Biorobotics: Skilled Human + Robotics = Better Care

Blake Hannaford, Biorobotics Laboratory

http://brl.ee.washington.edu
Biorobotics Lab, Dept. of EE, U of W

<table>
<thead>
<tr>
<th>Prof.</th>
<th>Research Area</th>
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<td>Sam Burden</td>
<td>Legged Robot / Animal Locomotion</td>
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<td>Howard Chizeck</td>
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<td>Medical Robotics, Telerobotics</td>
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Spinout Companies:

- AppliedDexterity
- BluHaptics
- CSATS
Biorobotics Lab, Dept. of EE, U of W

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Spinout Companies:

- [Applied Dexterity](#)
- [BluHaptics](#)
- [CSATS](#)
Key Collaborators

- **Surgeons:** Mika Sinanan, Thomas Lendvay, Laligam Sekhar, Kris Moe, Randy Bly
- **Engineers:** Jacob Rosen, Eric Seibel
- **Universities:** Johns Hopkins, Stanford, Berkeley
- **Companies:** Applied Dexterity, Google-X/Verily → Verb Surgical
Representative Projects

- Raven Robotics Research Platform
- Advanced Photonics for Image-Guided Robotic Surgery
- Behavior Trees for introducing AI into surgery
Clinical Challenges

● Better patient outcomes
  ✓ safety/effectiveness/new cures?
  ✓ quicker/more comfortable recovery
  ✓ cost effectiveness
  ✓ cosmetics

● Smaller and fewer incisions: “MIS” “SILS”

● Natural orifices: “NOTES”
Minimally Invasive Surgery

Natural Orifice Surgery

1. An endoscope is inserted into the patient's mouth...
   - Endoscope

2. Fed through the esophagus...
   - Esophagus

3. And into the stomach...
   - Stomach

4. Where it pierces the stomach wall.
   - Stomach Wall

5. The device passes underneath the liver to the gallbladder, which it grasps, ties off, cuts and removes through the mouth.
   - Liver
   - Gallbladder

nih.gov

washingtonpost.com
Da Vinci Hand-Eye Registration / Coordination
Da Vinci Hand-Eye Registration / Coordination

3D Vision for Surgeon

5-8mm diameter

“intuitive” motion control
Over 4,000,000 human patients
Over 4000 systems sold
Over $3B per year in revenue
Hundreds of patents

So far:
100% manual teleoperation
Can we augment surgeon’s capabilities with partial automation?
Raven: Goals (2002)

- Portable and robust surgical telerobot research platform
- Minimize mechanism size
- Maximize $\frac{V_w}{V_m}$ (workspace/total volume)
- Enable field use
- Support open software development
- Support Interoperable Teleoperation
Raven-I
Raven Scaling

- NSF: Build for 7 US institutions (~2011)
- Contracts: 5 more institutions
- Applied Dexterity: commercialization for research market
Raven II Software APIs

User / Research Applications

ROS

1000 Hz real time control

UDP Teleop.

Linux Kernel (RT-Preempt Config)

https://github.com/uw-biorobotics/raven2
Raven II Software APIs

2017+: Joint API with Johns Hopkins

- User / Research Applications
- ROS
  - 1000 Hz real time control
  - UDP Teleop.
  - Linux Kernel (RT-Preempt Config)

https://github.com/uw-biorobotics/raven2
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<th>University of Washington</th>
<th>Prof. Blake Hannaford</th>
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<td>U.C. Santa Cruz</td>
<td>Prof. Jacob Rosen</td>
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2012

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<tr>
<td>Harvard</td>
<td>Prof. Rob Howe</td>
<td>Beating Heart Surgery</td>
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<tr>
<td>Hopkins</td>
<td>Prof. Greg Hager</td>
<td>Human-Machine Cooperation</td>
</tr>
<tr>
<td>Nebraska</td>
<td>Prof. Shane Farritor</td>
<td>Deployable surgical robots</td>
</tr>
<tr>
<td>UCLA</td>
<td>Prof. Warren Grundfest</td>
<td>Tactile feedback to surgeon</td>
</tr>
<tr>
<td>U.C. Berkeley</td>
<td>Prof. Ken Goldberg &amp; Pieter Abbeel</td>
<td>Machine Learning of surgical autonomy</td>
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2013

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<tr>
<td>Stanford University</td>
<td>Prof. Allison Okamura</td>
<td>NRI Large Project</td>
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<tr>
<td>Montpellier University (Fr)</td>
<td>Prof. Philine Poignet</td>
<td>LIRMM</td>
</tr>
<tr>
<td>U. of Central Florida</td>
<td>Prof. Zihua Xu</td>
<td></td>
</tr>
<tr>
<td>U. of Western Ontario (Canada)</td>
<td>Prof. Rajni Patel</td>
<td>(four-arm system)</td>
</tr>
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Raven-II Sites

NSF CRI Sites (installed 2012)
Raven-II Sites

- NSF CRI Sites
- Contracted Sites (2013)
Raven-II Sites

- NSF CRI Sites
- UW Contract Sites
- ADI Sites 2015-17
Raven Commercialization

Open source software:
https://github.com/uw-biorobotics/raven2
July 2018 Raven map: 17 sites, 20 systems
Coming soon: Advanced Surgical Console
Exploratory Project: Raven in ISS???
AI in robotic surgery?
Surgical plans – a **contrast** to A.I.

“Traditional” A.I.:

1. Initial State
2. Goal State
3. Affordances
4. Synthesize Sequence of Actions
NOT:

- Initial State
- Goal State
- Affordances

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**NOT:** Deep Neural Networks

- Neural inspired
- Thousands of identical units
- Trained on “ground truth” data (supervised learning)
- Major successes at Google etc.
- Huge amounts of training data
Characteristics of Surgical Plans

• Memorized or semi-automatic / required
• Robust to
  • Anatomical Variation
  • Pathology Variation
  • Accidents / slipups
• Probabilistic affordances
• “Concurrent threads”
• Exploration and Treatment
• Alternative methods / Fallbacks
Behavior Trees

- Video Game Industry
- Notation for composition of behaviors


• Thanks!!
Behavior Trees

• Root generates periodic ‘tics’
• A ‘pointer’ designates a single active node
• At each tick the active node can return:
  • “Working”
  • “Success”
  • “Failure”
• Leaf = robotic procedure / macro / control loop

Blake Hannaford, Danying Hu, University of Washington
Node types

• **Selector** Pass the tick to each child in turn
  Return Success when first child returns Success
  (try each child).

• **Sequence** Pass the tick to each child in turn
  Return Failure when first child returns Failure
  (perform each child in sequence)

• **Parallel** Launch all children simultaneously
  Return Success when > 50% of children return
  Success.
In order, Succeed when the FIRST child succeeds

In order, Succeed when all children succeed

Simultaneous: Succeed when xx% of children succeed

Leaves
Example

Get the Shoes

Blake Hannaford, Danying Hu, University of Washington
Medical Behavior Trees

\[
\varphi 
\rightarrow
\]

Diagnose
- Treat
Examples of BTs applied to Medicine
Blood Draw

**Source:** World Health Organization (WHO).

WHO guidelines on drawing blood: best practices in phlebotomy.
Geneva (Switzerland): World Health Organization (WHO); 2010. 109 p. *(Highly Abbreviated!)*
Blood Draw (W.H.O.)

1. Assemble Equipment
2. Patient Paperwork
3. Patient Ready?
4. Sanitize
5. Puncture
6. Draw
7. Left Arm
8. Right Arm
9. etc. etc. etc.
Emergency Airway Algorithm

• Source: emcrit.org

(http://emcrit.org/blogpost/shock-trauma-center-failed-airway-algorithm/)

http://orangecountyfl.net/emsref/
Emergency Airway Algorithm

• Source: emcrit.org

(http://emcrit.org/blogpost/shock-trauma-center-failed-airway-algorithm/)
If SP02 drops to 93% at any point:

- Facemask + OPA or SGA
- If no ETCO2 progress to Surgical Airway
Emergency Airway

- SpO2 < 93%?
  - O2 via facemask
  - Maintain Airway
- Absent ETCO2 (capnograph)
  - Surgical Airway
  - Induction, Muscle Relaxation
  - SGA Placement
    - Laryngoscopy, #1
    - Laryngoscopy, #2 (+/- Bougie)
    - Laryngoscopy, #3 With Bougie
- Intubation through SGA
- Post Tube Management
- Surgical Airway
NRI-Small: Advanced biophotonics for image-guided robotic surgery

University of Washington team of investigators:
Eric Seibel, PhD – laser imaging, diagnostics, surgery (PI)
Blake Hannaford, PhD – medical surgical robotics (co-I)
James M. Olson, MD, PhD – brain tumor fluorescence marker
Richard Ellenbogen, MD – brain surgeon, neurosurgery chair
Laligam Sekhar, MD – brain surgeon, neurosurgery vice-chair

Project Goals:
1. Small keyhole incision
2. Laser micro-endoscope (eye) on robotic surgical tool
3. Fluorescence highlights tumor cells in the brain
4. All tumor cells removed using computer vision based identification & navigation
5. Smallest possible margin to minimize loss of healthy tissue

Eye
Tumor in brain

Image-guided miniature robotic tool to surgically remove tumors (pathways top-right).

Laser imaging (left) on robot arms (center) manipulated by surgeon’s console of display and hand controls (right).
• **Behavior Tree Modeling of the Tumor Ablation Procedure**

![Behavior Tree](image)

Figure: BT representation of the tumor ablation procedure

• **3D virtual reconstruction of surgical field**

![3D reconstruction images](image)

(a) (b) (c) (d) (e)

• **Ablation path planning (in the planar surgical field)**

![Ablation path planning](image)
• Behavior Tree Modeling of the Tumor Ablation Procedure
Post Operative Patient Management: Pediatric Total Thyroidectomy

**Risk:** Do NOT accidentally take out the parathyroid glands

(Key function: life dependent regulation of Ca++ ions in your bloodstream)
Post operative management of Ca++ in pediatric total thyroidectomy

Anatomy of the Thyroid and Parathyroid Glands

Discharge

Post Op

Pre Op

Total of Completion Preparation Thyroidectomy Protocol

Fig. 1: Postoperative Thyroidectomy Protocol (Copyright, 2003, Randy Bly M.D., co-author)

Source: https://visualsonline.cancer.gov

Source: Randy Bly M.D., co-author
Post operative management of Calcium in pediatric total thyroidectomy: Behavior Tree
Conclusions

- **Raven II**
  - Much exciting research being done in surgical robotics
  - Worldwide community of Researchers
  - Exciting business opportunities

- **Behavior Trees**
  - A promising way to represent medical procedures / “clinical practice guidelines”
  - Human authorable, readable
  - Connect to AI techniques:
    - Hybrid dynamical systems
    - Hidden Markov Models
    - Machine Learning
Kinematics Tool: IKBT

https://github.com/uw-biorobotics/IKBT

- **Symbolic** Forward Kinematics, Jacobian Matrix, Inverse Kinematics
- All solutions, Solution sets, solution graph,
- LaTex, Python, C++ output.
非常感谢你
Thank you very much!