How is skill acquired?


The Oldest Skilled Trade Jobs

- **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**

**Share of 45+ Workers**

**Share of 55+ Workers**
Skill Acquisition: Apprenticeship

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

Training and Skill Impacts Patient Outcomes

- **Readmission**
  - Score Bottom Quartile: 6.30%
  - Score Top Quartile: 2.70%

- **Reoperation**
  - Score Bottom Quartile: 3.40%
  - Score Top Quartile: 1.60%

- **Complication**
  - Score Bottom Quartile: 14.50%
  - Score Top Quartile: 5.20%

- **Mortality**
  - Score Bottom Quartile: 0.26%
  - Score Top Quartile: 0.05%
  - 3x Mortality Rate!

Michigan Bariatric Surgery Collaborative

**Samples:**
20 bariatric “expert” surgeons ranked by at least 10 reviewers.

**10,343 patients admitted 2006-2012**

What Could You Do With a Million Surgeries?

Annual Worldwide Procedures (Figure 1)

- Company Estimates
- 2015 Guidance: 7-10% Growth
- 2014: 9% Growth

- Urology
- Gynecology
- General Surgery
- Other

SOURCE: Intuitive Surgical 2014 Annual Report
Can Machines Help Train Surgeons?

- **Demonstrate**: Expert behavior
- **Test**: Trainee performance
- **Evaluate**: Task score, Segment scores
- **Monitor**: Skill progress
- **Recommend**: Deliberate practice
- **Critique**: Errors, Deficits

- **How do I do it correctly?**
- **When do I become proficient?**
- **How did I do?**
- **What do I do to improve?**
- **Where and why was I wrong?**
Can Machines Help Train Surgeons?

how do I do it correctly?

how did I do?

what do I do to improve?

where and why was I wrong?

MONITOR
Skill progress

EVALUATE
Task score
Segment scores

CRITIQUE
Errors
Deficits

RECOMMEND
Deliberate
practice

TEST
Trainee
Performance

DEMONSTRATE
Expert behavior

when do I become proficient?

when do I become proficient?
Translate movement to a string

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)


Monitoring Skill Progress

Providing On-Site Feedback

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

how do I do it correctly?

how did I do?

when do I become proficient?

what do I do to improve?

where and why was I wrong?

DEMONSTRATE
Expert behavior

TEST
Trainee Performance

EVALUATE
Task score
Segment scores

RECOMMEND
Deliberate practice

CRITIQUE
Errors
Deficits

© Anand Malpani, 2016. Automated Virtual Coach for Surgical Training
Where Did I Under-Perform?

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.” M2CAI 2016.
Phases, Maneuvers, Gestures

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

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

Table 1: Quantitative results and comparisons to prior work.

<table>
<thead>
<tr>
<th>JIGSAWS</th>
<th>Accuracy (%)</th>
<th>Edit Dist. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC-SC-CRF [10]</td>
<td>82.5 ± 5.4</td>
<td>14.8 ± 9.4</td>
</tr>
<tr>
<td>Forward LSTM</td>
<td>80.5 ± 6.2</td>
<td>19.8 ± 8.7</td>
</tr>
<tr>
<td>Bidir. LSTM</td>
<td><strong>83.3 ± 5.7</strong></td>
<td><strong>14.6 ± 9.6</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MISTIC-SL</th>
<th>Accuracy (%)</th>
<th>Edit Dist. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC-SC-CRF [10]</td>
<td>81.7 ± 6.2</td>
<td>29.7 ± 6.8</td>
</tr>
<tr>
<td>Forward LSTM</td>
<td>87.8 ± 3.7</td>
<td>33.9 ± 13.3</td>
</tr>
<tr>
<td>Bidir. LSTM</td>
<td><strong>89.5 ± 4.0</strong></td>
<td><strong>19.5 ± 5.2</strong></td>
</tr>
</tbody>
</table>

Ahmidi et al. A dataset and benchmarks for segmentation and recognition of gestures in robotic surgery. *TBME, 2017*
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

**Demonstrate**: Expert behavior

**Test**: Trainee performance

**Evaluate**: Task score, Segment scores

**Monitor**: Skill progress

**Recommend**: Deliberate practice

**Critique**: Errors, Deficits

**How do I do it correctly?**

**How did I do?**

**When do I become proficient?**

**What do I do to improve?**

**Where and why was I wrong?**

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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

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Improvement over baseline performance between groups

\[ \Delta M_{\text{expt}} - \Delta M_{\text{ctrl}} \]

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

Motion metrics

Error metrics

Deficit metrics

Larger Experimental group learning

Larger Control group learning

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A Final Thought: Public Health Implications

- **Number of Surgeries**
  - US: 50M
  - Worldwide: 312M

- **The Cost of Surgery**
  - US: 180B

- **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

---

### Table: First-listed OR procedures

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

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

---

Surgical data science for next-generation interventions. Maier-Hein, Vedula, ... Hager. Nature Biomedical Engineering, 2017

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

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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
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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

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- Balazs Vagvolgyi
- Benjamín Béjar, PhD
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---

**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)
QUESTIONS?
Learned Cooperative Execution

![Diagram](image_url)

**Suturing Task**

<table>
<thead>
<tr>
<th>#</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Grasp needle (RT) from pod, move to 1st suture point (RT), Insert needle (RT), grasp it (LT)</td>
</tr>
<tr>
<td>2*</td>
<td>Pull thread out (LT), move back to 2nd suture point (LT)</td>
</tr>
<tr>
<td>3</td>
<td>Grasp needle (RT) from (LT), Insert needle (RT), grasp it (LT)</td>
</tr>
<tr>
<td>4*</td>
<td>Pull thread out (LT), move back to 3rd suture point (LT)</td>
</tr>
<tr>
<td>5</td>
<td>Grasp needle (RT) from (LT) Insert needle (RT), grasp it (LT)</td>
</tr>
<tr>
<td>6*</td>
<td>Pull thread out (LT), move back to pod end point (LT)</td>
</tr>
</tbody>
</table>

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