, genetics, etc.)

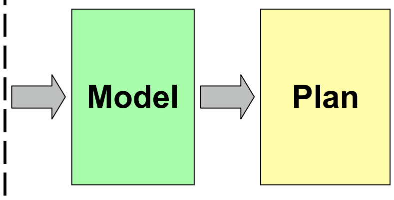
General information (anatomic atlases, statistics, rules)

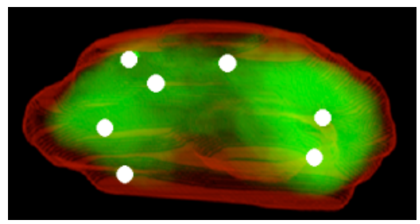
Model → Plan



Example: Optimal planning of prostate biopsy from US and cancer atlas







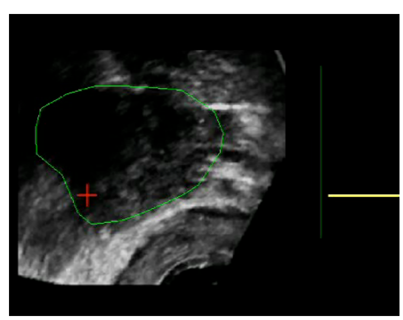
D. Shen, C. Davatzikos, Y. Zhan, C. Tempany, G. Fichtinger, S. Haker, …

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

Tissue deformations cause seed placement error



Planner computes offsets to compensate for simulated tissue deformations

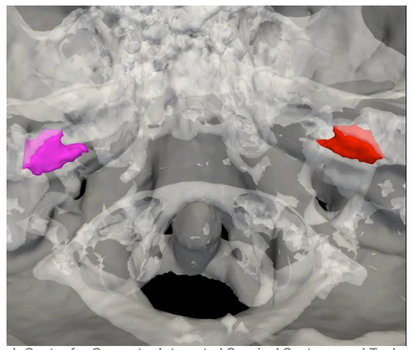
Example: Planning Access and Safety Constraints for Skull Base Drilling

Information

Patient-specific Information (Images, lab results, genetics, etc.)

General information (anatomic atlases, statistics, rules)

Model → Plan



P. Kaznzides, C. Baird, T. Xia, N. Hata, …

Information

Patient-specific Information (Images, lab results, genetics, etc.)

General information (anatomic atlases, statistics, rules)

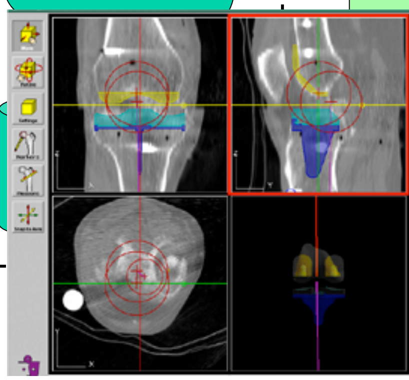
Model → Plan → Action

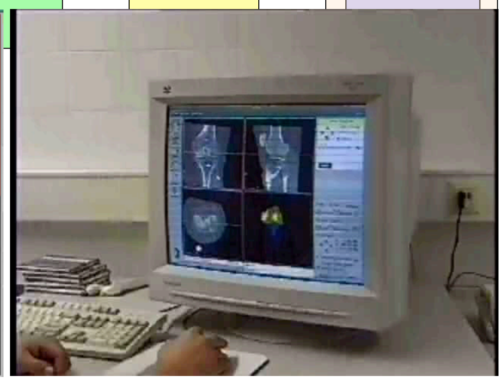
Example: Robotic Knee Replacement Surgery

Information

Patient-specific Information (Images, lab results, genetics, etc.)

Model → Plan → Action





Photos: Integrated Surgical Systems

Figure: R. Taylor

Example: Surgical Navigation Systems

Information

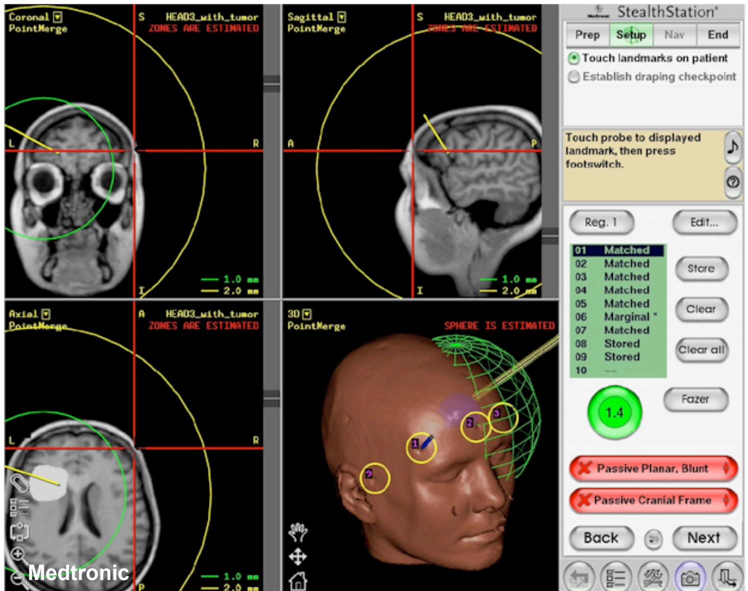
Patient-specific Information (Images, lab results, genetics, etc.)

General information (anatomic atlases, statistics, rules)

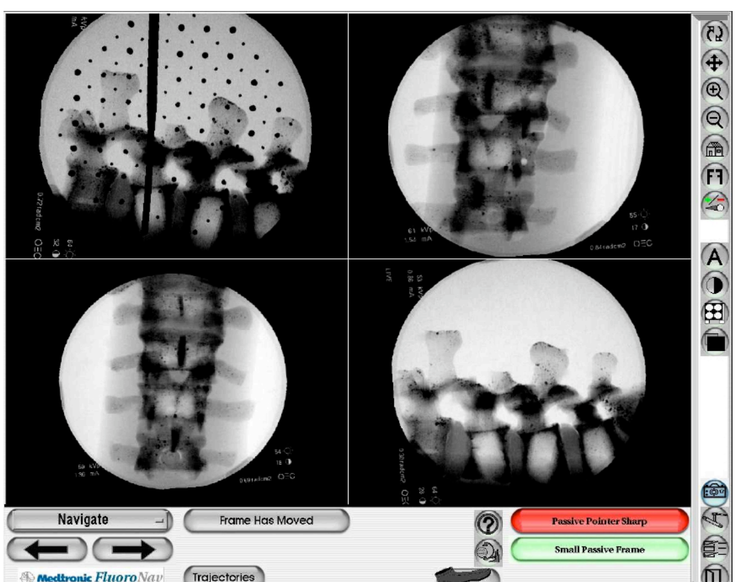
Model → Plan → Action

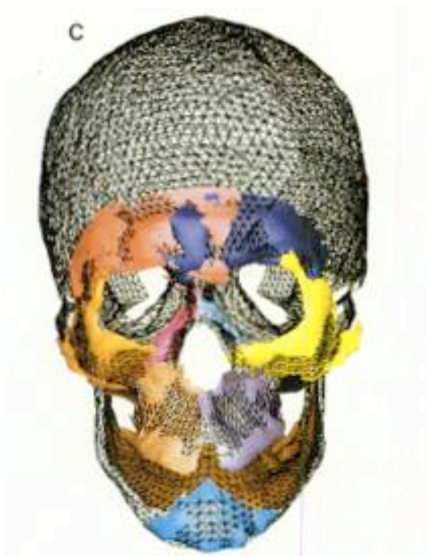

Photo: VTI Inc.

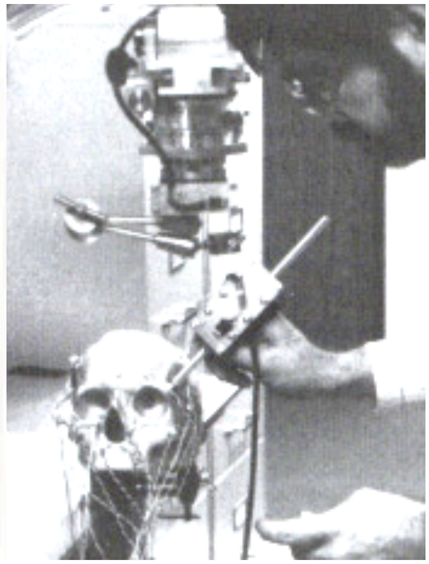
Navigation Systems



Navigation Systems

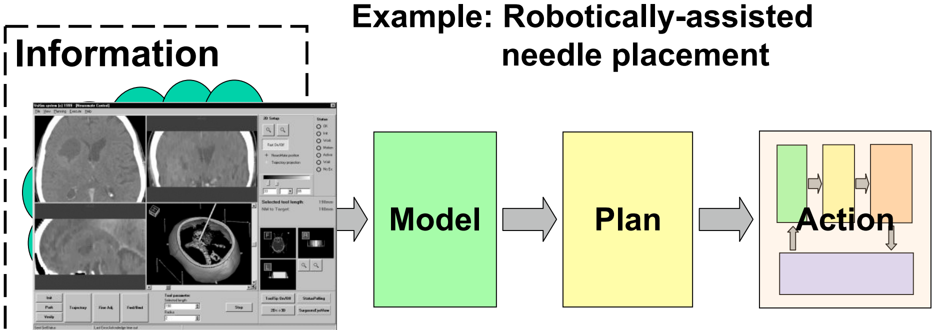


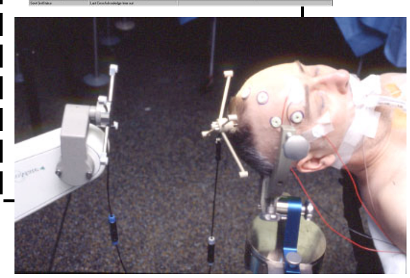


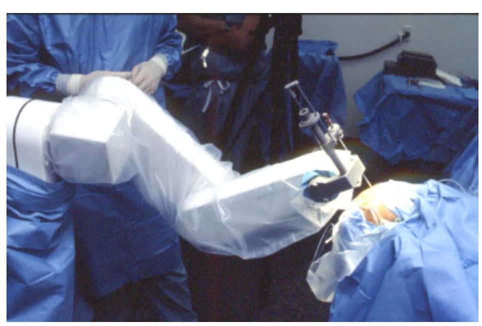


Cutting, Bookstein, Taylor, *et al.*

Example: Robotically-assisted needle placement

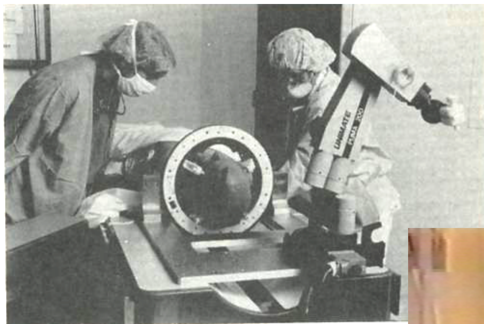






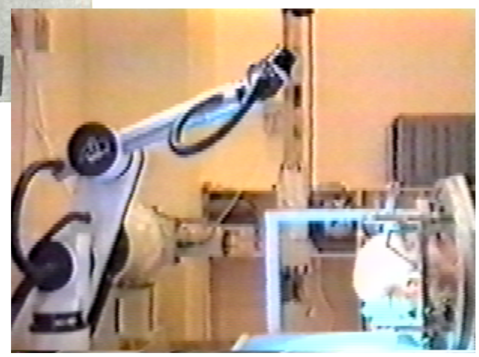
Courtesy: Integrated Surgical Systems

Robotic Needle Guidance



Kwoh, *et al. 1988*

Lavallee, Troccaz, *et al. 1989*

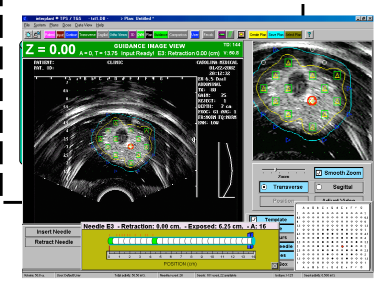


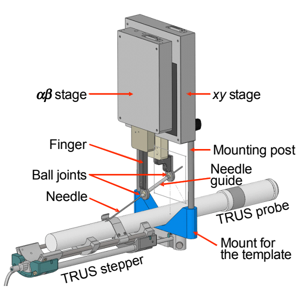
Example: Computer-integrated prostate brachytherapy

Information

Patient-specific Information (Images, lab results, genetics, etc.)

Model → Plan → Action



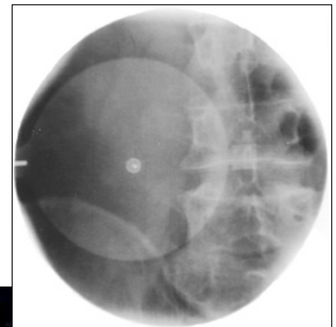


Kennedy, Fichtinger, Burdette, *et al.*

Xray-guidance example:

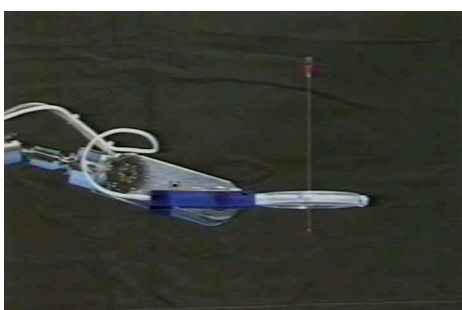
Percutaneous access to kidney

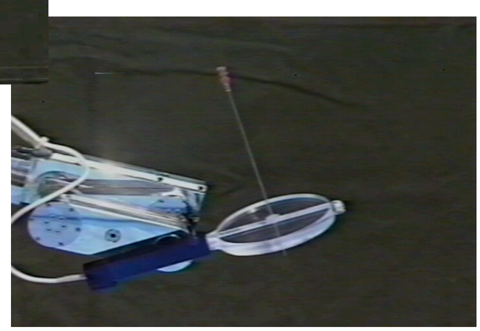
- Radiolucent needle driver
- Robot aligns needle under x-ray fluoroscopy guidance
- Has been done both locally and remotely



Engineering Research Center for Computer Integrated Surgical Systems and Technology

RCM Robot with Radiolucent Needle Driver





Stoianovici, Taylor, Whictomb, *et al.*

Engineering Research Center for Computer Integrated Surgical Systems and Technology

Example: CT-guided robot for biopsy and therapy

Information

Patient-specific Information (Images, lab results, genetics, etc.)

General information (anatomic atlases, statistics, rules)

Model → Plan → Action

D. Stoianovici, L. Kavoussi, A. Patriciu, S. Solomon (JHU Bayview); R. Susil, L. Whitcomb, G. Fichtinger, K. Masamune, R. Taylor (JHU WSE)

Example: MRI-guided robot for trans-rectal prostate biopsy and therapy

Information

Patient-specific Information (Images, lab results, genetics, etc.)

General information (anatomic atlases, statistics, rules)

Model → Plan → Action

CREDIT: Krieger, Susil, Ménard, Coleman, Singh, Whitcomb, Atalar, Fichtinger

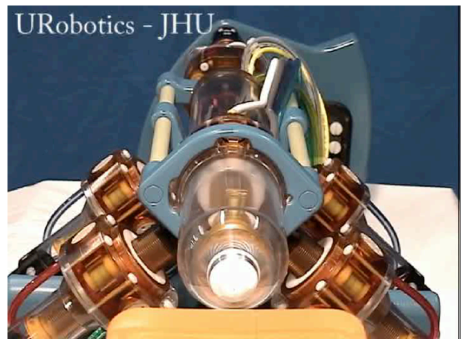
Example: MRI-guided robot trans-perineal prostate brachytherapy

Information

Patient-specific Information (Images, lab results, genetics, etc.)

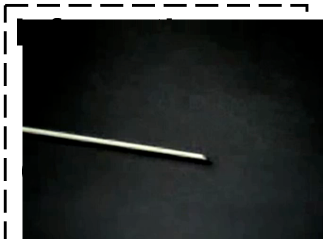
General information (anatomic atlases, statistics, rules)

Model → Plan → Action



D. Stoainovici, A. Patriciu, *et al.*

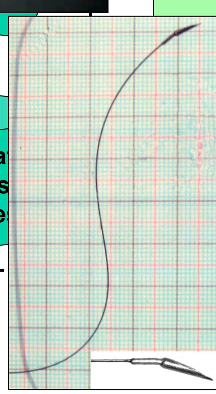
Steering the needle …

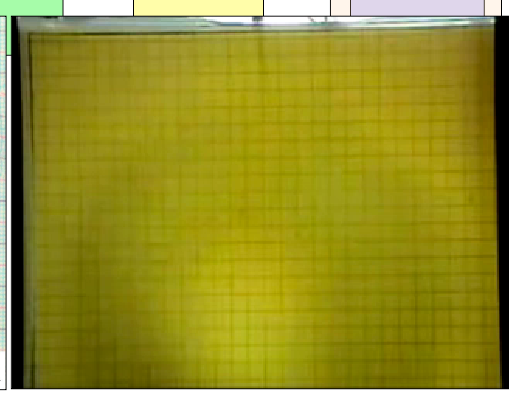


R. Webster *et al.*

General informa
(anatomic atlas
statistics, rule

Model → Plan → Action

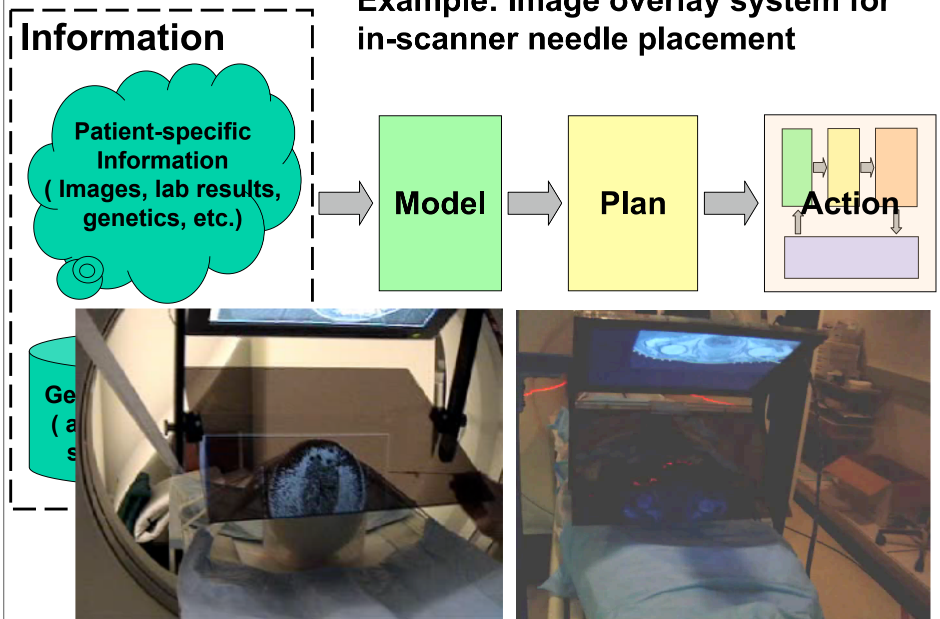




CMU: Riviere, Engh, *et al.*

JHU: R. Webster, A. Okamura, *et al.*

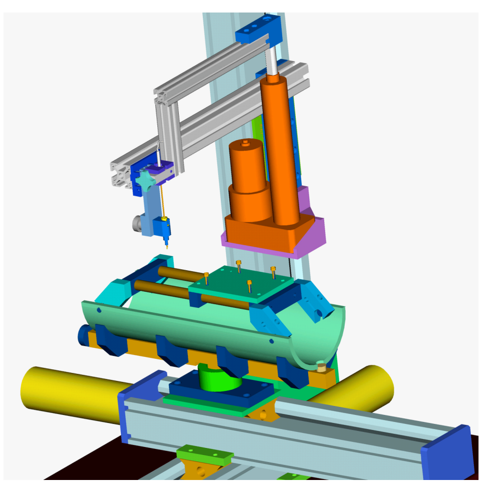
Example: Image overlay system for in-scanner needle placement



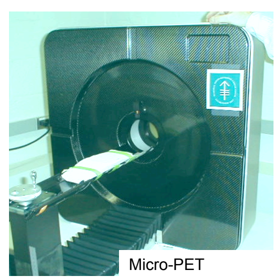
Masamune, Fischer, Deguet, Csoma, Taylor, Sauer, Iorchidata, Masamune, Zinreich, Fichtinger, …

Robotic Needle Placement in Rodents

P. Kazanzides, G. Fichtinger, C. Ling



Credit: Jack Li, I. Iordachita



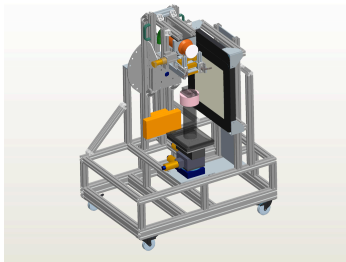
Micro-PET scanner

Courtesy of MSKCC

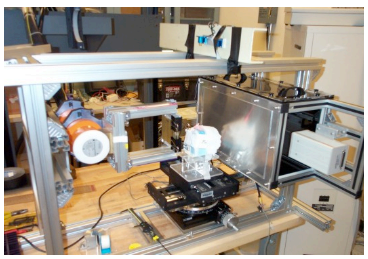
Research contract from Sloan Kettering

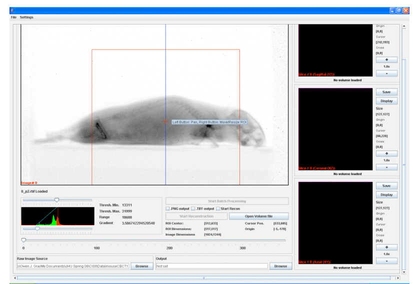
Small Animal Radiation Research Platform

John Wong (PI), Peter Kazanzides, *et al.*

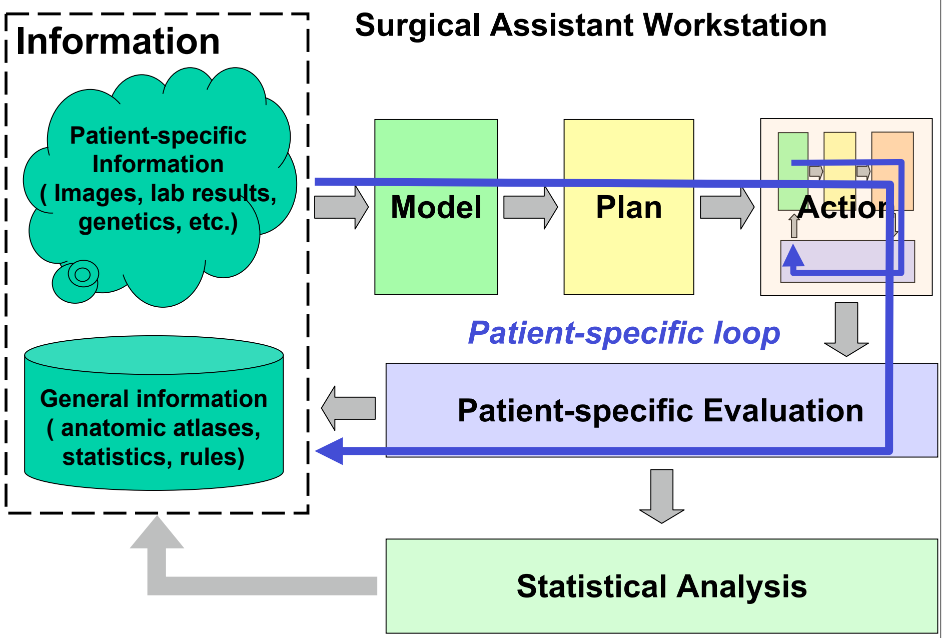


- Prototype, self-contained, very compact imaging and radiation therapy research platform for small animals
- In development as collaboration between JHU Radiation Oncology and CISST ERC

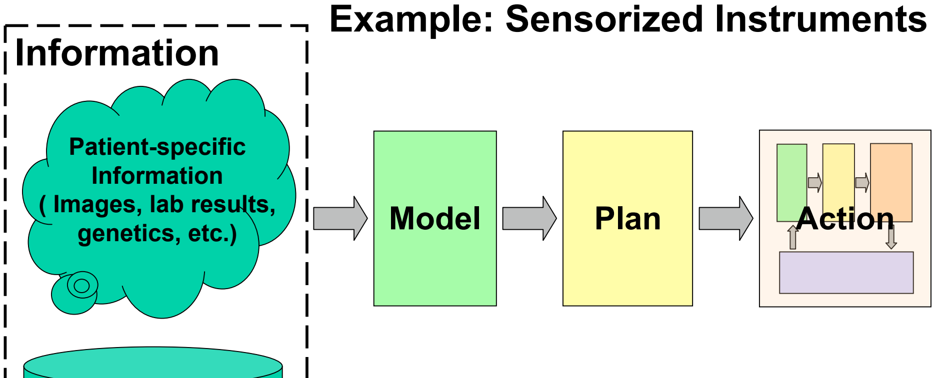


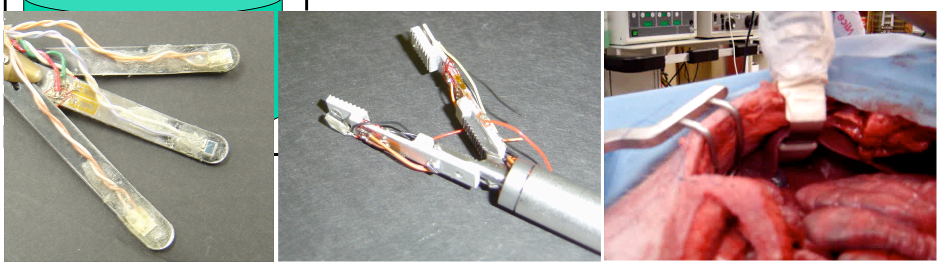


Surgical Assistant Workstation



Example: Sensorized Instruments

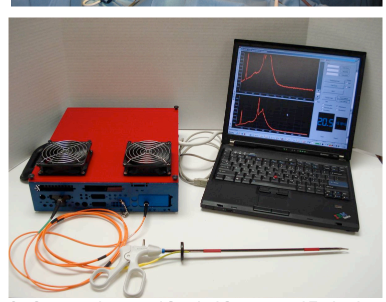




Fischer, Akinbiyi, Balicki ,Saha, Meireles, Talamini, Marohn, Taylor, *et al.*

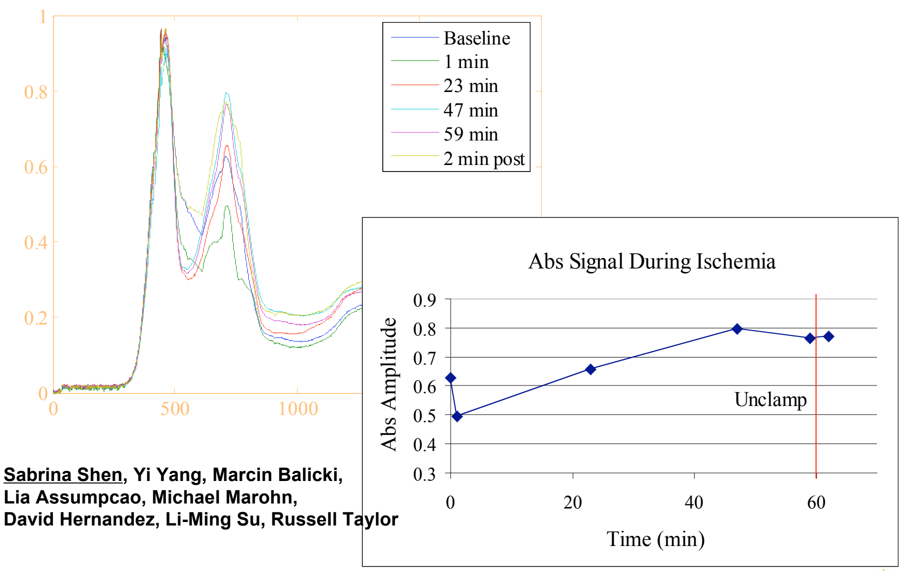
Kidney Ischemia Assessment

- Major concern in laparoscopic partial nephrectomies
- Preliminary *in vivo* study on pigs using fiber-optic probe and visible light spectroscopy



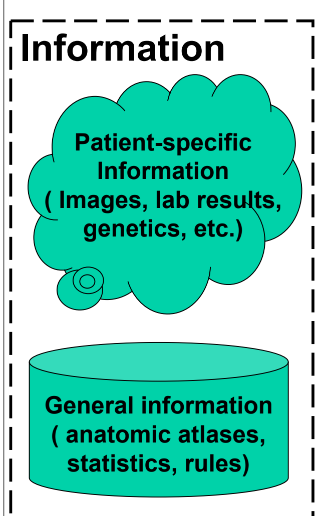
Sabrina Shen, Yi Yang, Marcin Balicki,
Lia Assumpcao, Michael Marohn,
David Hernandez, Li-Ming Su, Russell Taylor

Kidney Ischemia Assessment



Sabrina Shen, Yi Yang, Marcin Balicki,
Lia Assumpcao, Michael Marohn,
David Hernandez, Li-Ming Su, Russell Taylor

Example: Telesurgical Assistants



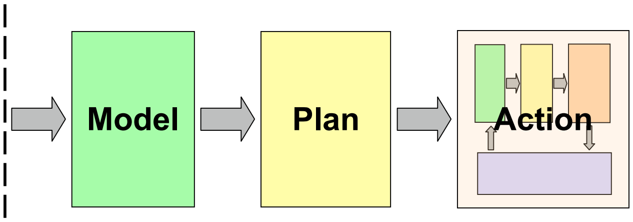
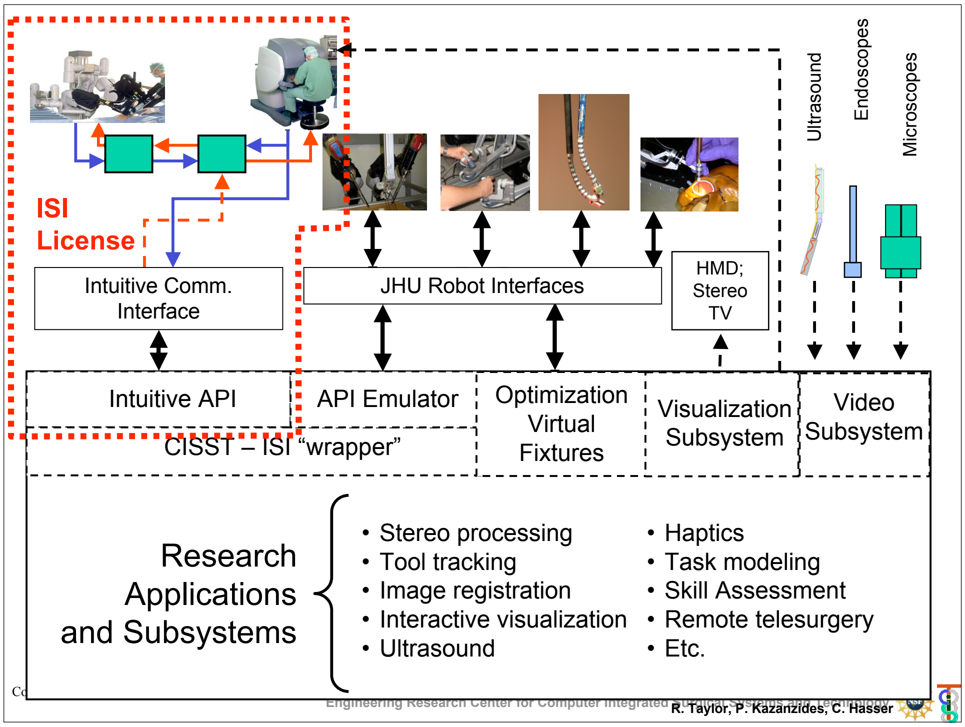
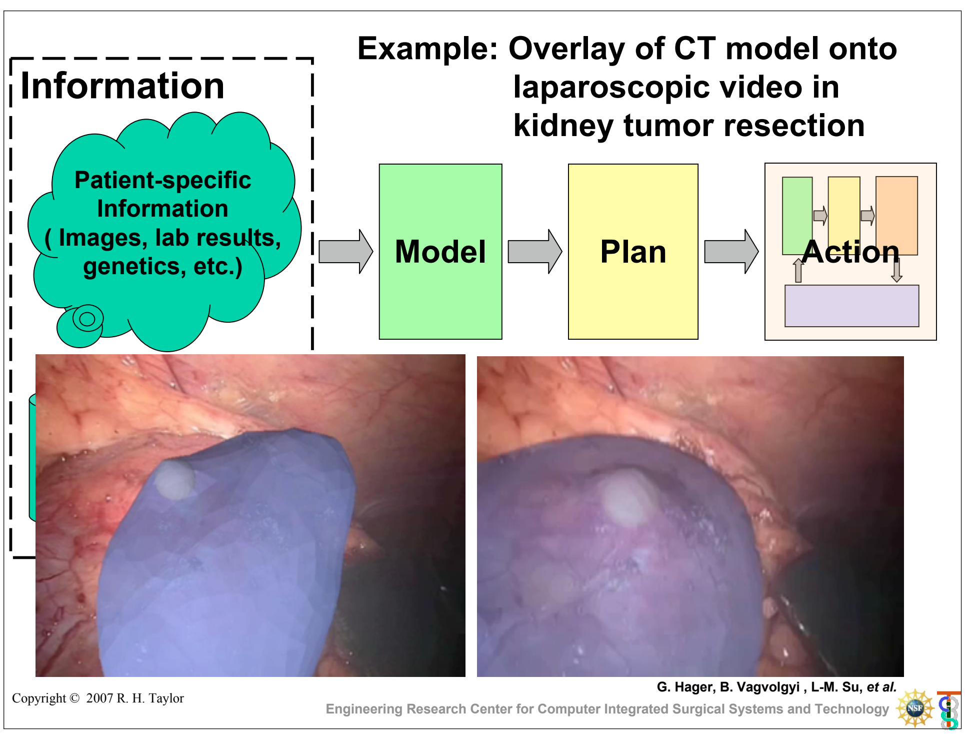


Photo: Intuitive Surgical



ISI
License
Intuitive Comm. Interface
JHU Robot Interfaces
HMD; Stereo TV
Ultrasound
Endoscopes
Microscopes
Intuitive API
API Emulator
CISST – ISI "wrapper"
Optimization Virtual Fixtures
Visualization Subsystem
Video Subsystem
Research Applications and Subsystems
• Stereo processing
• Tool tracking
• Image registration
• Interactive visualization
• Ultrasound
• Haptics
• Task modeling
• Skill Assessment
• Remote telesurgery
• Etc.
R. Taylor, P. Kazanzides, C. Hasser



Example: Overlay of CT model onto laparoscopic video in kidney tumor resection
Information
Patient-specific Information (Images, lab results, genetics, etc.)
Model
Plan
Action
G. Hager, B. Vagvolgyi , L-M. Su, et al.
Copyright © 2007 R. H. Taylor
Engineering Research Center for Computer Integrated Surgical Systems and Technology

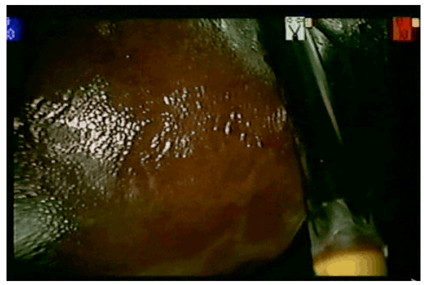
Example: Intraoperative Laparoscopic Ultrasound with daVinci

Information

Patient-specific Information (Images, lab results, genetics, etc.)

General information (anatomic atlases, statistics, rules)

Model → Plan → Action



R. Taylor, C. Hasser, J. Leven, *et al.*

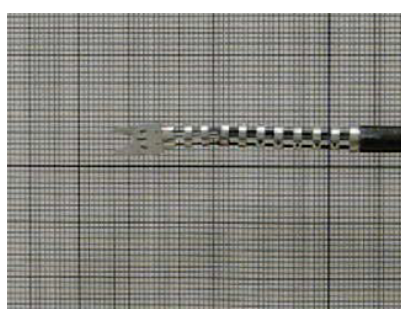
Example: Snake-like robot for minimally invasive surgery of the throat and upper airway

Information

Patient-specific Information (Images, lab results, genetics, etc.)

Genera
(anato
statis

Model → Plan → Action



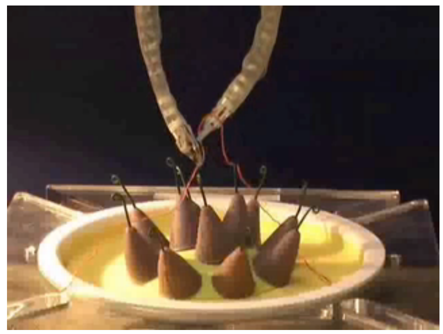
Simaan, Taylor, Flint, Kapoor, Wei , Xu

Example: Snake-like robot for minimally invasive surgery of the throat and upper airway

Information

Patient-specific Information (Images, lab results, genetics, etc.)

Model → Plan → Action

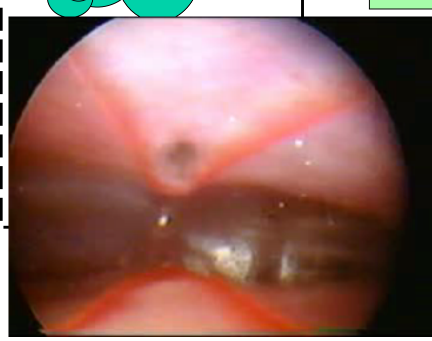


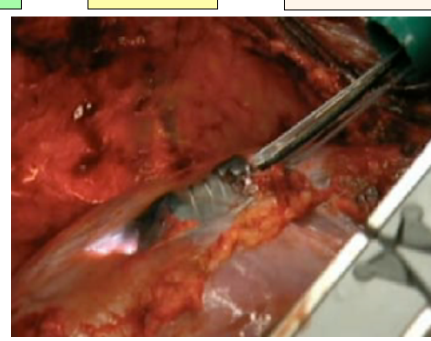
Example: CMU HeartLander Robot for Epicardiac Procedures

Information

Patient-specific Information (Images, lab results, genetics, etc.)

Model → Plan → Action





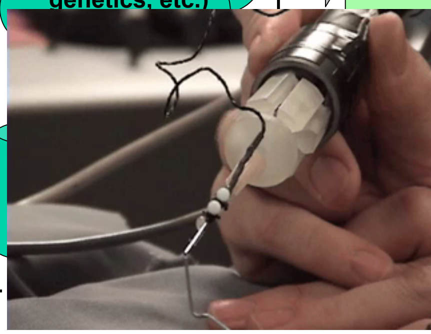
Patronik, Riviere, *et al.*

Example: Microsurgery Tremor Reduction

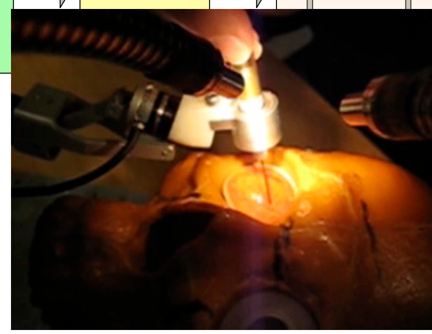
Information

Patient-specific Information (Images, lab results, genetics, etc.)

Model → Plan → Action



CMU MICRON Robot
Ang, Machlachlan, Riviere

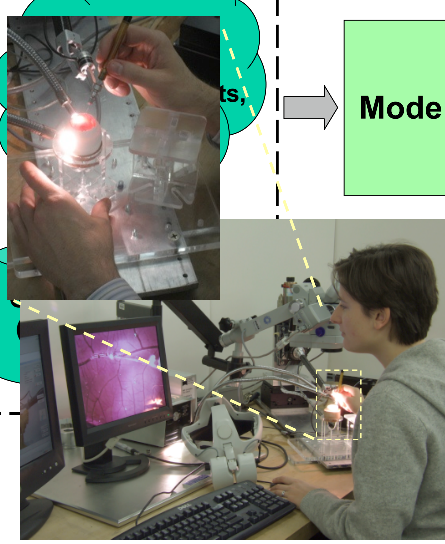


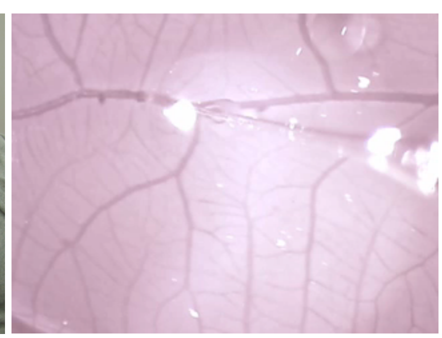
JHU Steady Hand "Eye Robot"
Iordachita, Kapoor, Kazanzides, Taylor

Example: Steady-hand robot for microsurgery

Information

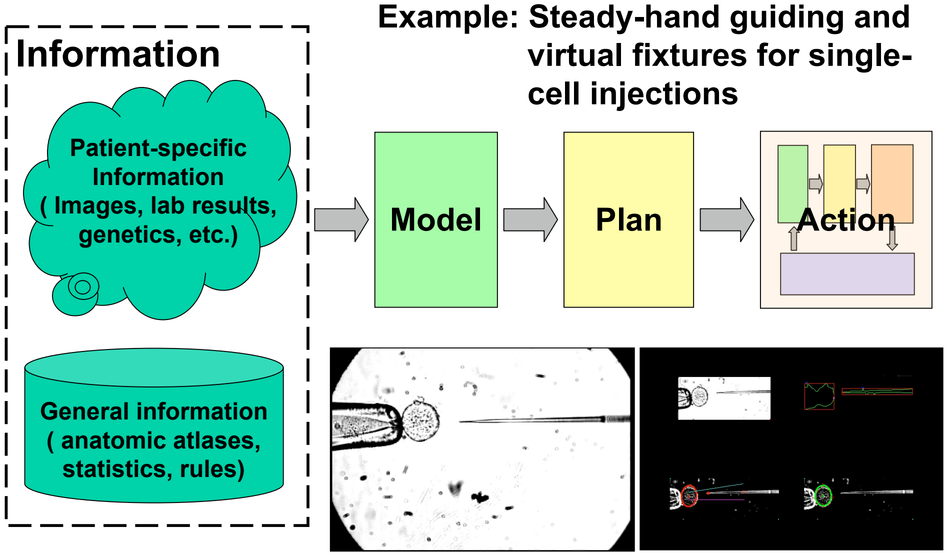
Model → Plan → Action





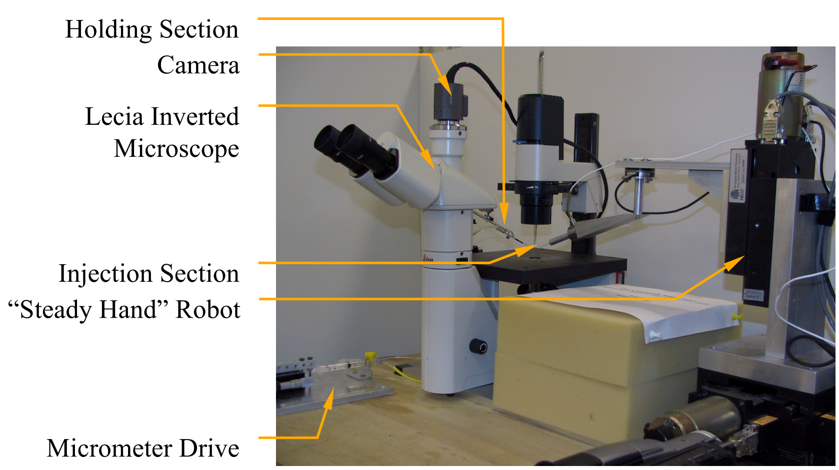
Taylor, Iordachita, Kapoor, Handa, Mitchell, Fleming, Gehlbach*et al.*

Example: Steady-hand guiding and virtual fixtures for single-cell injections



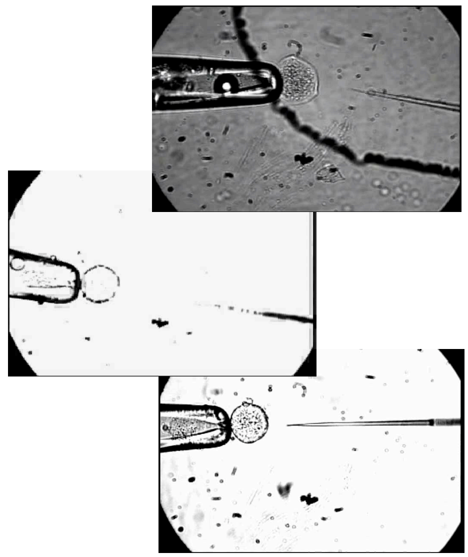
Kapoor, Kumar, Taylor

Our Experimental Setup



Injection step strategies

- Compliant
  - The robot complies with scaled user forces
- "Augmented" compliant
  - Asymmetric and non-linear compliance gains
  - Slow approach
  - Faster withdrawal to facilitate sealing
  - Selective locking of DOF
- Supervisory
  - User selects injection point and robot injects



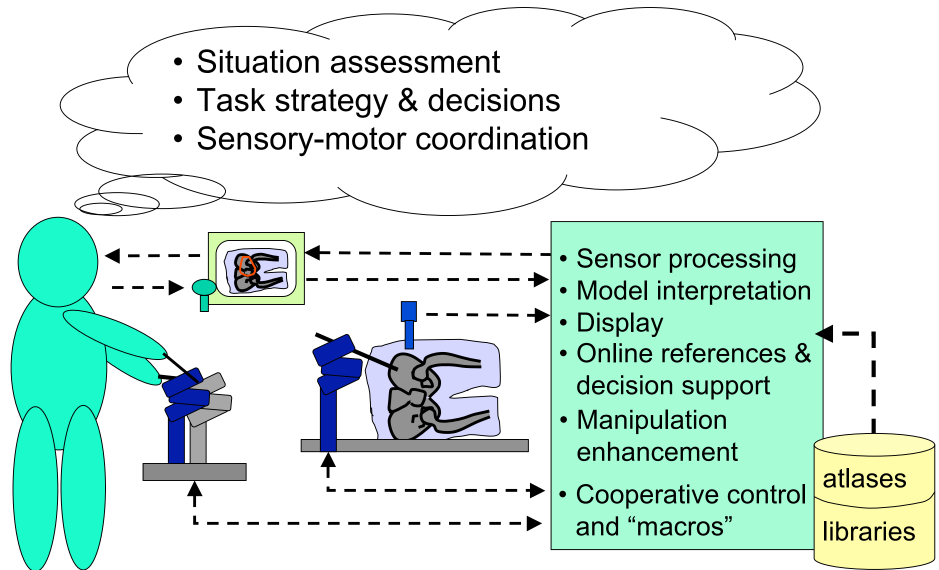
Results

Completion times for different strategies

	# Trials	Time Required (seconds)		Survival Rate
		Average	Std. Dev	
Approach	20	109.8	78.5	
Injection/ Withdraw				
Compliant	2	1.6	-	100%
Augmented	8	0.747	0.067	100%
Supervisory	12	0.678	0.024	100%

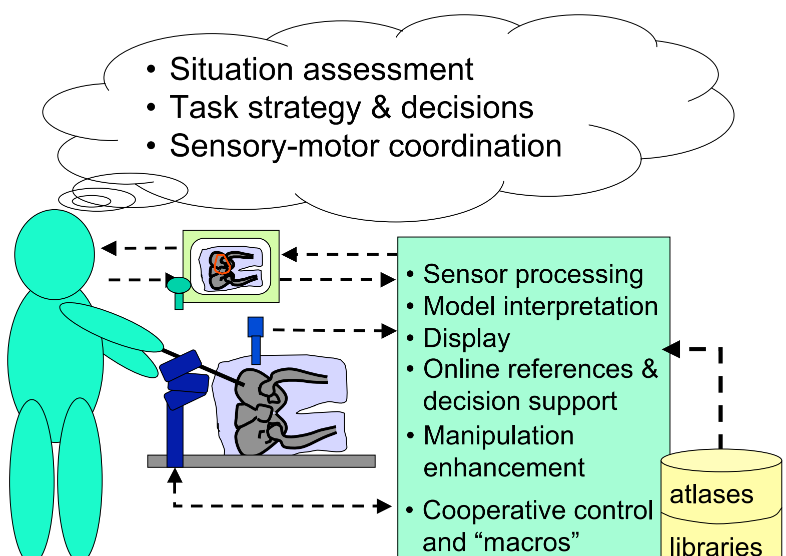
- These results are from single user trials, not trained in conventional setup
- These times are indicative of speed of microinjection and are preliminary

Evolution to human-machine partnership



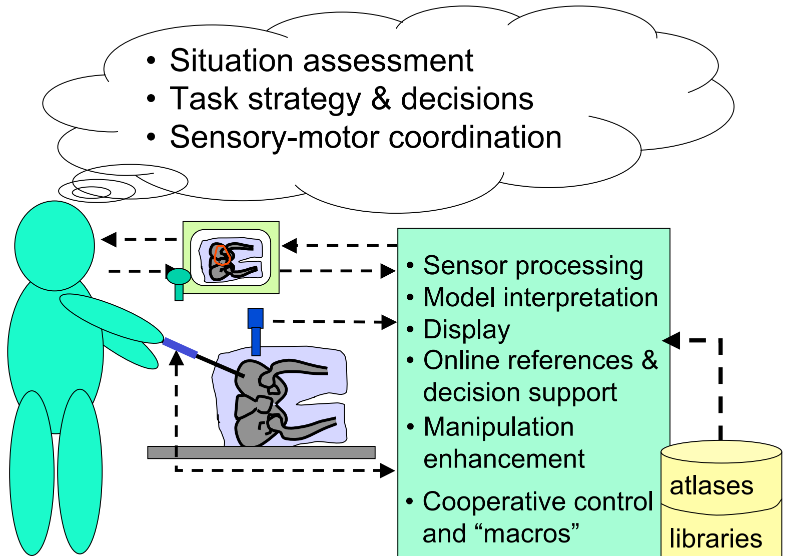
R. Taylor

Evolution to human-machine partnership



R. Taylor

Evolution to human-machine partnership

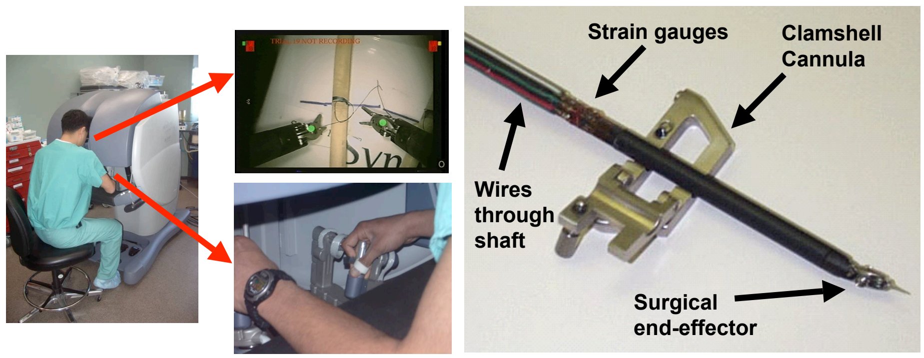


R. Taylor

Enhanced Interfaces for Surgical Robots

IBM/JHU LARS, *circa* 1993-4

Dynamic Augmented Reality for Sensory Substitution in Robot-Assisted Surgical Systems



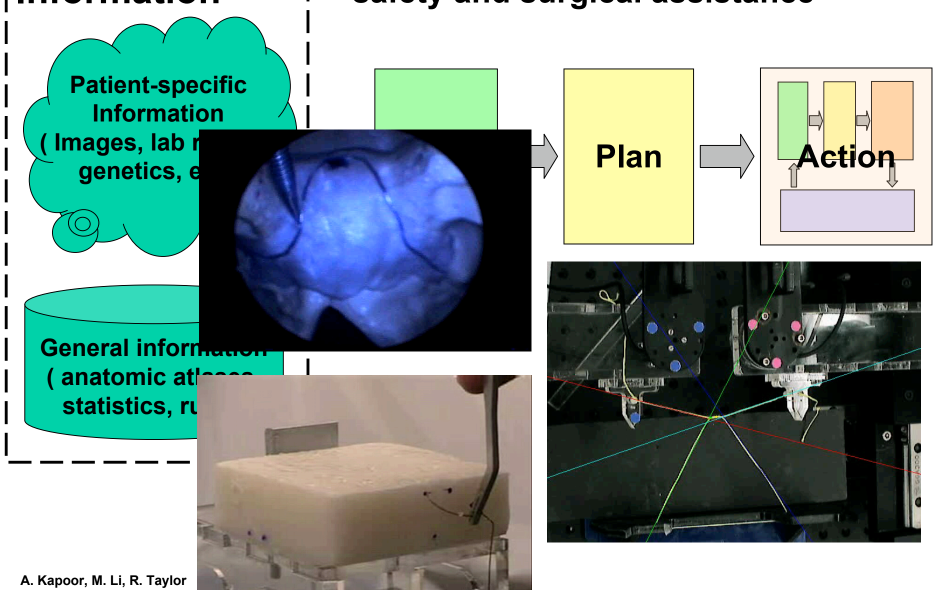
Sensory substitution of force information improves performance:

Metric	p-value	Significant
Number of broken sutures	.0111	Y
Standard deviation of forces	.0414	Y
Average peak applied force	.0539	*
Number of loose knots	.0667	*
Average task completion time	.7934	N

A. Okamura, T. Akinbiyi, *et al.*

Example: "Virtual fixtures" for safety and surgical assistance

Information



A. Kapoor, M. Li, R. Taylor

Constrained Optimization Framework

- **Single frame**

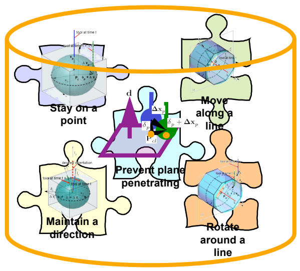
Translational part

$$\begin{bmatrix} \mathbf{H}_p \\ \mathbf{H}_r \end{bmatrix} \mathbf{J}(\mathbf{q})\Delta\mathbf{q} \ge \begin{bmatrix} \mathbf{h}_p \\ \mathbf{h}_r \end{bmatrix}$$

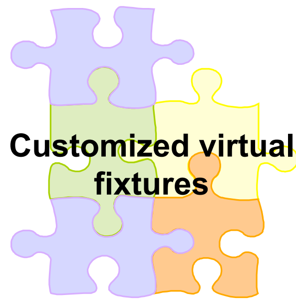
Rotational part

- **Multiple frames**

$$\begin{bmatrix} \mathbf{H}_1 & & 0 \\ & \ddots & \\ 0 & & \mathbf{H}_k \end{bmatrix} \begin{bmatrix} \mathbf{J}_1(\mathbf{q}) \\ \vdots \\ \mathbf{J}_k(\mathbf{q}) \end{bmatrix} \Delta\mathbf{q} \ge \begin{bmatrix} \mathbf{h}_1 \\ \vdots \\ \mathbf{h}_k \end{bmatrix}$$

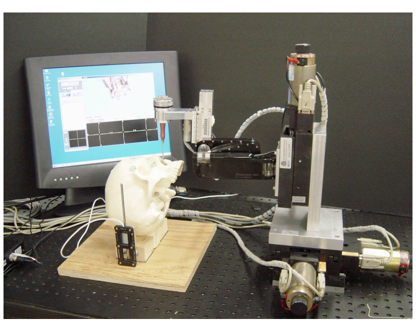


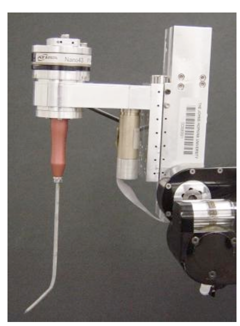
Select one or more

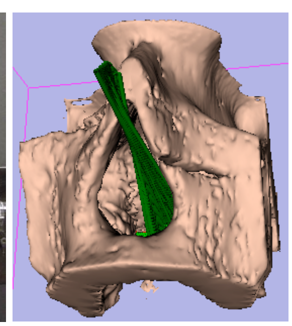


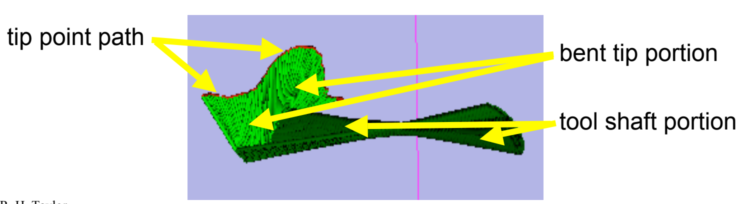
Steady-hand sinus surgery with virtual fixtures derived from CT models

Ming Li, Russell Taylor

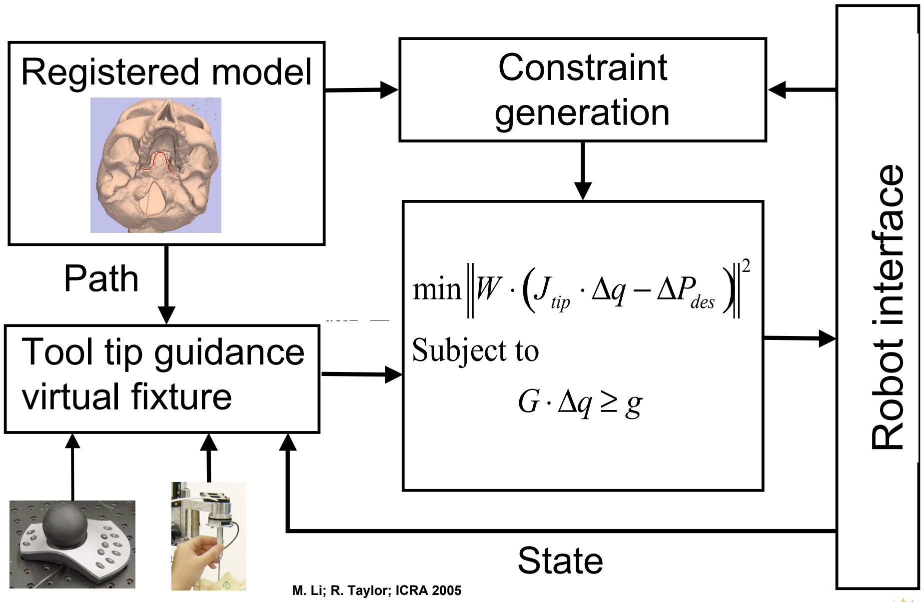




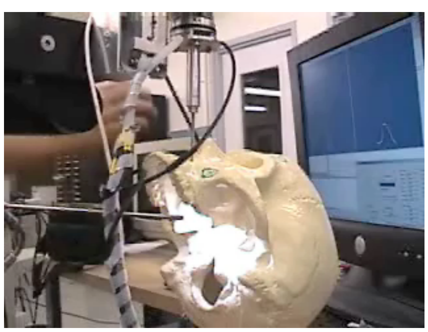


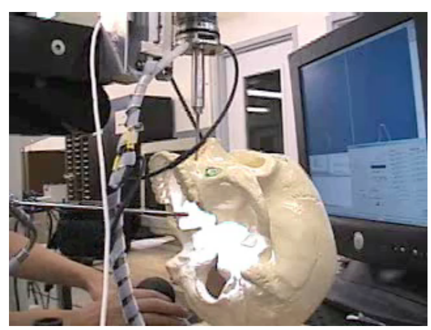


Virtual Fixture Online Implementation



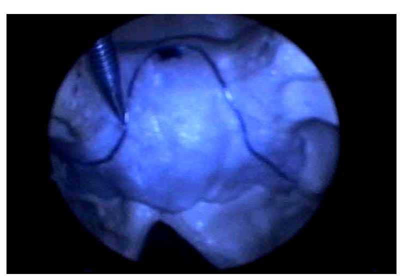
M. Li; R. Taylor; ICRA 2005





Cooperative control guiding

3D mouse guiding

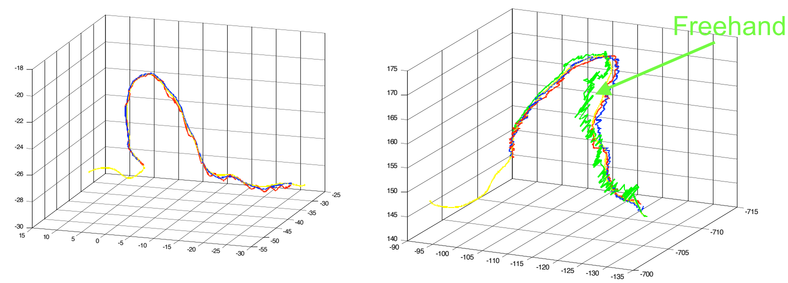


View of path & tool

M. Li; R. Taylor; ICRA 2005

Performance of Teleoperation *vs* Cooperatively Hands-on Operation

Trajectory of the path

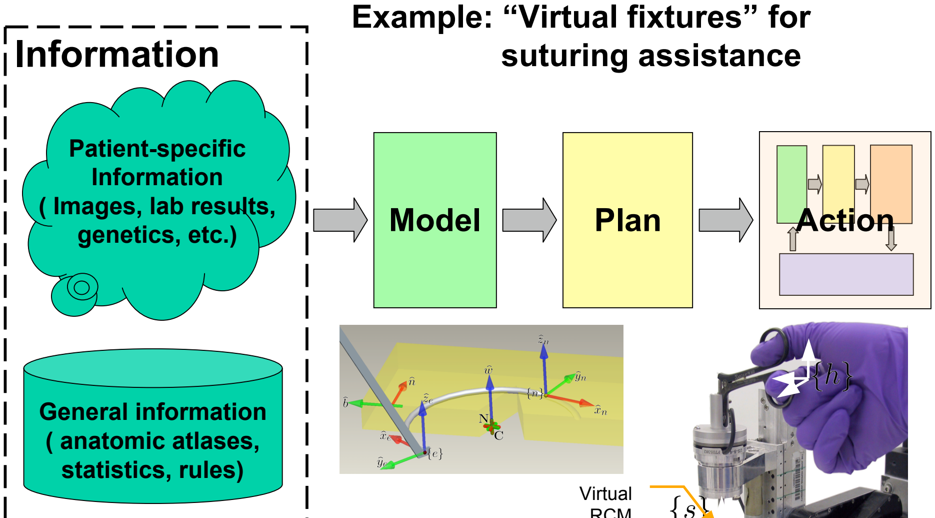


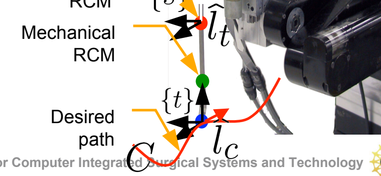
Yellow: given path; Red: remote; Blue: hands-on

Robot context | Optical Tracking context

M. Li; R. Taylor; ICRA 2005

Example: "Virtual fixtures" for suturing assistance





Error (mm)	Entry	Exit
Robot VF	0.63 ± .12	0.77 ±.37
Manual	--	2.1 ± 1.2

M. Li, A. Kapoor, *et al*

Example: “Virtual fixtures” for suturing assistance

Information

Patient-specific Information
(Images, lab results, genetics, etc.)

General information
(anatomic atlases, statistics, rules)

Model → Plan → Action

M. Li, A. Kapoor, et al

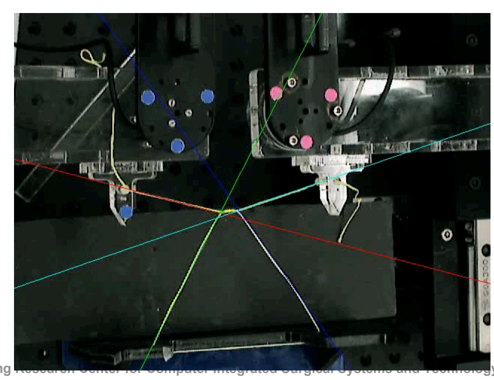
Example: Two-handed virtual fixture for centering knot with visual feedback

Information

Patient-specific Information
(Images, lab results, genetics, etc.)

General information
(anatomic atlases, statistics, rules)

Model → Plan → Action



Ankur Kapoor

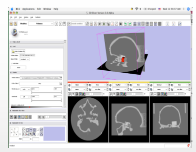
Example: Steady-hand guiding and virtual fixtures for neurosurgery

Information

Patient-specific Information (Images, lab results, genetics, etc.)

General infor
(anatomic a
statistics, r

Model → Plan → Action



3D Slicer

NeuroMate

StealthStation

surgeon

cooperative control w/ virtual fixture

patient

VF definition

navigation data

input force

calibration registration

Application & Robot Control

motion control

Kazanzides, Tian, Baird, Jallo

Example: Steady-hand guiding and virtual fixtures for neurosurgery

Information

Patient-specific Information (Images, lab results, genetics, etc.)

Ge
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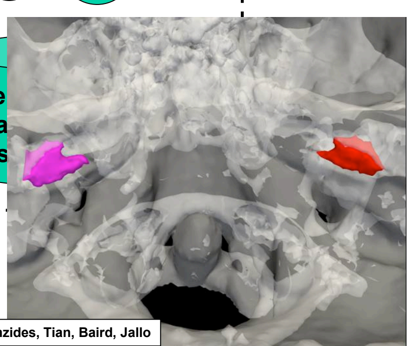
Model → Plan → Action



Kazanzides, Tian, Baird, Jallo

Engineering Research Center for Computer Integrated Surgical Systems and Technology

Research Issue: Understanding intent in human-machine cooperation

Information

Patient-specific Information (Images, lab results, genetics, etc.)

General information (anatomic atlases, statistics, rules)

Model → Plan → Action

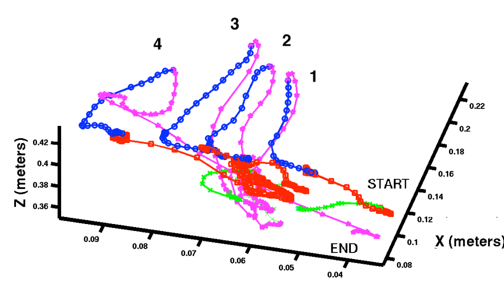
Figure: R. Taylor

Research Issue: Understanding intent in human-machine cooperation

Information

Patient-specific Information (Images, lab results, genetics, etc.)

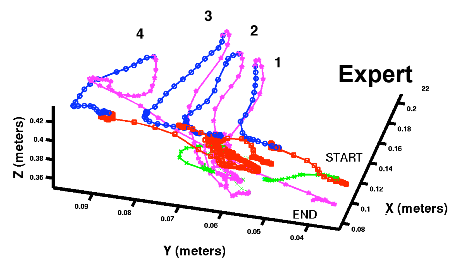
Model → Plan → Action

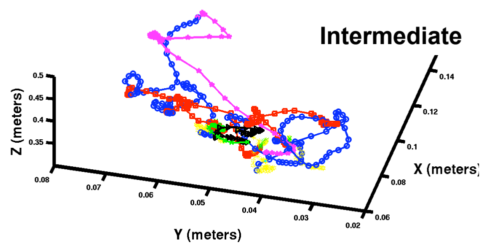


Hager, Lin

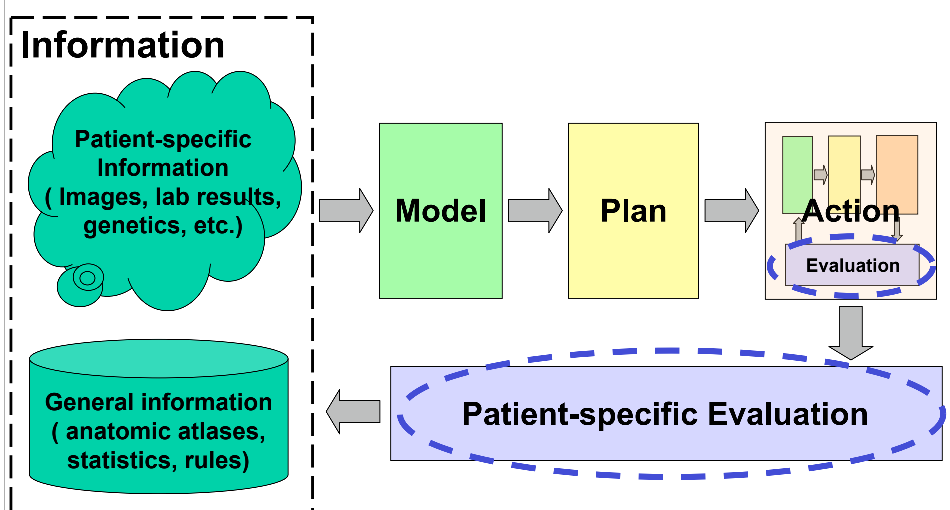
Example: Automatic Detection and Segmentation of Robot-Assisted Surgical Motions

- Goals:
  - Automatic recognition of different surgical motions
  - Comparison of skill level differences between surgeons
- Method
  - Extract features from position and velocity traces
  - Linear discriminant analysis with probabilistic Bayesian classifier





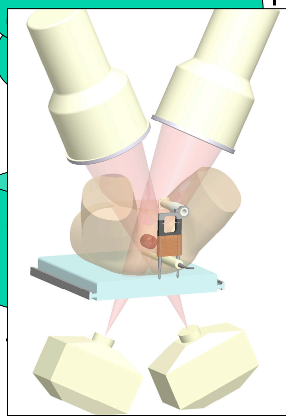
H. Lin, I. Shafran, T. Murphy, D. Yuh, A. Okamura, G. Hager (MICCAI 2005)



Example: Intraoperative Assessment of Brachytherapy Patterns

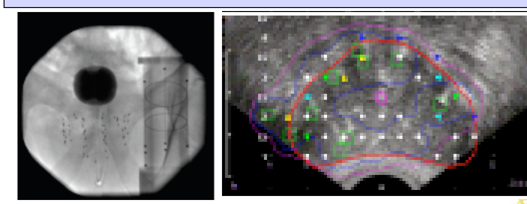
Information

Patient-specific Information



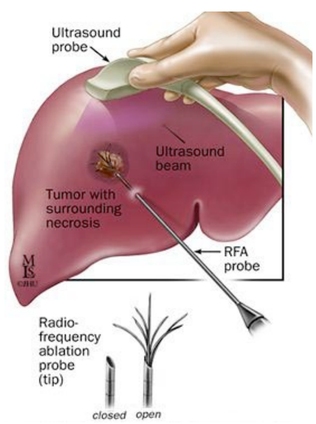
Model → Plan → Action

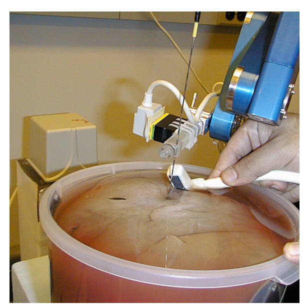
Patient-specific Evaluation

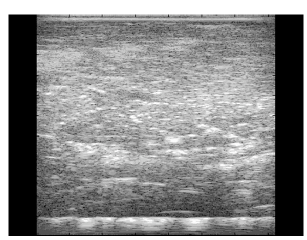


Jain *et al.*

US-Guided Ablation of Tumors

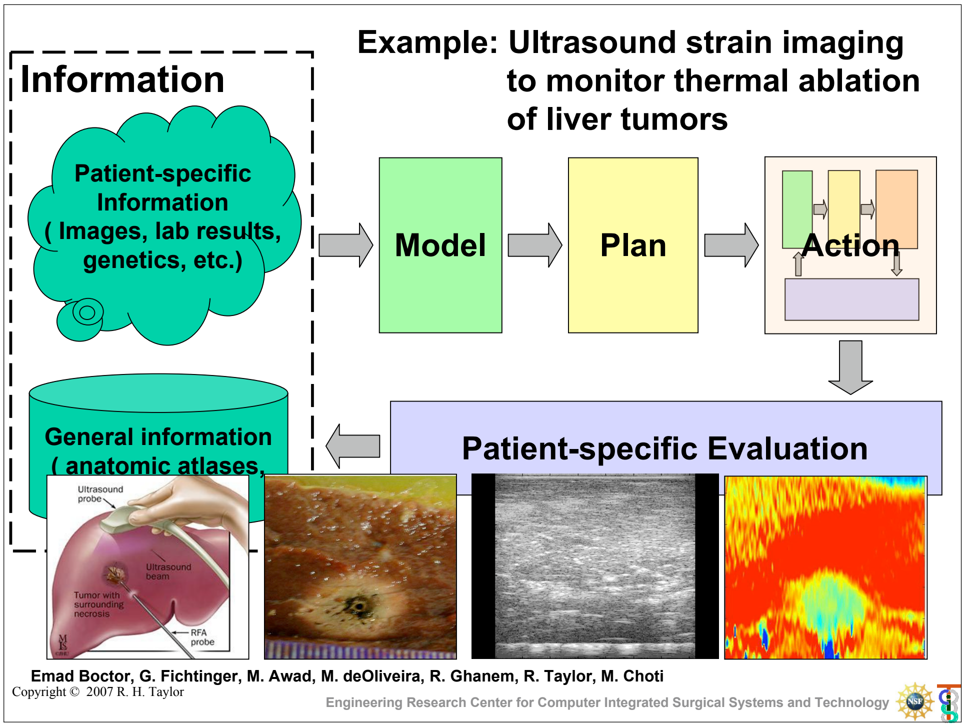






Targeting & Assessment – US
Probe Placement – Freehand or robot
Monitoring - ???????????

Emad Boctor, G. Fichtinger, M. Awad, M. deOliveira, R. Ghanem, R. Taylor, M. Choti



Example: Ultrasound strain imaging to monitor thermal ablation of liver tumors
Information
Patient-specific Information (Images, lab results, genetics, etc.)
General information (anatomic atlases,
Model
Plan
Action
Patient-specific Evaluation
Ultrasound probe
Ultrasound beam
Tumor with surrounding necrosis
RFA probe
Emad Boctor, G. Fichtinger, M. Awad, M. deOliveira, R. Ghanem, R. Taylor, M. Choti
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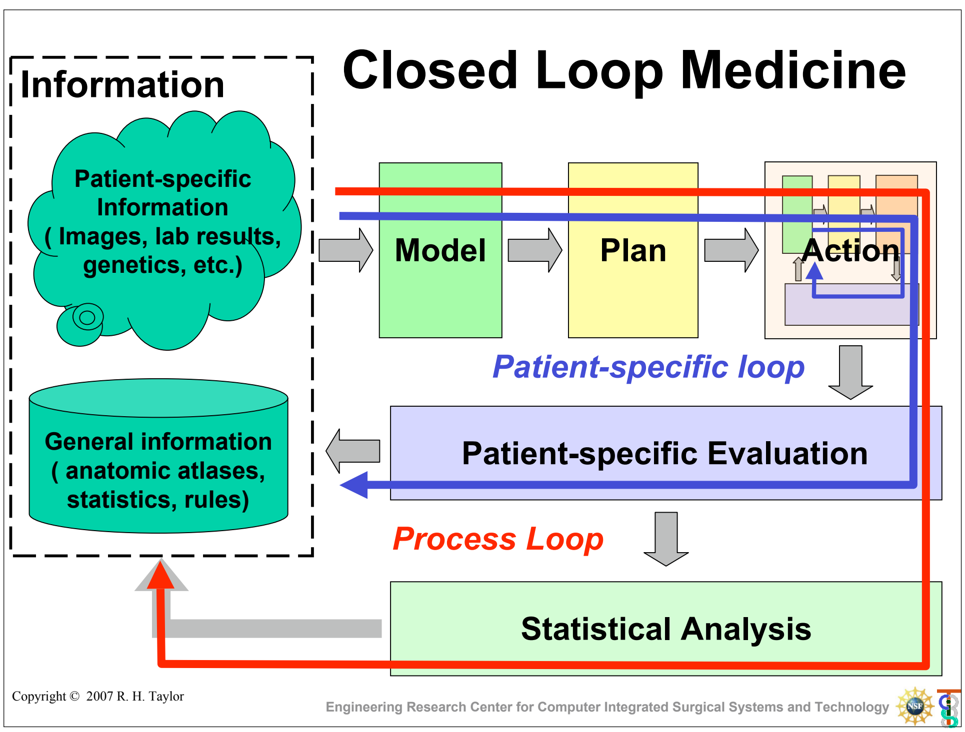

Closed Loop Medicine
Information
Patient-specific Information (Images, lab results, genetics, etc.)
General information (anatomic atlases, statistics, rules)
Model
Plan
Action
Patient-specific loop
Patient-specific Evaluation
Process Loop
Statistical Analysis
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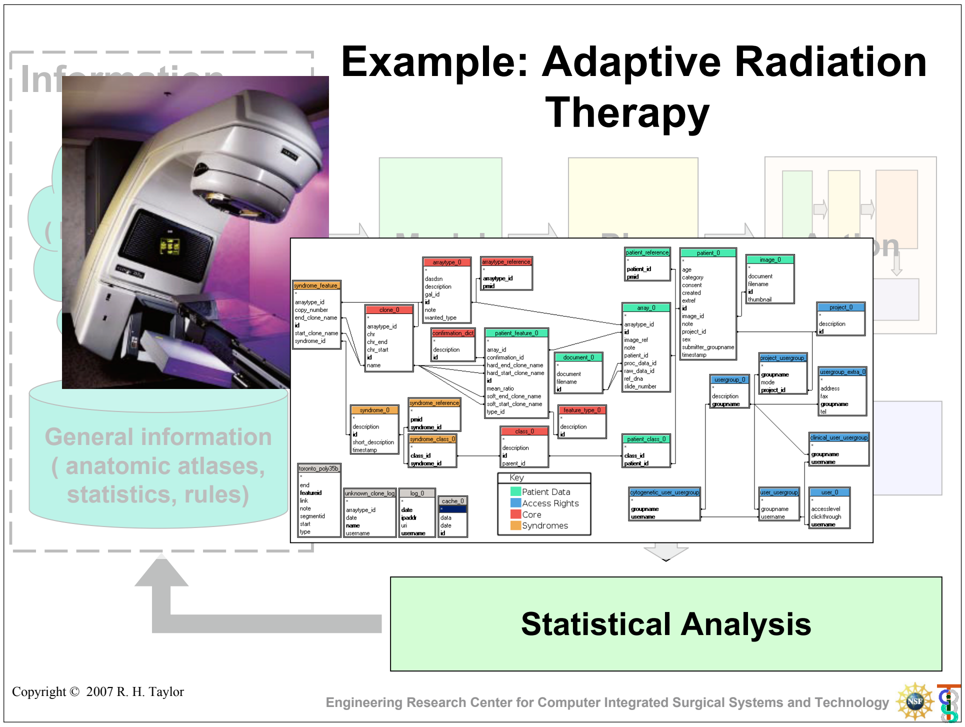
Example: Adaptive Radiation Therapy
General information (anatomic atlases, statistics, rules)
Key
Patient Data
Access Rights
Core
Syndromes
Statistical Analysis
Copyright © 2007 R. H. Taylor
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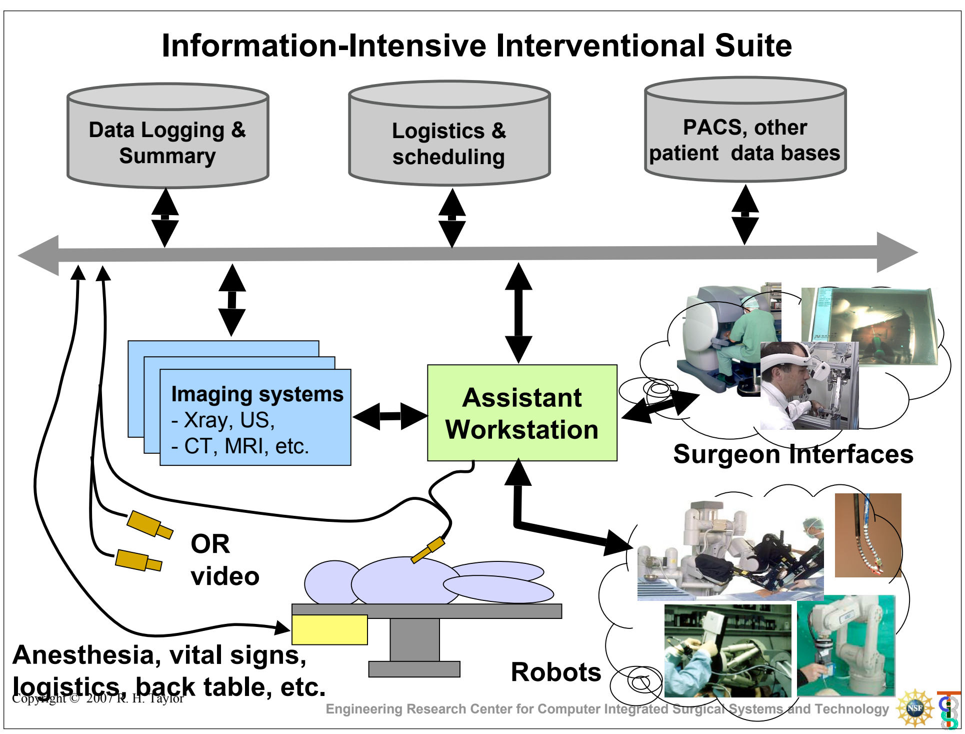
Information-Intensive Interventional Suite
Data Logging & Summary
Logistics & scheduling
PACS, other patient data bases
Imaging systems
- Xray, US,
- CT, MRI, etc.
Assistant Workstation
Surgeon Interfaces
OR video
Anesthesia, vital signs, logistics, back table, etc.
Robots
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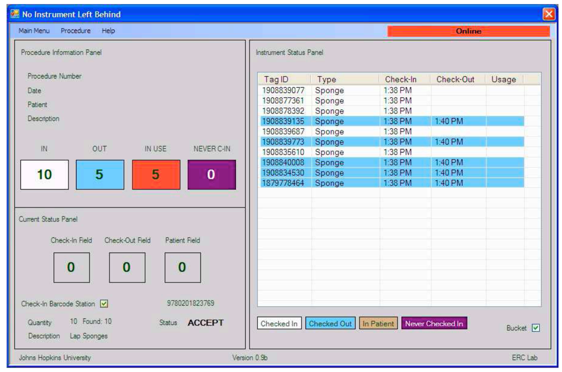
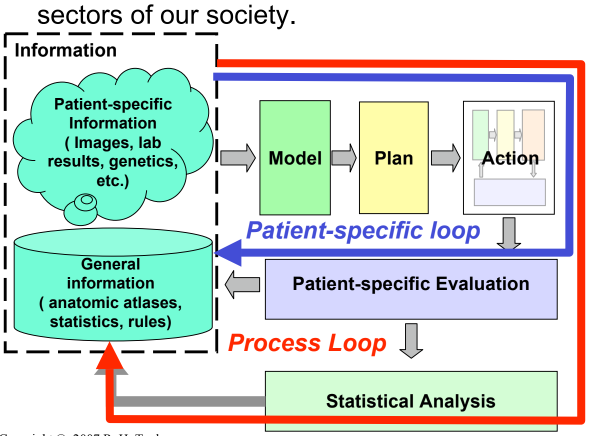
Ensuring no sponge (or instrument) gets left in the patient



Lia Assumpcao, Michael Marohn, Rosemary Mountain, Nilo Rivera, Russell Taylor, and Allen A. Williams

Evolution: Integrating Imaging, Intervention, and Informatics in Medicine (I^4M)

Strategy: develop comprehensive program to address the technological, clinical and educational challenges that need to be met in order to fundamentally transform interventional medicine in the say ways that computer-integrated systems have transformed manufacturing and other sectors of our society.



- Transcend human limitations.
- Improve safety, consistency, and overall quality.
- Improve the efficiency and cost-effectiveness.
- "Closed loop medicine"
  - For treating individual patients
  - Improving treatment processes

Figure: R. Taylor

Integrating Imaging, Intervention, and Informatics in Medicine (I^4M)

Technology & Systems

- Imaging & analysis
- Robotics & devices
- Systems
- Clinical engineering
- Validation, quality control, safety
- Informatics

Clinical Applications

- Microsurgery
- MIS
- Image-guided local interventions
- Targeted energy delivery
- etc.

Education & Infrastructure

- Laboratories
- Training facilities
- Simulation
- Certification
- Traineeships
- Fellowships
- Seminars
- Outreach
- Formal Courses

New Home for ERC Engineering Activity at JHU

Laboratory for Computational Sensing and Robotics (LCSR)

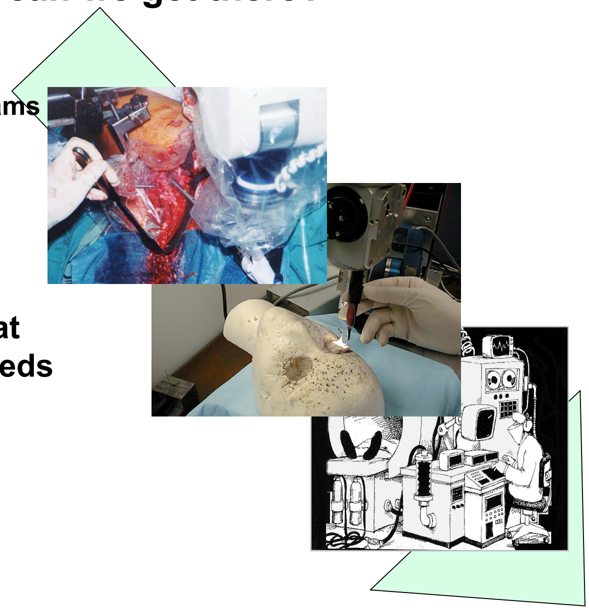
- Approx 15,000 square feet in new building on engineering campus
- Main shared lab area
- 10 adjoining labs
- Mock operating room
- Offices for faculty, staff, post-docs, students

- Come see us!

LABORATORY FOR Computational Sensing + Robotics THE JOHNS HOPKINS UNIVERSITY

NSF Engineering Research Center for Computer Integrated Surgical Systems and Technology

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

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

Discussion