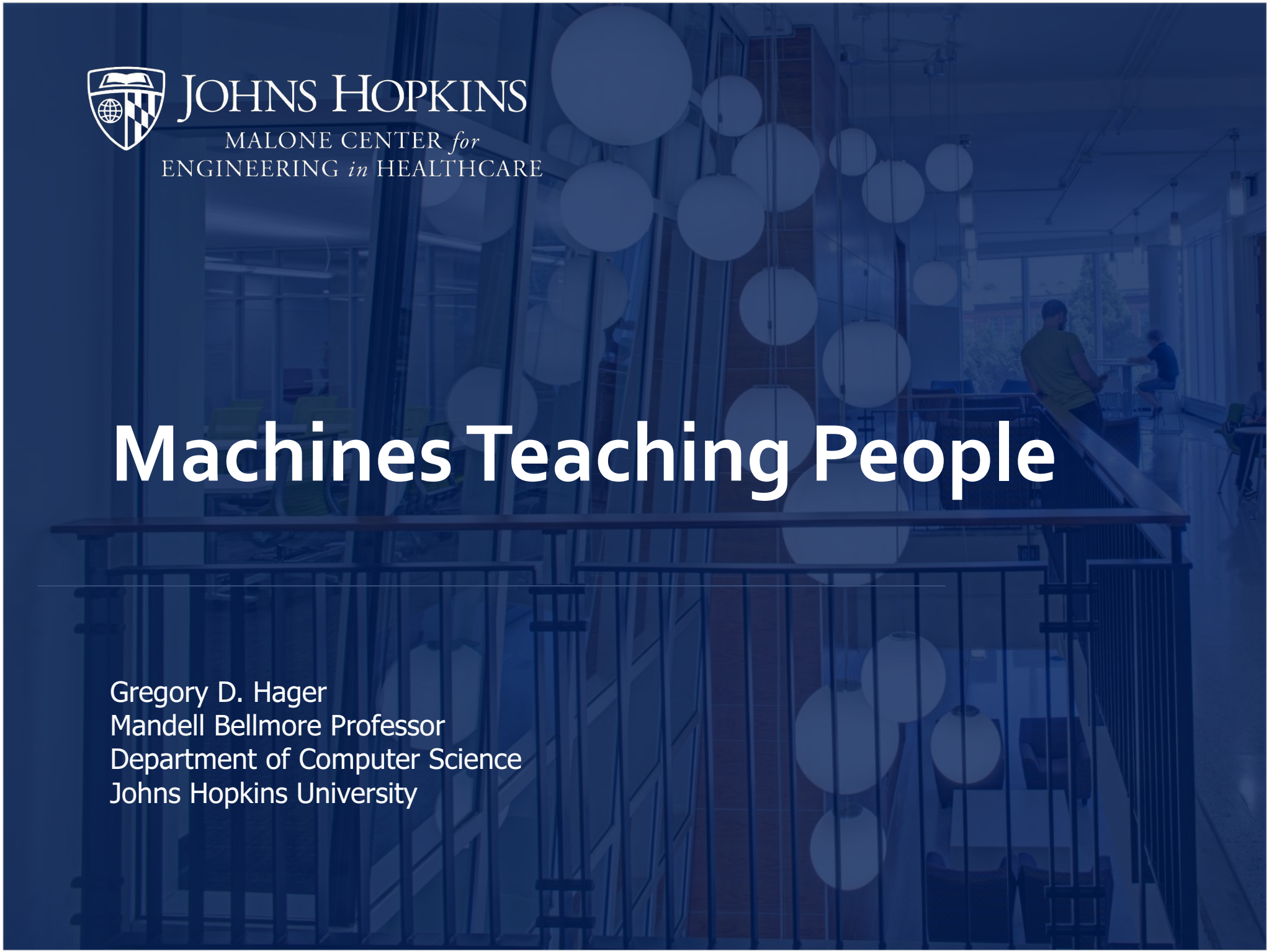


Machines Teaching People

Gregory D. Hager
Mandell Bellmore Professor
Department of Computer Science
Johns Hopkins University

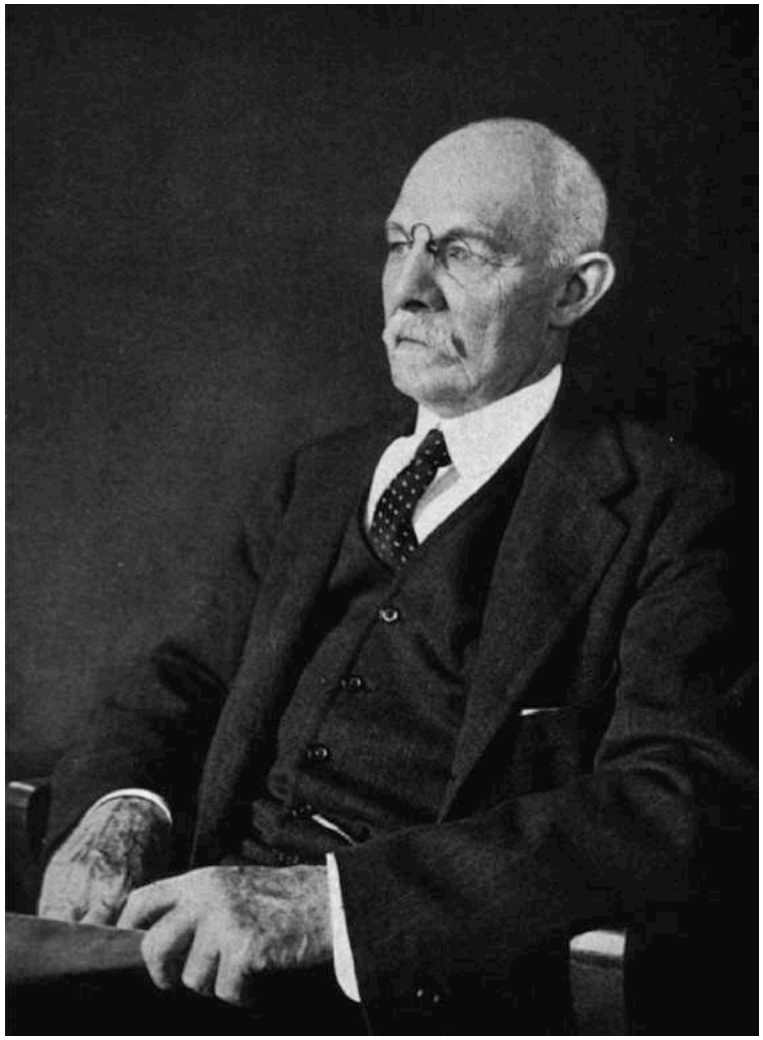
How is skill acquired?

Gladwell, Malcolm. *Outliers: The story of success*. Penguin UK, 2008.

Campitelli, Guillermo, and Fernand Gobet. "Deliberate Practice Necessary But Not Sufficient." *Current Directions in Psychological Science* 20, no. 5 (2011): 280-285.


The Oldest Skilled Trade Jobs
Share of 45+ Workers
Share of 55+ Workers
Electrical and Electronic Repairers
Extruding and Drawing Machine Setters
Electrical and Electronics Engineering Technicians
Stationary Engineers and Boiler Operators
Maintenance Workers, Machinery
Electricians
Computer-Controlled Machine Tool Operators
0%
15%
30%
45%
60%
75%

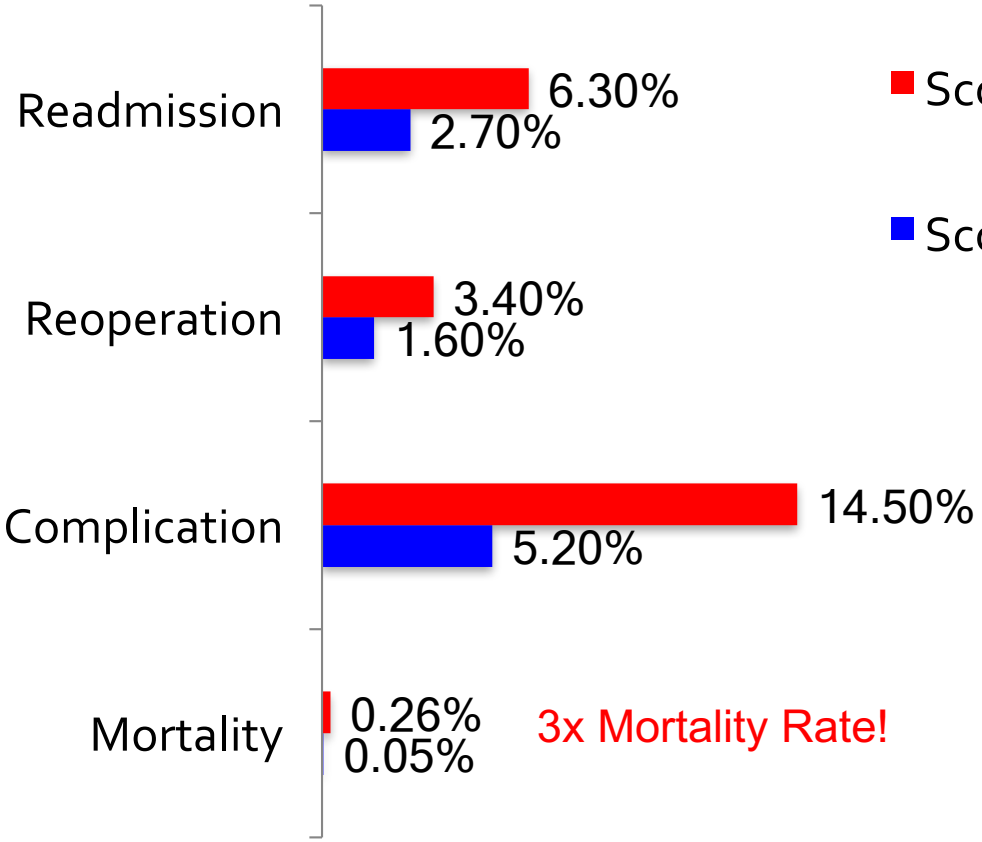
Skill Acquisition: Apprenticeship



William S. Halsted, JHU 1889
“See one, do one, teach one.”

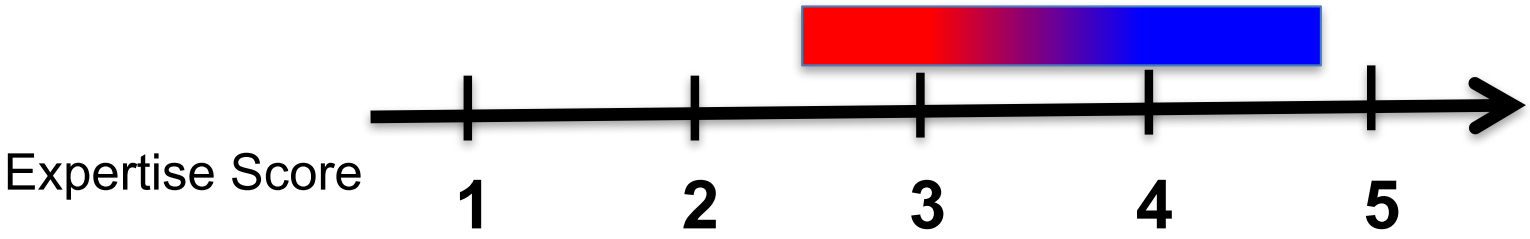
C. Franzese and S. Stringer. The Evolution of Surgical Training: Perspectives on Educational Models from the Past to the Future. Otolaryngologic Clinics of North America, 40(6):1227–1235, 2007.

Training and Skill Impacts Patient Outcomes



Michigan Bariatric Surgery Collaborative

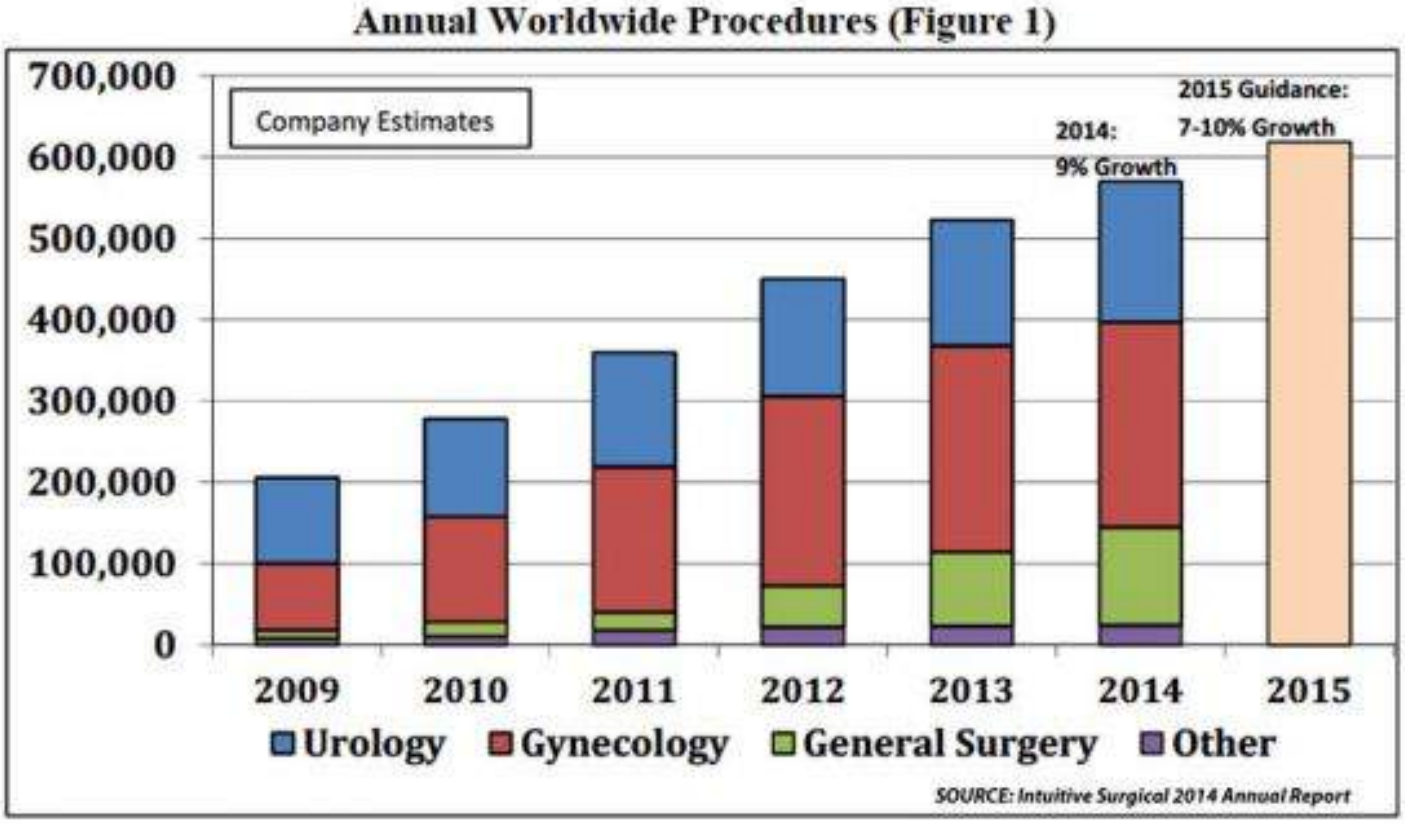
Samples:
20 bariatric "expert" surgeons ranked by at least 10 reviewers.
10,343 patients admitted 2006-2012



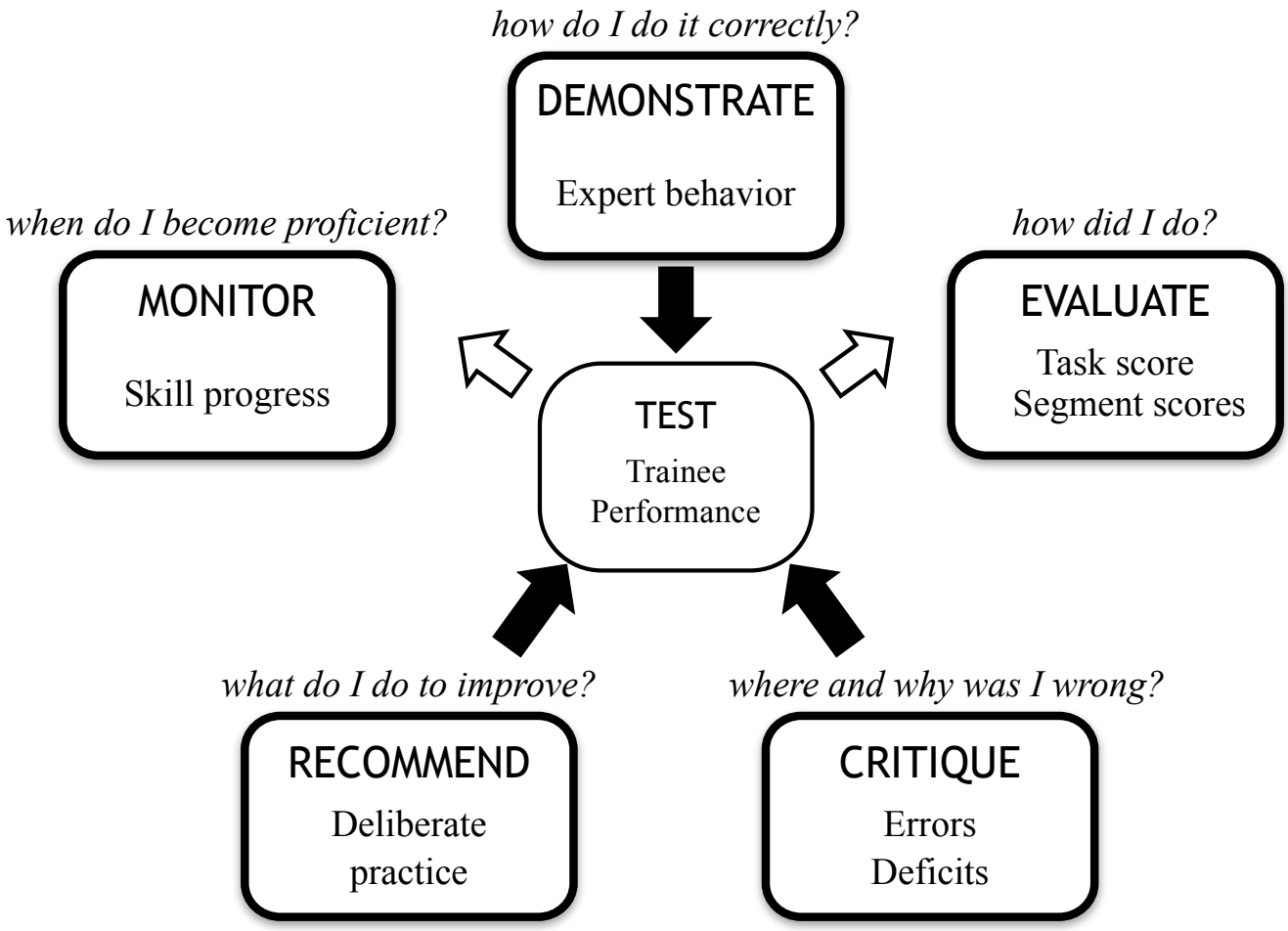
Birkmeyer J.D, et al. Surgical Skill and Complication Rates after Bariatric Surgery. NEJM, 2013.

Credit: Intuitive Surgical

What Could You Do With a Million Surgeries?

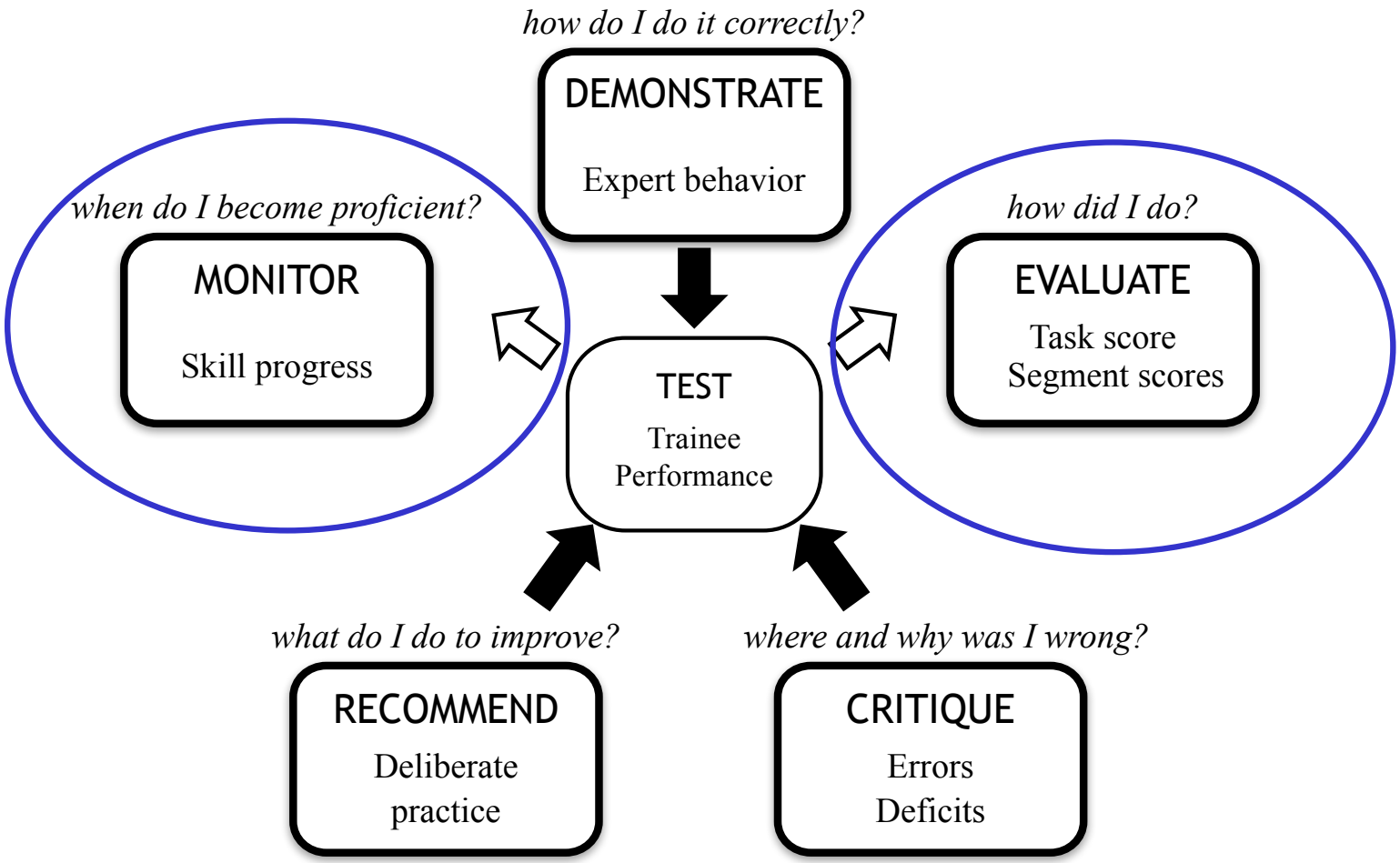


Can Machines Help Train Surgeons?

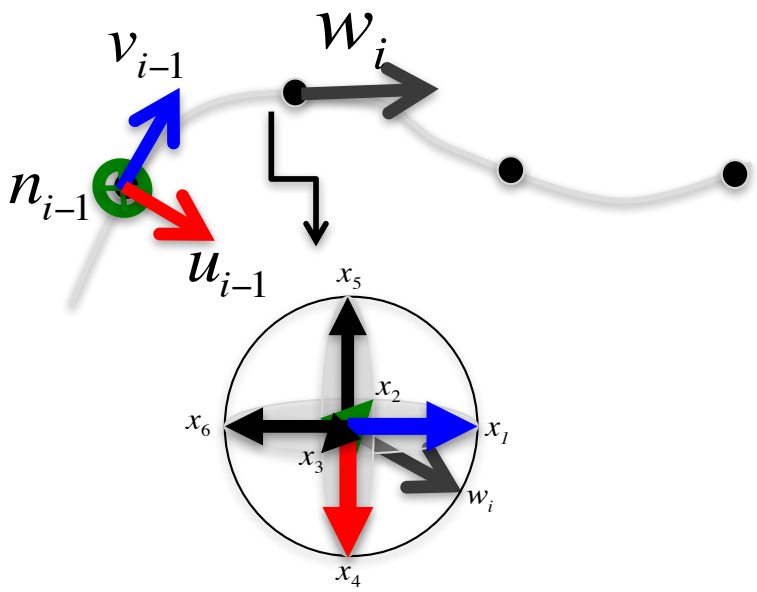


© Anand Malpani, 2016. Automated Virtual Coach for Surgical Training

Can Machines Help Train Surgeons?



Evaluate: How Am I Doing?

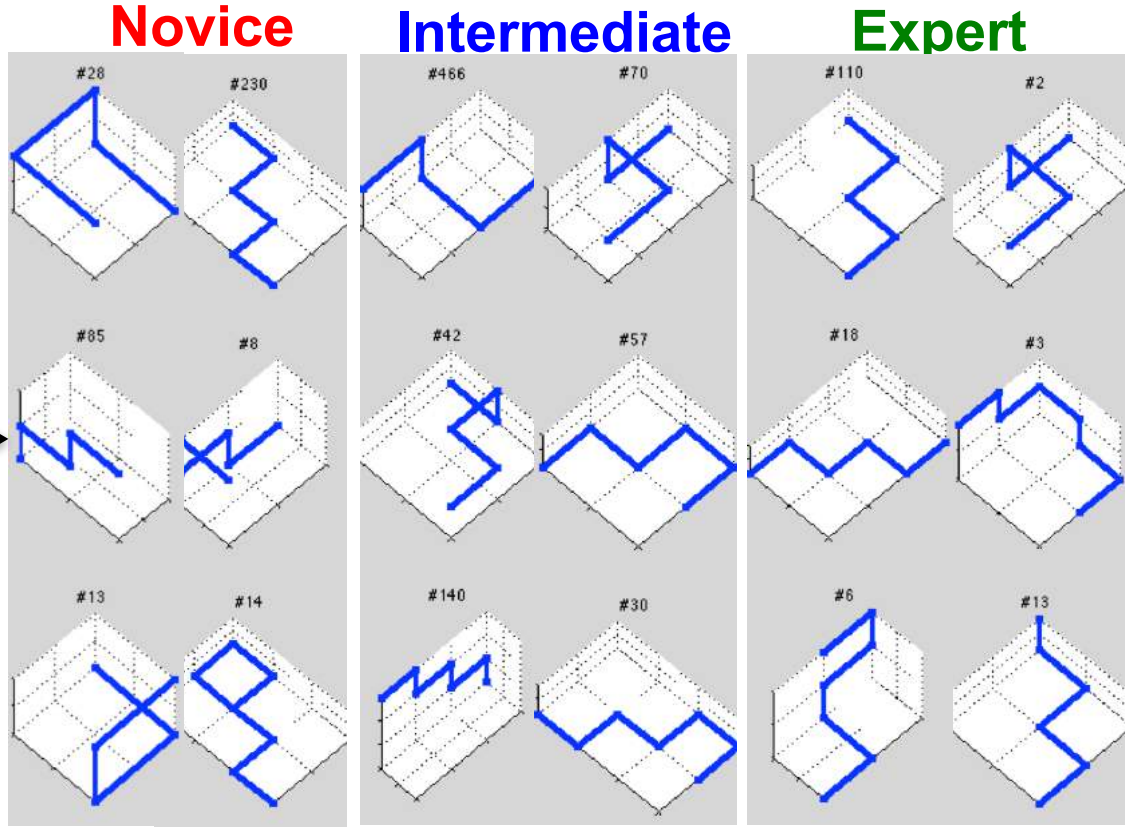



```
ID=1
gddfdfffffffeggefgeegefdeffffgeedfggfefefe

ID=2
cggeefcdffeffegcfgeeffgefgefgefggeddggcffff

ID=3
ecffdfgeeggcfgeeffggcffffegeeggfegggeccffff
```

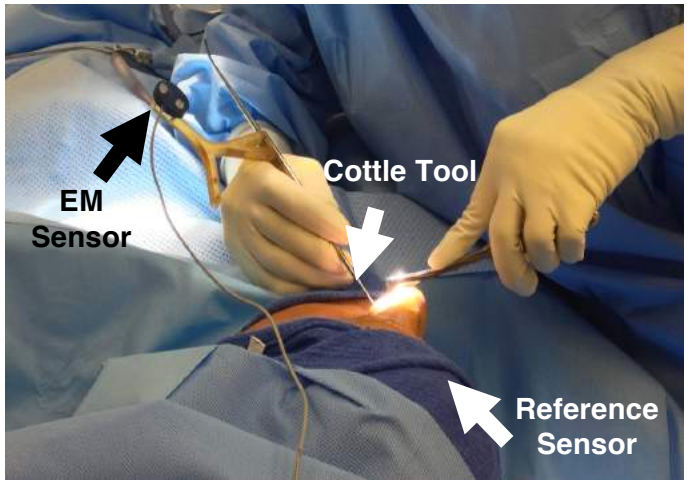
Translate movement to a string

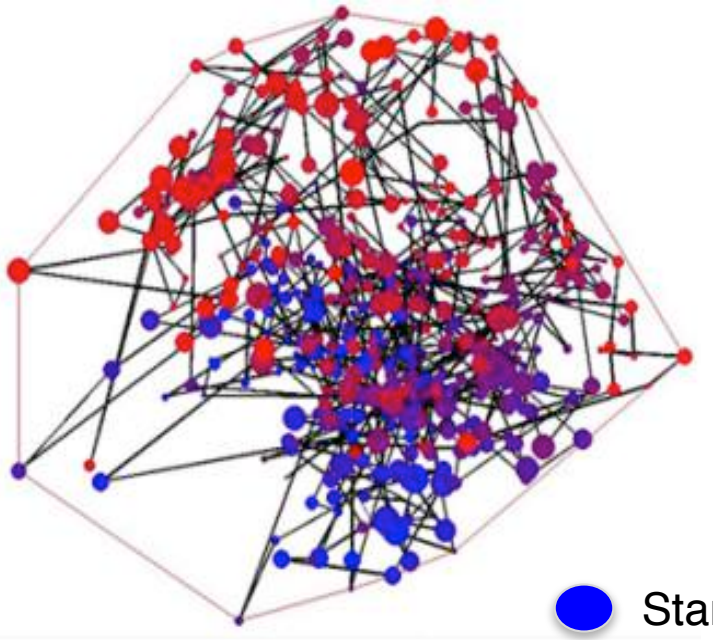


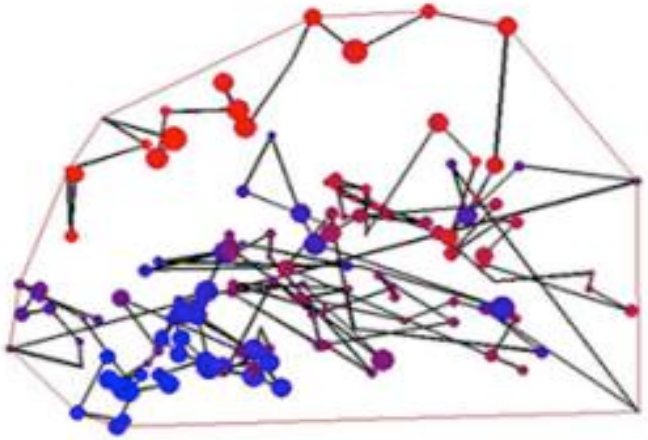
Build category-specific dictionaries

Ahmidi et al. Automated objective surgical skill assessment in the operating room from unstructured tool motion in septoplasty." IJCARS (2015)
Ahmidi, et al. "String Motif-Based Description of Tool Motion for Detecting Skill and Gestures in Robotic Surgery." *MICCAI*, 2013.

An Example: Sinus Surgery







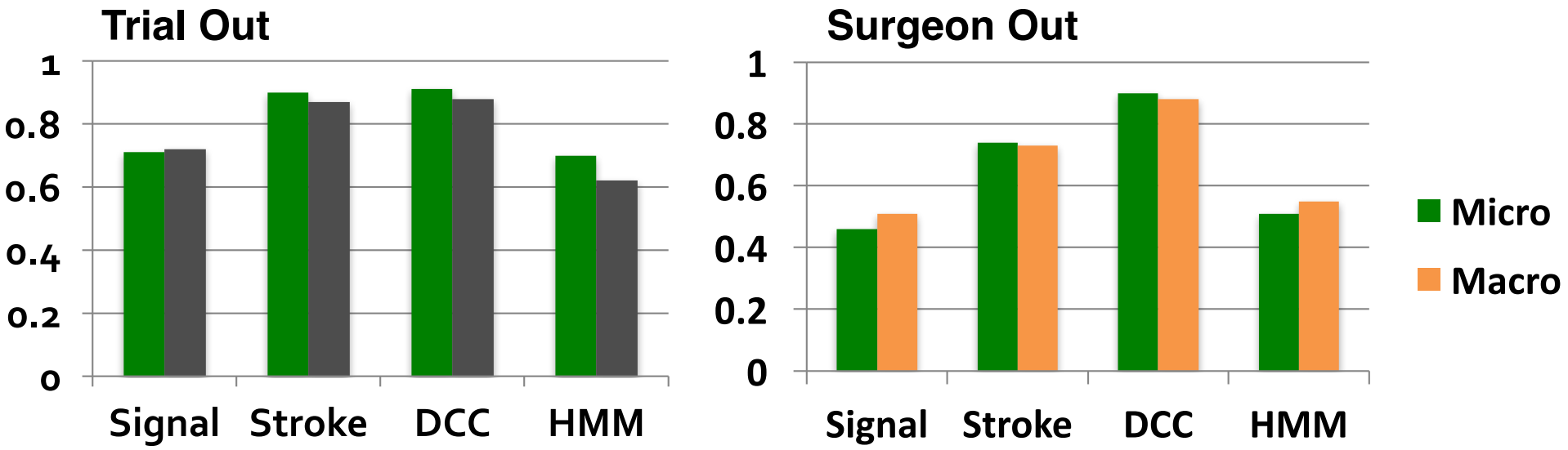
Start of Surgery

End of Surgery

NOVICE

EXPERT

Classifying Attending vs. Resident: Results

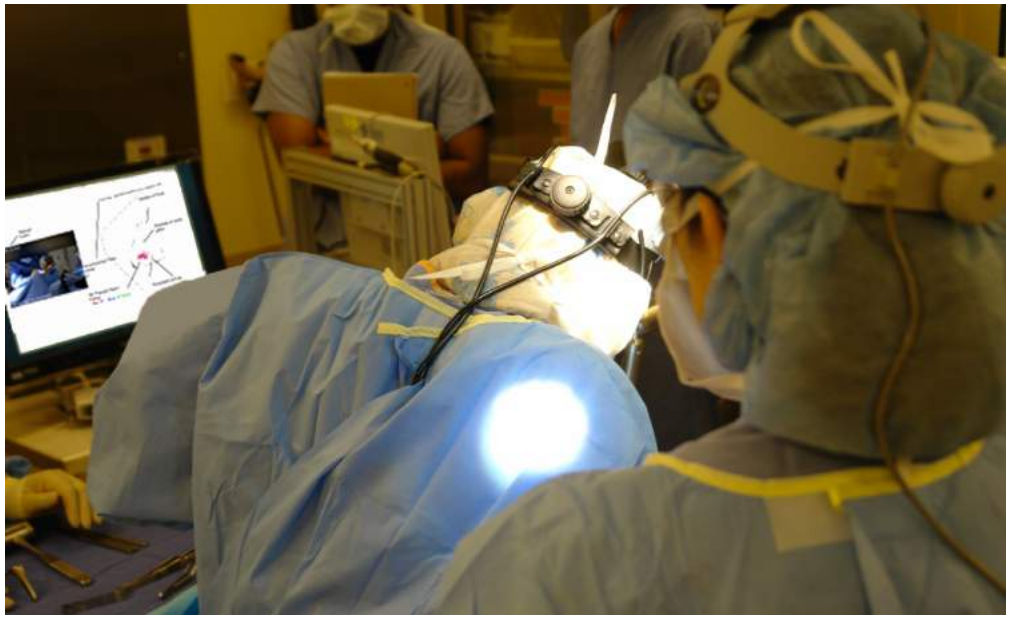


Ahmidi et al. Automated objective surgical skill assessment in the operating room from unstructured tool motion in septoplasty." IJCARS (2015)

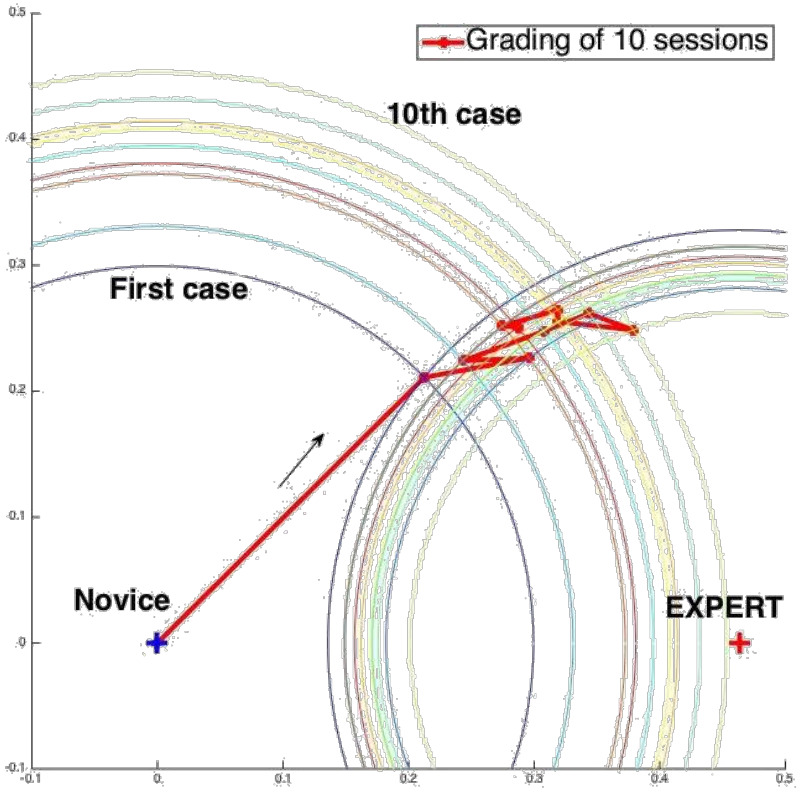
[DCC] Ahmidi N, et al.: String Motif-Based Description of Tool Motion for Detecting Skill and Gestures in Robotic Surgery. MICCAI (2013)

[HMM] Varadarajan B, et al.: Data-derived models for segmentation with application to surgical assessment and training. MICCAI (2009)

Monitoring Skill Progress



Providing On-Site Feedback

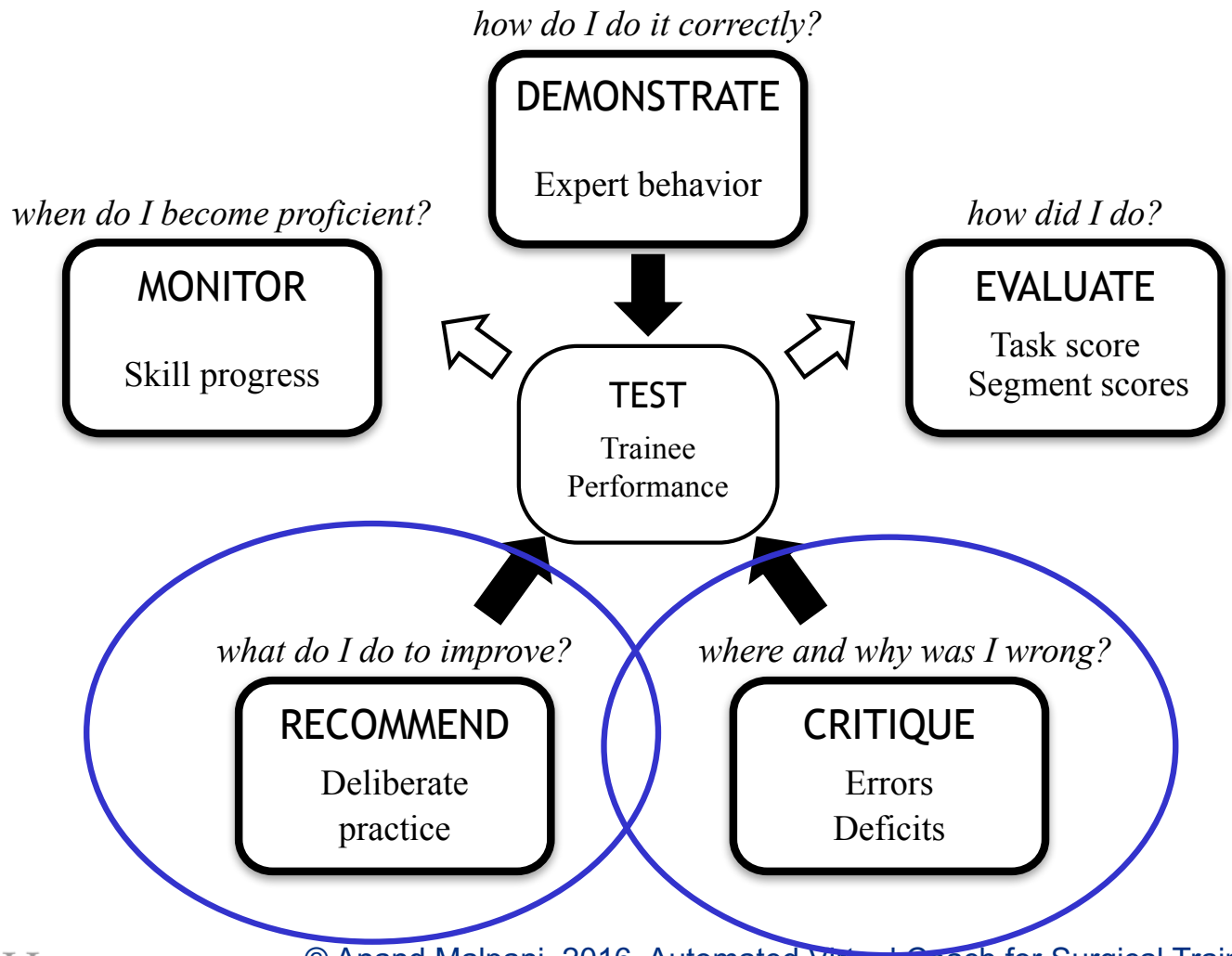


Following Trainees' Progress

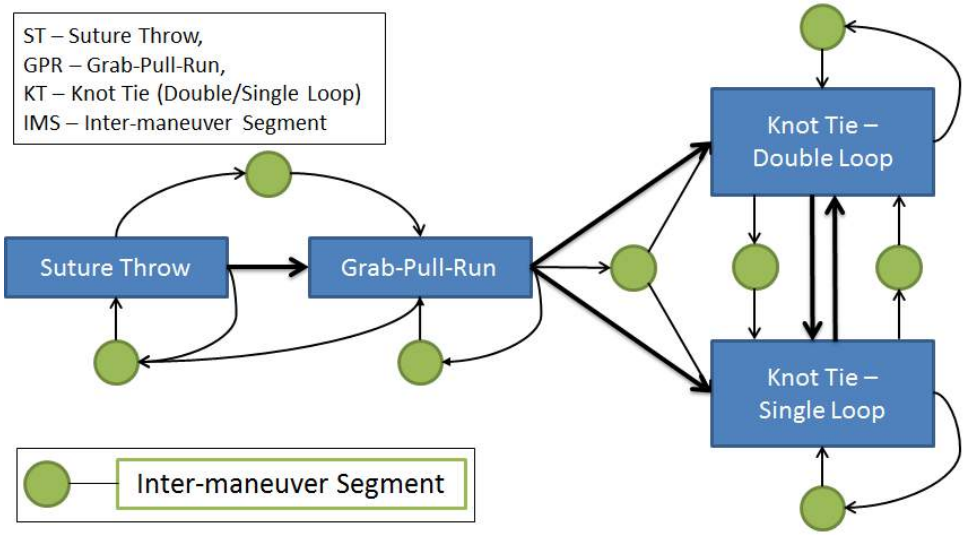
Collecting another 500+ trials (R01-DE025265 01)

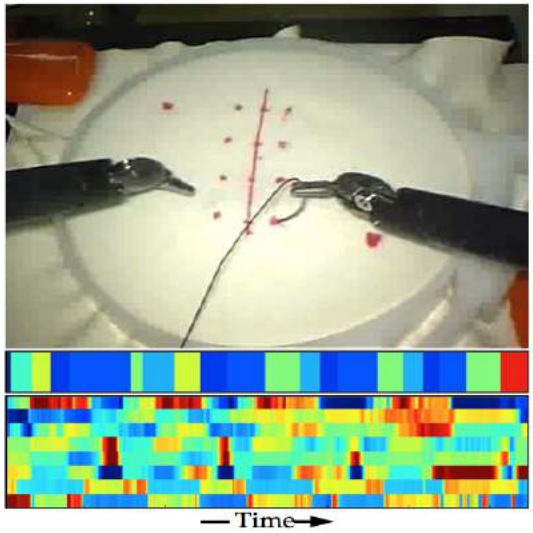
- 2 academic medical centers
- 6 operating room suites
- 29 surgeons: 7 faculty; 22 trainees
- 181 procedures

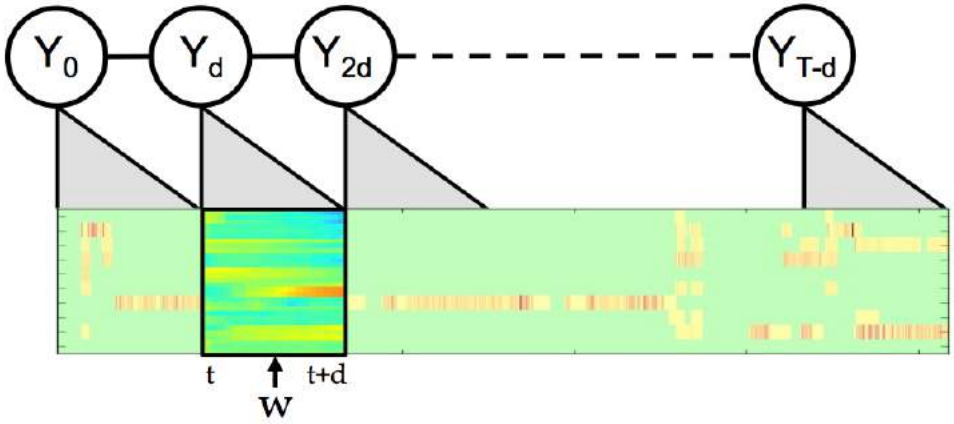
Automated Feedback for Training



Where Did I Under-Perform?







Lea, Colin, et al. Temporal Convolutional Networks for Action Segmentation and Detection CVPR 2017.
Lea et al. Learning Convolutional Action Primitives for Fine-grained Action Recognition ICRA 2016
Lea et al. Segmental spatiotemporal CNNs for fine-grained action segmentation. ECCV 2016
Lea et al. Surgical phase recognition: From instrumented ORs to hospitals around the world." M*2CAI* 2016.

Phases, Maneuvers, Gestures

	Spatial CNN			ST-CNN				
Data source(s)	LM	SMM	DTW	LM	SMM	DTW	[3]	[15]
Video	57.6	78.8	81.2	69.0	77.8	**84.6**	68.1	79.7*
Tools	58.5	76.5	85.7	56.4	78.3	**91.2**	78.9	73.0
Video + Tools	73.7	87.3	92.3	81.8	88.5	**92.8**	88.9	-

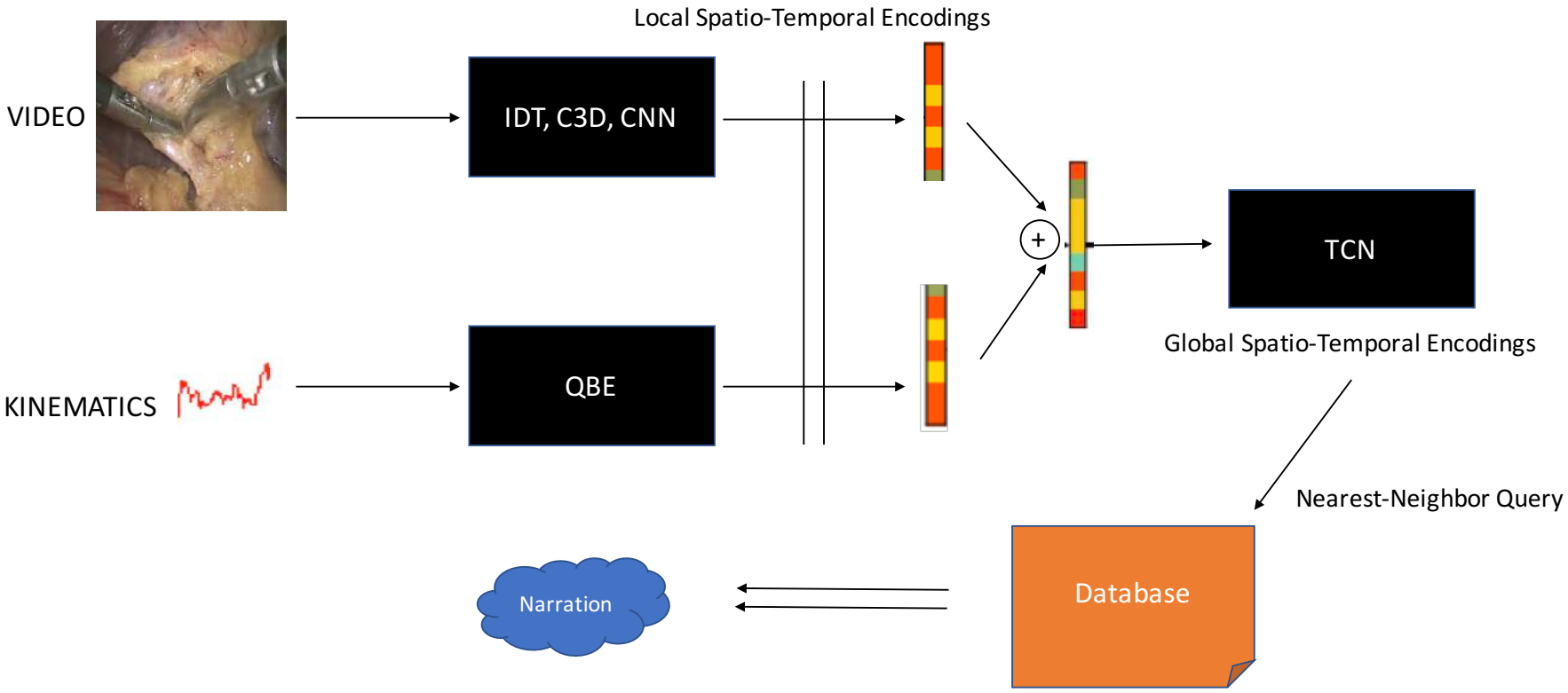
[3] Dergachyova IPCAI 2016 [15] Twinanda TMI 2016

*=86.0% if trained using outside surgical data + tools

	JIGSAWS		MISTIC-SL	
	Accuracy (%)	Edit Dist. (%)	Accuracy (%)	Edit Dist. (%)
LC-SC-CRF [10]	82.5 ± 5.4	14.8 ± 9.4	81.7 ± 6.2	29.7 ± 6.8
Forward LSTM	80.5 ± 6.2	19.8 ± 8.7	87.8 ± 3.7	33.9 ± 13.3
Bidir. LSTM	**83.3 ± 5.7**	**14.6 ± 9.6**	**89.5 ± 4.0**	**19.5 ± 5.2**

Ahmidi et al. A dataset and benchmarks for segmentation and recognition of gestures in robotic surgery. *TBME, 2017*
DiPietro et al. "Recognizing surgical activities with recurrent neural networks." *MICCAI, 2016*

What Did I Do Wrong?

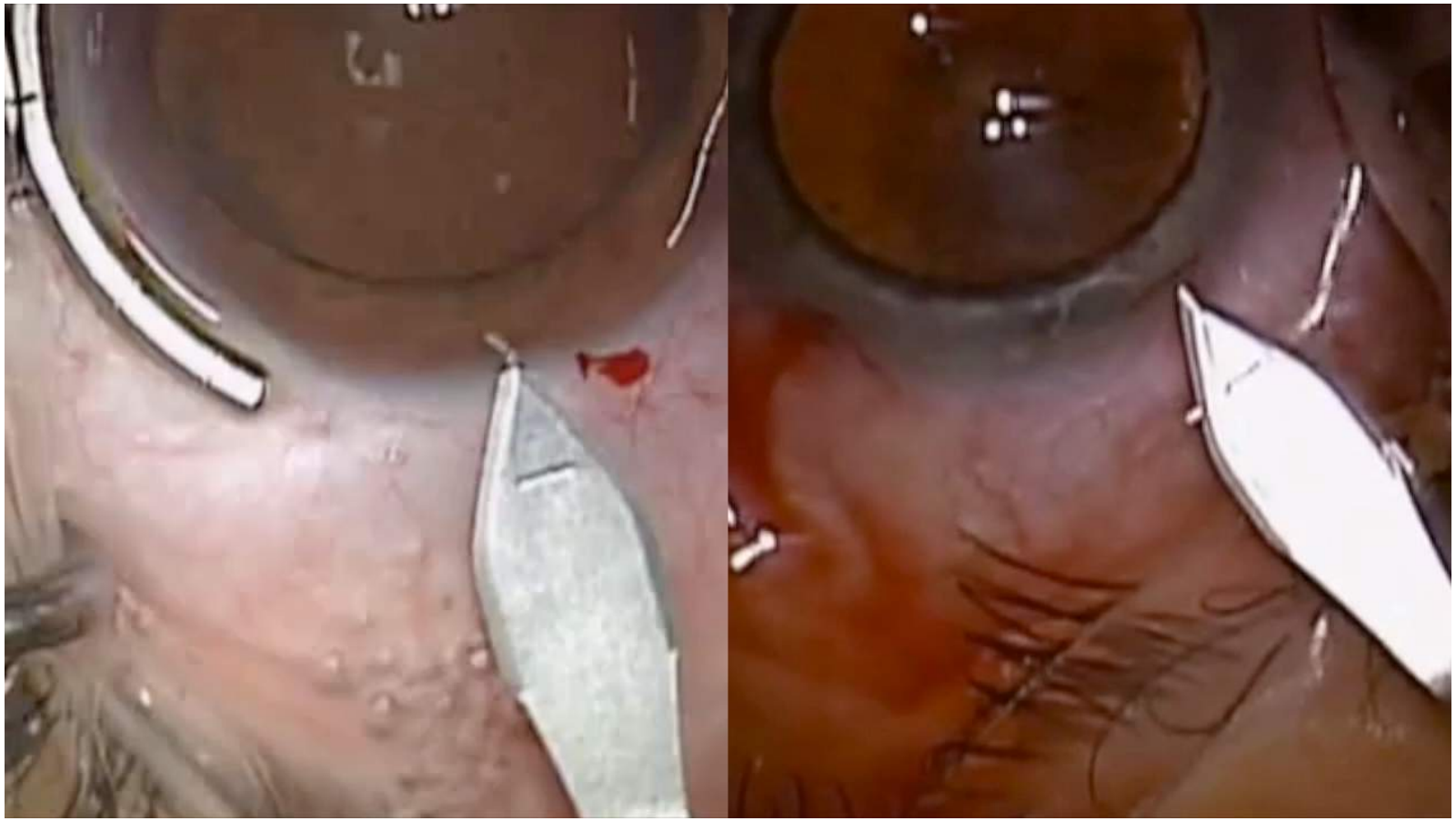


Use video as an index into feedback for a trainee based on most similar known performance

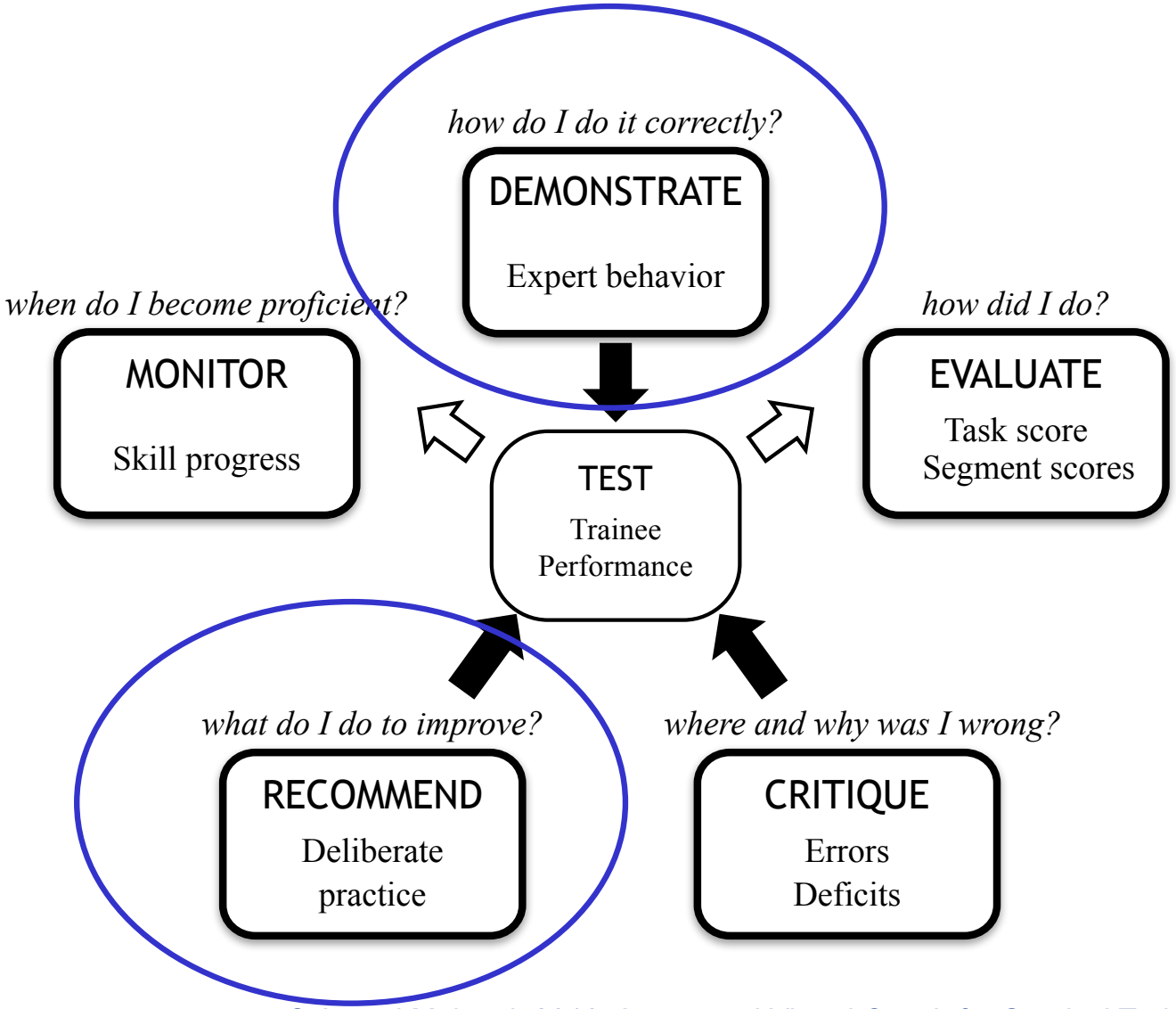
What Did I Do Wrong?

Query Video (Phase #2)

Closest Matching Clip



Automated Feedback for Training



What Can I Do To Improve?

Grasp Needle

↓

Insert Needle in Tissue

↓

Drive Needle through Tissue

↓

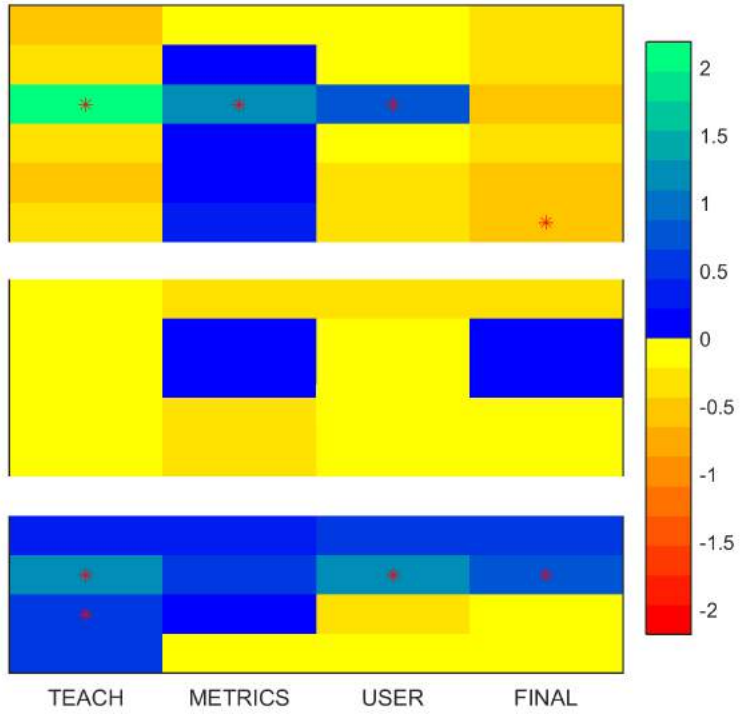
Pull out Needle

Malpani et al. Real-time Teaching Cues for Automated Surgical Coaching.
https://arxiv.org/abs/1704.07436

Improvement over baseline performance between groups

$$\Delta M_{expt} - \Delta M_{ctrl}$$

(*) indicate P-values < 0.05 using a Mann-Whitney *U*-test



Larger Experimental group learning

Larger Control group learning

A Final Thought: Public Health Implications

- Number of Surgeries
  - US: 50M
  - Worldwide: 312M
- The Cost of Surgery
  - US: 180B

Rank	First-listed OR procedure*	Aggregate costs for hospital stays, $ in millions	Percent of aggregate costs for stays with OR procedures, %	Mean cost per hospital stay, $	Number of stays, in thousands
First-listed OR procedures		**180,335**	**100.0**	**16,600**	**10,867**
1	Spinal fusion	12,837	7.1	27,600	465
2	Arthroplasty of knee	11,317	6.3	15,900	711
3	Percutaneous coronary angioplasty (PTCA)	9,730	5.4	18,800	517
4	Hip replacement, total and partial	7,962	4.4	17,200	464
5	Cesarean section	7,481	4.1	5,900	1,269
6	Colorectal resection	6,747	3.7	23,400	289
7	Coronary artery bypass graft (CABG)	6,411	3.6	38,700	166
8	Heart valve procedures	6,070	3.4	53,400	114
9	Cholecystectomy and common duct exploration	5,048	2.8	12,600	400
10	Treatment, fracture or dislocation of hip and femur	4,275	2.4	16,800	255

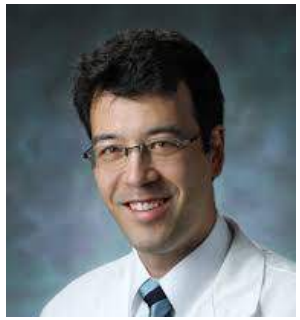
Agency for Healthcare Research and Quality (AHRQ), Center for Delivery, Organization, and Markets, Healthcare Cost and Utilization Project (HCUP), Nationwide Inpatient Sample (NIS), 2011

- Limitations
  - 5B people lack access to high quality surgical care
  - 5.6M deaths due to lack of access to quality surgical care
  - 9M procedures (3%) encounter major complications; 0.5% deaths

Surgical data science for next-generation interventions. Maier-Hein, Vedula,… Hager. Nature Biomedical Engineering, 2017
Surgical data science: the new knowledge domain. Vedula, Hager. *Innovative Surgical Sciences*, 2017.

Machines can learn from people, not to replace them, but to help make people better at what they do!

Clinical Collaborators



Masaru Ishii
Otolaryngology – Head & Neck Surgery

Lisa Ishii
Otolaryngology – Head & Neck Surgery

Mohamad Allaf
Urology

Shameema Sikder
Ophthalmology

Susan Gearhart
General Surgery

Gina Adrales
Minimally Invasive Surgery

Grace Chen
Obstetrics & Gynecology

Engineering Collaborators

Rene Vidal
BME

Sanjeev Khudanpur
ECE

Russ Taylor
CS

Austin Reiter
CS

Narges Ahmidi
Malone Center

Swaroop Vedula
Malone Center

Anand Malpani
Malone Center

The Motion Modeling and HMCS Mafia

Faculty:	**Students and Staff:**	Kel Guerin	**Alumni:**	David Yuh, MD
Gregory Hager, PhD	Anand Malpani	Jon Bohren	Sebastian Reidel, MS	Ehsan Elhamifar, PhD
René Vidal, PhD	Christopher Paxton	Amanda Edwards	Hanyue Llang	Henry Lin, PhD
Sanjeev Khudanpur, PhD	Colin Lea	Carol Reiley	Amod Jog	Luca Zappella, PhD
Grace Chen, MD	George Chen	Chi Li	Anton Deguet	Nicolas Padoy, PhD
Gyusung Lee, PhD	Lingling Tao	Amir Ghalamazan	Balakrishnan Varadarajan, PhD	Rajesh Kumar, PhD
Lisa Ishii, MD	Mija Lee, PhD	Xiang Xiang	Balazs Vagvolgyi	Sebastian Bodenstedt, MS
Masaru Ishii, MD, PhD	Narges Ahmidi	Yixin Gao	Benjamín Béjar, PhD	Steven Hsiao, PhD
Michael Marohn, DO	Swaroop Vedula, MD PhD		Piyush Poddar, MS	Thomas Tantillo, MS

Publications: **https://publications.lcsr.jhu.edu/groups/HMM**

NSF NRI 1227277, NSF CPS 0931805, NSF CDI-II 0941362, NIH 1R21EB009143, NIH 5R21DE022656-02, NIH R01DE025265

Intuitive Surgical, Inc., Science of Learning Institute (JHU)

European Commission

IAS TUM Institute for Advanced Study

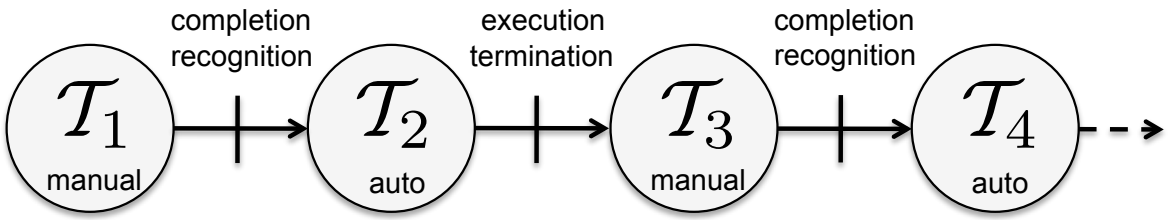
The Center For Language and Speech Processing at the Johns Hopkins University

Center for IMAGING SCIENCE JOHNS HOPKINS UNIVERSITY

CIRL Computational Interaction and Robotics Laboratory

QUESTIONS?

Learned Cooperative Execution



Suturing Task

#	Name
1	Grasp needle (RT) from pod, move to 1st suture point (RT), Insert needle (RT), grasp it (LT)
2*	Pull thread out (LT), move back to 2nd suture point (LT)
3	Grasp needle (RT) from (LT), Insert needle (RT), grasp it (LT)
4*	Pull thread out (LT), move back to 3rd suture point (LT)
5	Grasp needle (RT) from (LT) Insert needle (RT), grasp it (LT)
6*	Pull thread out (LT), move back to pod end point (LT)

Padoy and Hager, Human-Machine Collaborative surgery using learned models, ICRA 2011

From Data to Collaboration

Padoy and Hager. "Human-machine collaborative surgery using learned models." *ICRA 2011*