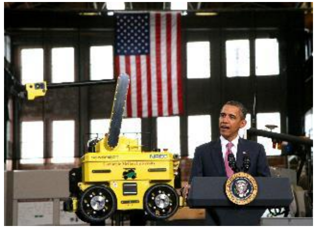
Biorobotics: Skilled Human + Robotics = Better Care

Blake Hannaford, Biorobotics Laboratory

UNIVERSITY OF WASHINGTON
ELECTRICAL ENGINEERING

http://brl.ee.washington.edu



Biorobotics Lab, Dept. of EE, U of W

Prof. Sam Burden	Legged Robot / Animal Locomotion	
Prof. Howard Chizeck	Brain-Computer-Interface	
Prof. Blake Hannaford	Medical Robotics, Telerobotics	

Spinout Companies:

Biorobotics Lab, Dept. of EE, U of W

Prof. Sam Burden	Legged Robot / Animal Locomotion	
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Spinout Companies:

AppliedDexterity — Driving Innovation in Surgical Robotics

BluHaptics

C-SATS

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

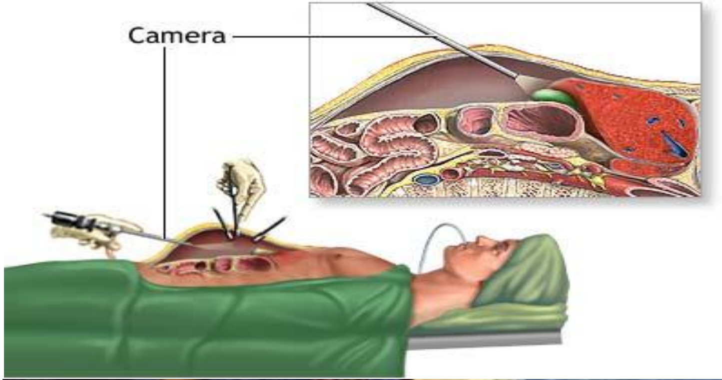
Representative Projects

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

Clinical Challenges

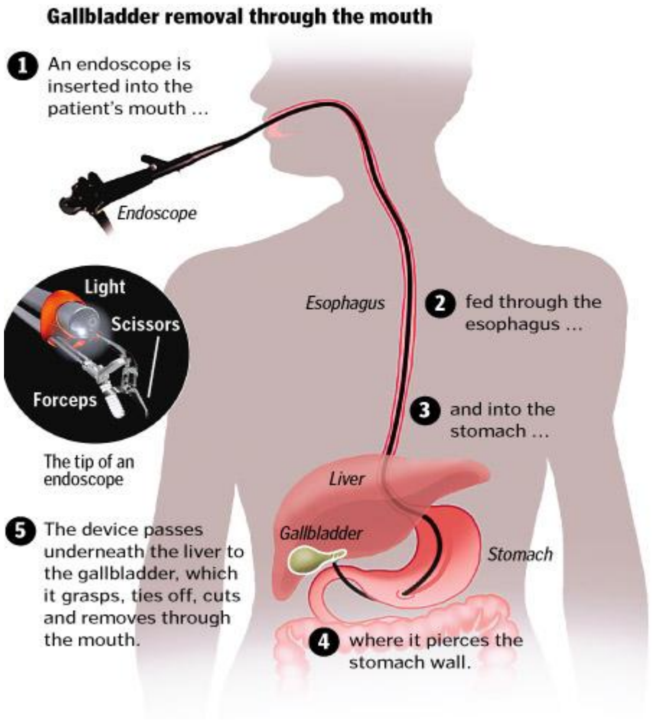
- Better patient outcomes
  - ✓ safety/effectiveness/new cures?
  - ✓ quicker/more comfortable recovery
  - ✓ cost effectiveness
  - ✓ cosmetics
- Smaller and fewer incisions: “MIS” “SILS”
- Natural orifices: “NOTES”

Minimally Invasive Surgery



nih.gov

Natural Orifice Surgery



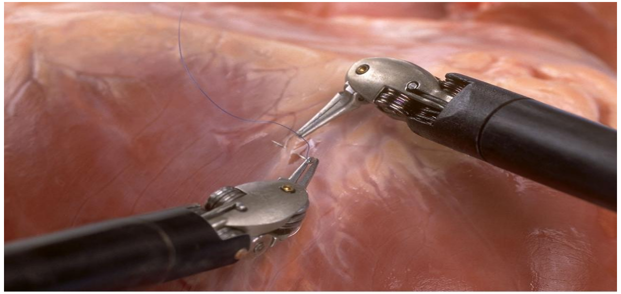
washingtonpost.com

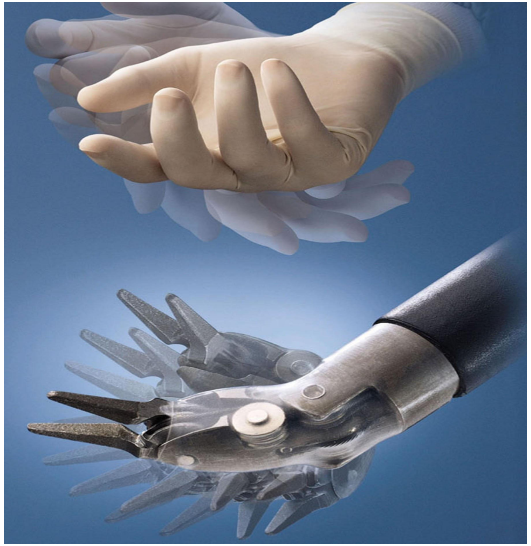
da Vinci

Fred
Moll


da Vinci
1
2
3

Da Vinci Hand-Eye Registration / Coordination

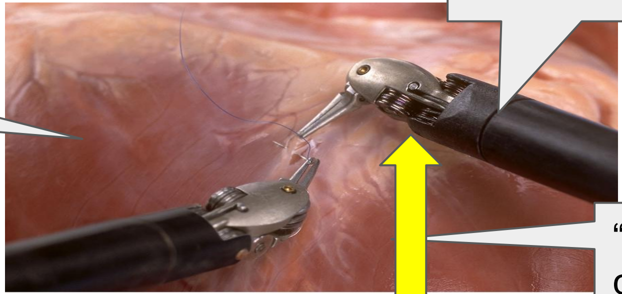




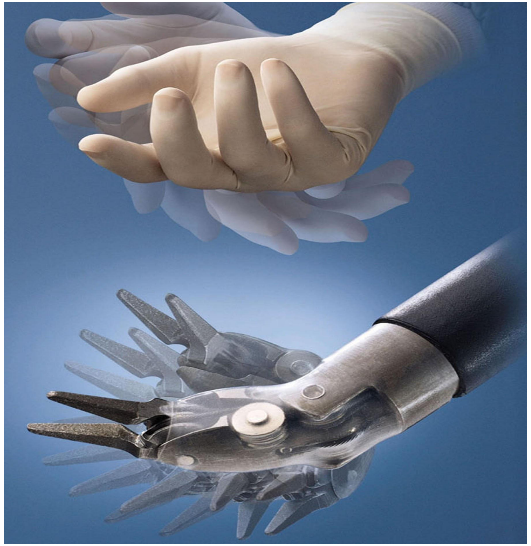
Da Vinci Hand-Eye Registration / Coordination

5-8mm diameter

3D Vision for Surgeon



"intuitive" motion control



- Over 4,000,000 human patients
- Over 4000 systems sold
- Over $3B per year in revenue
- Hundreds of patents

INTUITIVE SURGICAL®

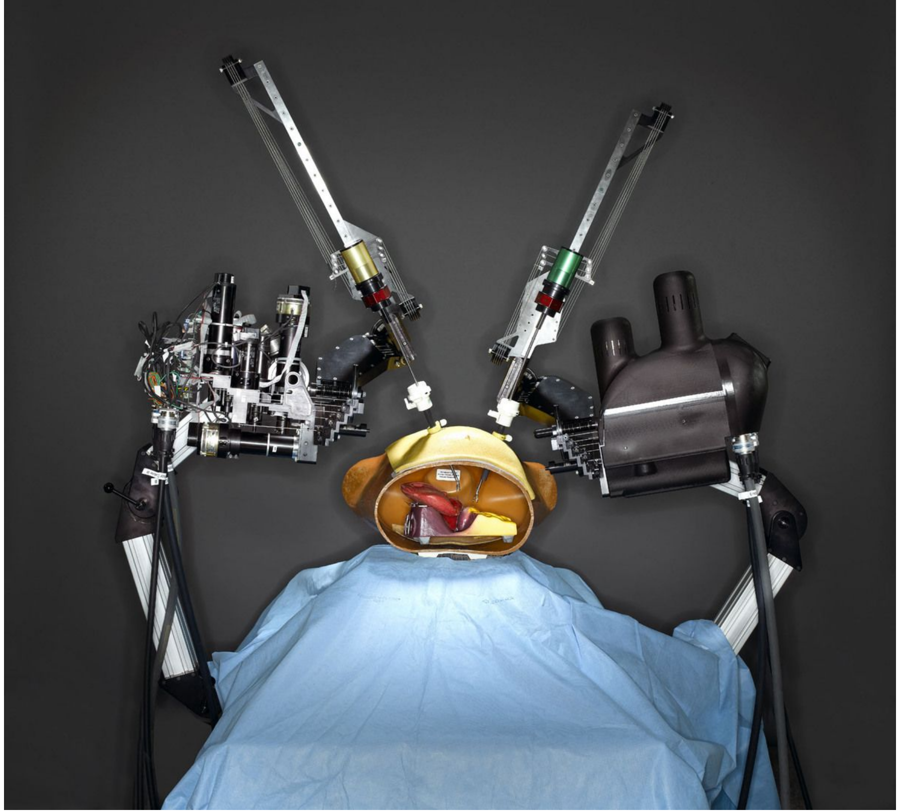
So far:

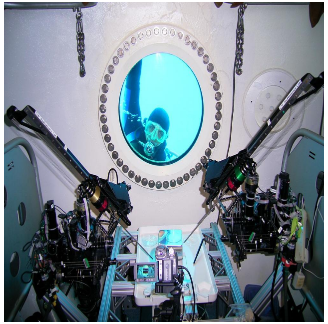
- 100% manual teleoperation
- Can we augment surgeon’s capabilities with partial automation?

Raven : Goals (2002)

- Portable and robust surgical telerobot research platform
- Minimize mechanism size
- Maximize Vw/Vm (workspace/total volume)
- Enable field use
- Support **open software development**
- Support Interoperable Teleoperation

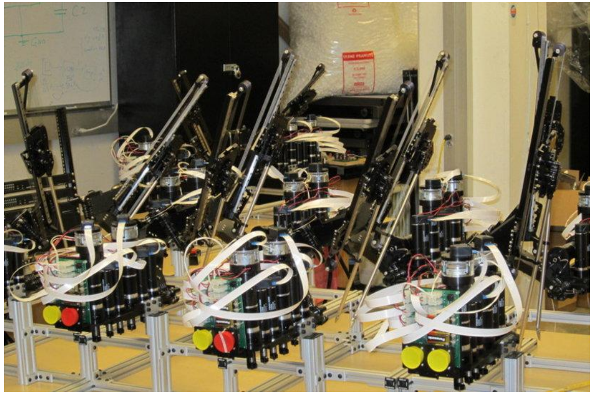
Raven-I





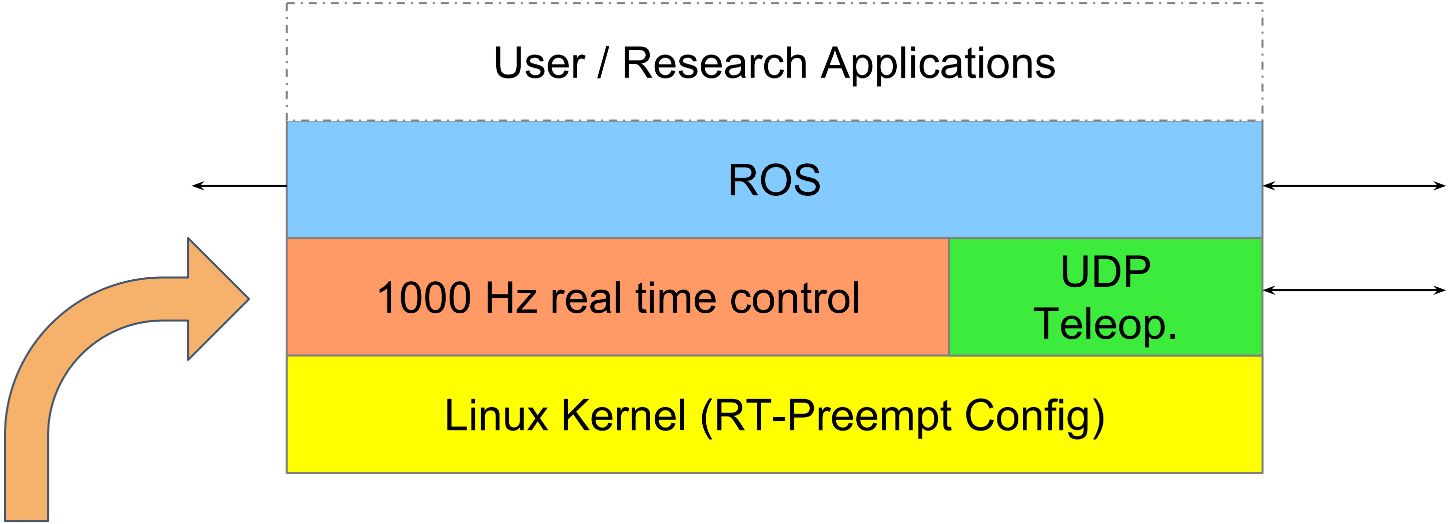
Raven Scaling

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



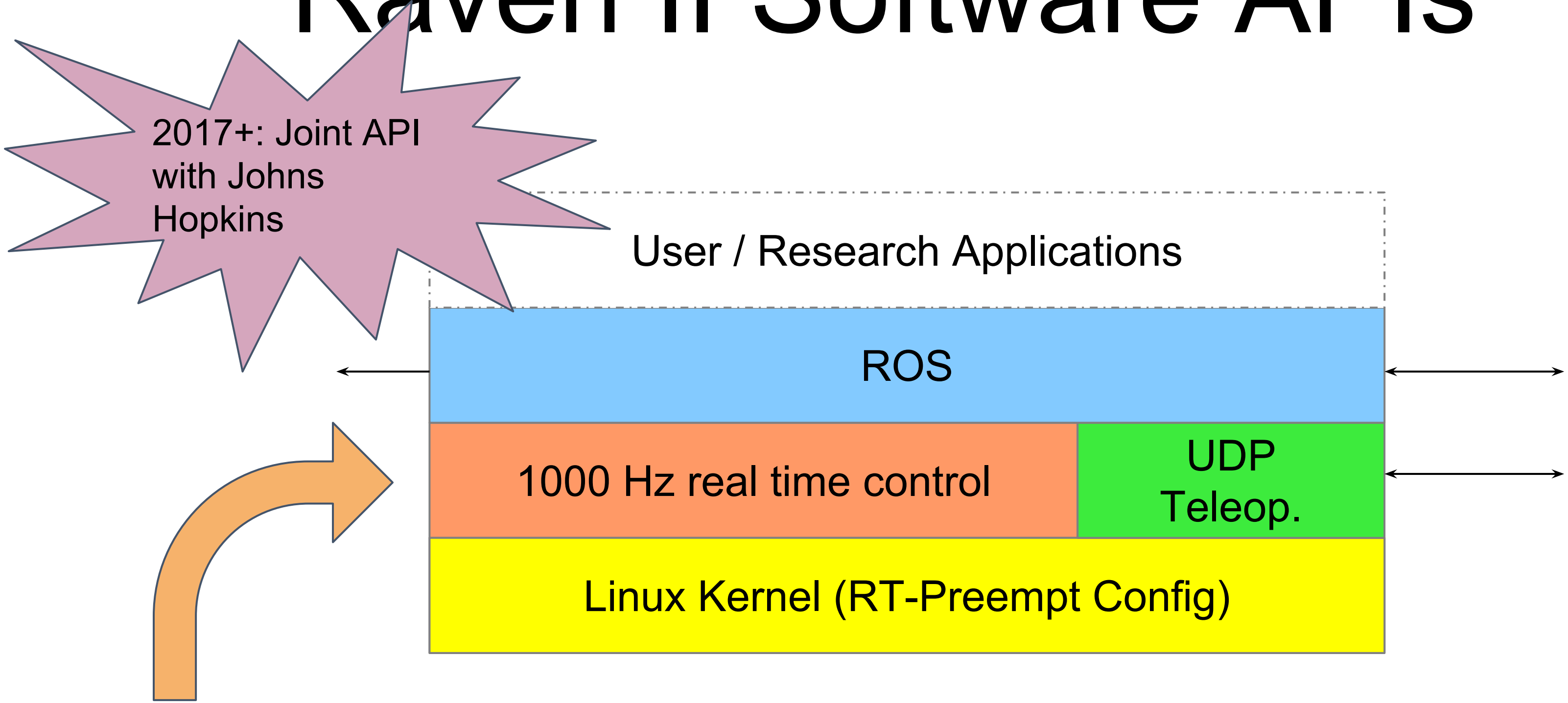
BioRobotics Lab

Raven II Software APIs



https://github.com/uw-biorobotics/raven2

Raven II Software APIs



https://github.com/uw-biorobotics/raven2

	University of Washington	**Prof. Blake Hannaford**	
	U.C. Santa Cruz	**Prof. Jacob Rosen**	
2012	Harvard	Prof. Rob Howe	Beating Heart Surgery
	Hopkins	Prof. Greg Hager	Human-Machine Cooperation
	Nebraska	Prof. Shane Farritor	Deployable surgical robots
	UCLA	Prof. Warren Grundfest	Tactile feedback to surgeon
	U.C. Berkeley	Prof. Ken Goldberg & Pieter Abbeel	Machine Learning of surgical autonomy
2013	Stanford University	Prof. Allison Okamura	NRI Large Project
	Montpellier University (Fr)	Prof. Philipe Poignet	LIRMM
	U. of Central Florida	Prof. Zihua Xu	
	U. of Western Ontario (Canada)	Prof. Rajni Patel	(four-arm system)

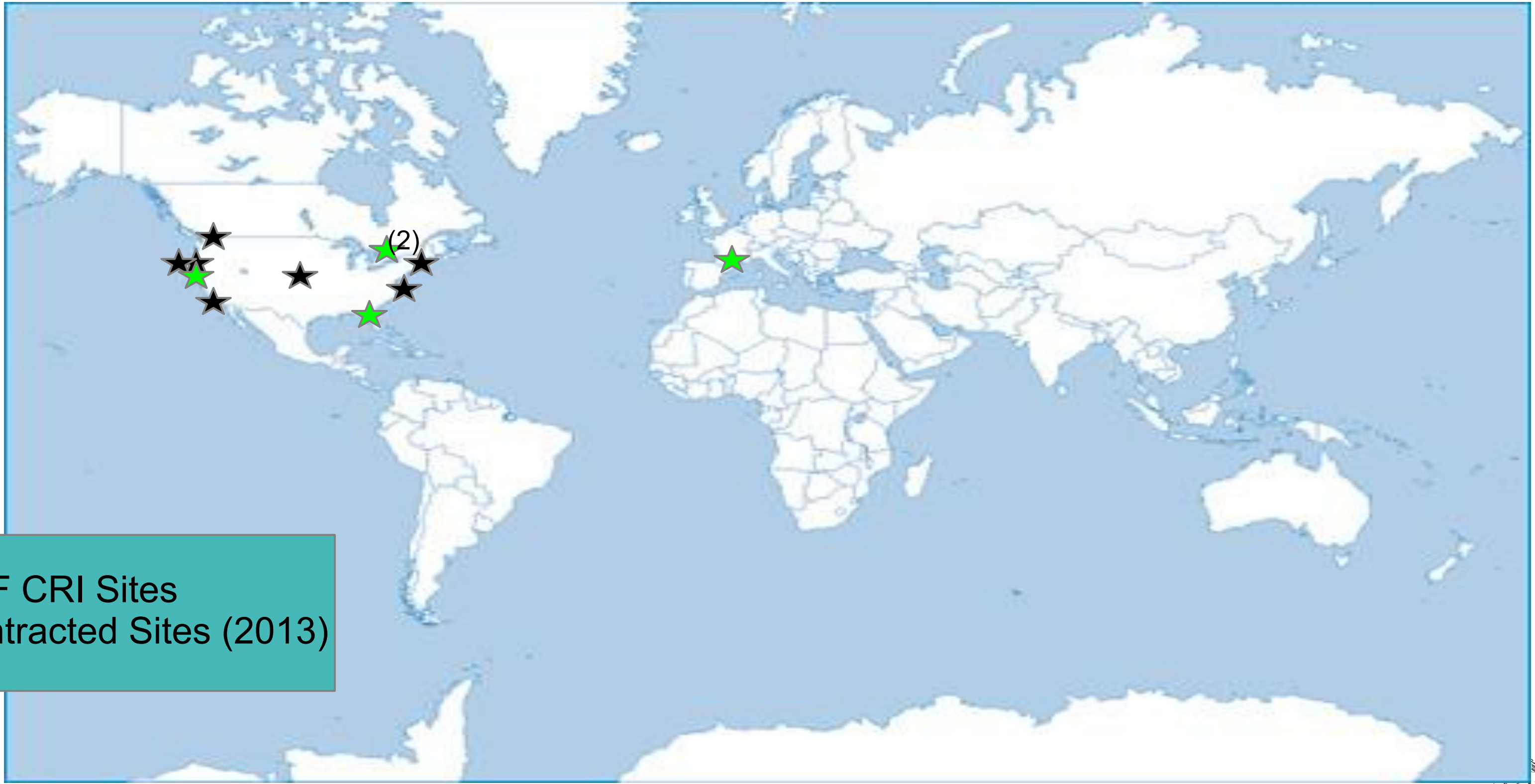
BioRobotics Lab

Raven-II Sites

★ NSF CRI Sites
(installed 2012)

BioRobotics Lab

Raven-II Sites



★ NSF CRI Sites
★ Contracted Sites (2013)

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Raven-II Sites

BioRobotics Lab

Raven Commercialization

+

Open source software:

`https://github.com/uw-biorobotics/raven2`

AppliedDexterity

Driving Innovation in Surgical Robotics

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July 2018 Raven map: 17 sites, 20 systems

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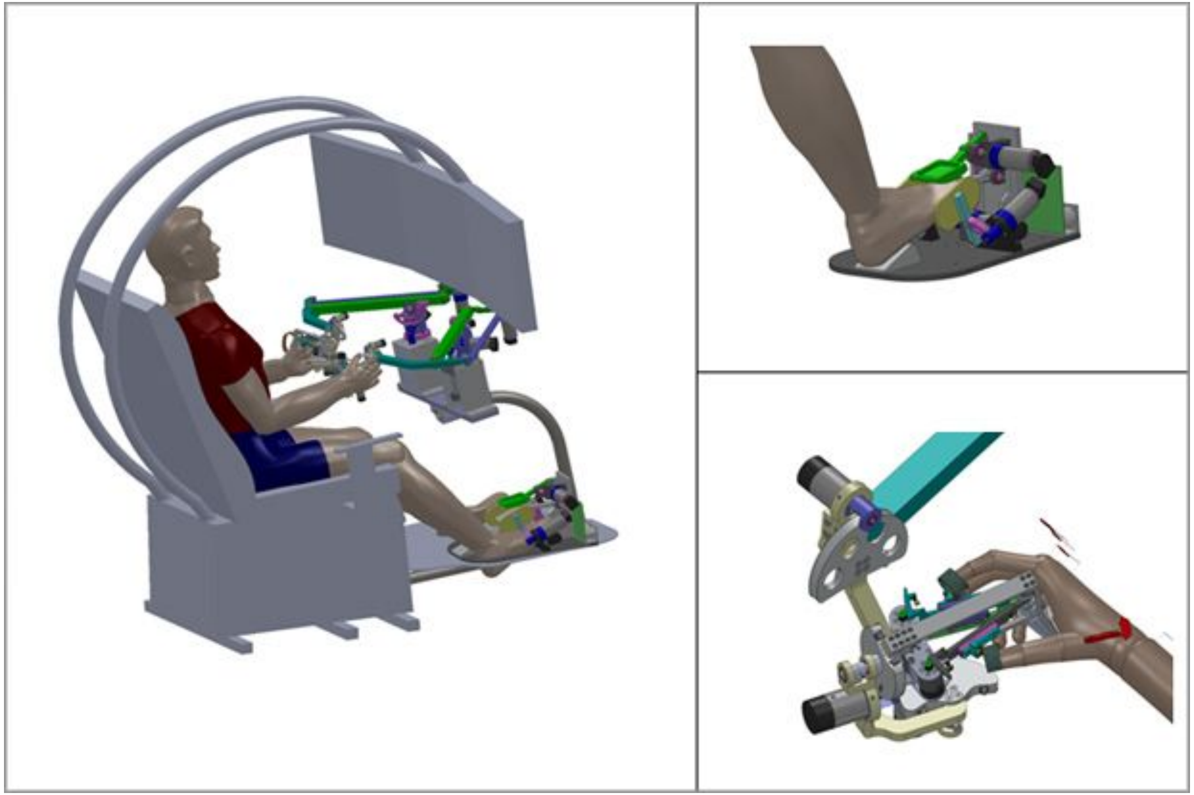
Coming soon: Advanced Surgical Console



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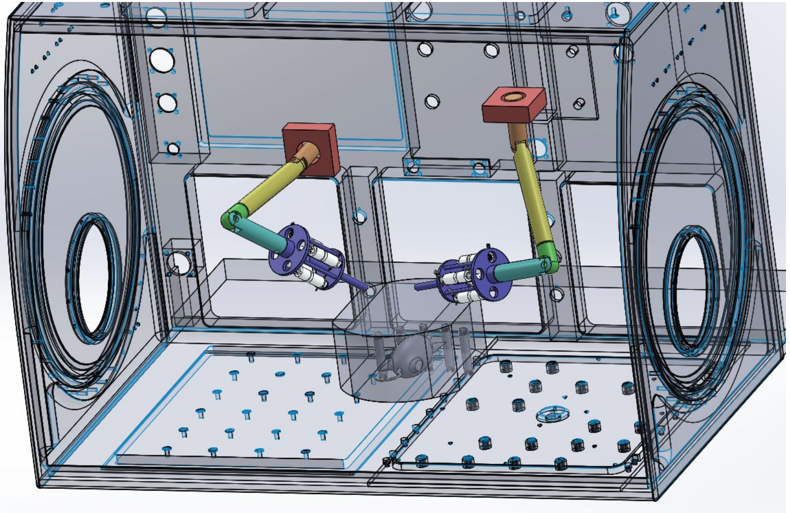
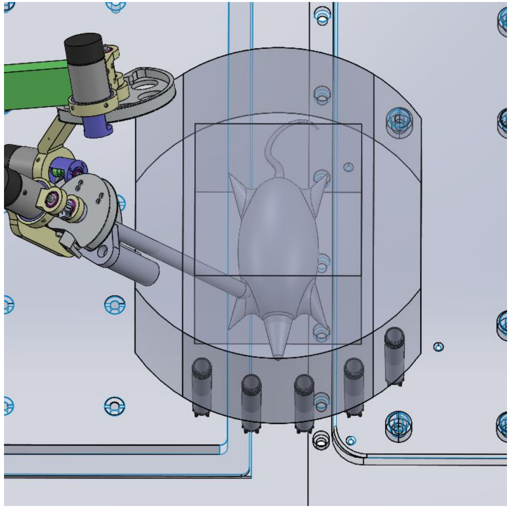
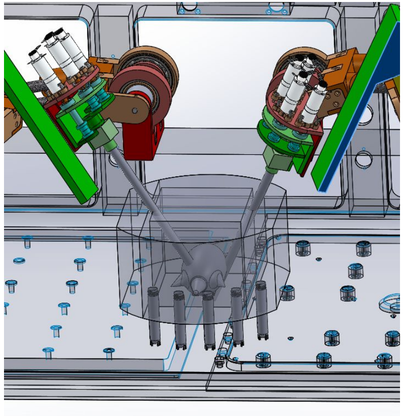
Exploratory Project: Raven in ISS???

NASA







AppliedDexterity

Driving Innovation in Surgical Robotics

UNIVERSITY · OF · WASHINGTON · 1861 · LVX · SIT

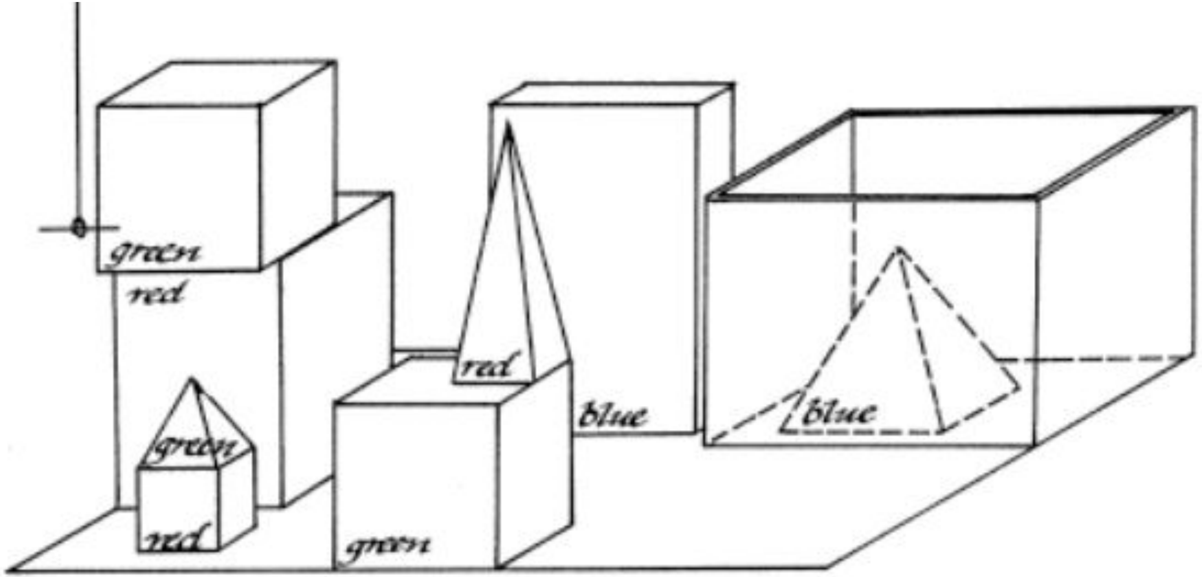
*Bio*Robotics Lab

AI in robotic surgery?

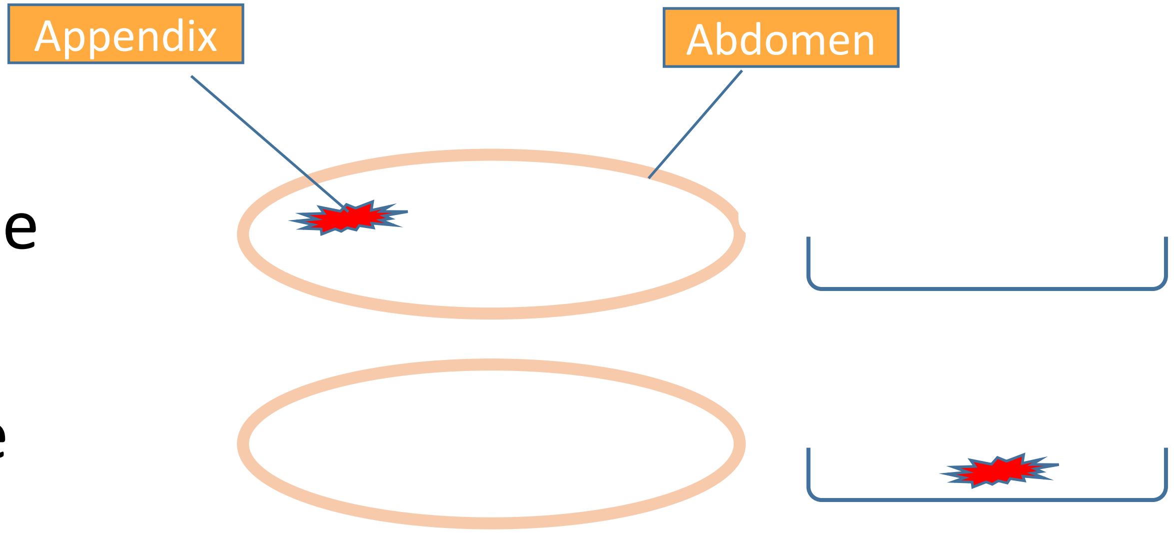
Surgical plans – a **contrast** to A.I.

"Traditional" A.I.:

1. Initial State
2. Goal State
3. Affordances
4. Synthesize
   Sequence of Actions

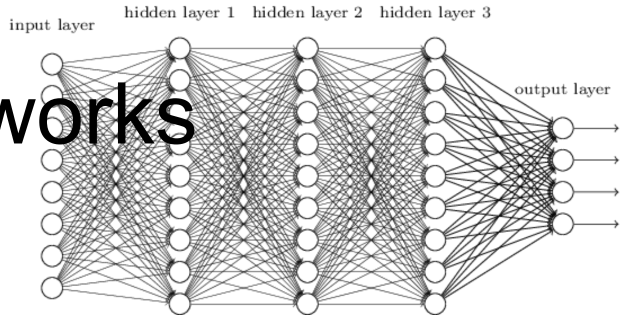


NOT:

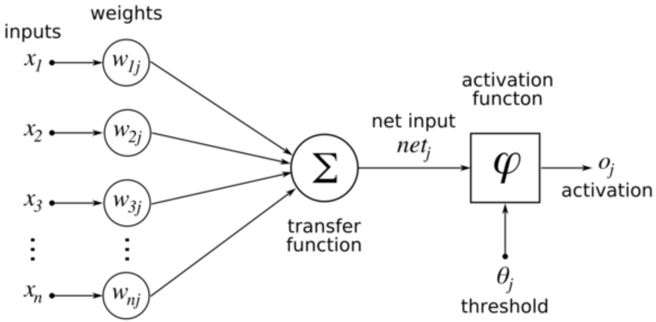


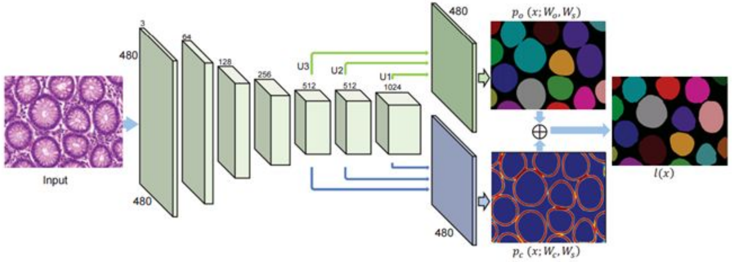
- Initial State
- Goal State
- Affordances

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

Marzinotto, A., Colledanchise, M., Smith, C., & Ogren, P. (2014, May). Towards a unified behavior trees framework for robot control. In *Robotics and Automation (ICRA), 2014 IEEE International Conference on* (pp. 5420-5427). IEEE.

- *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

Node types

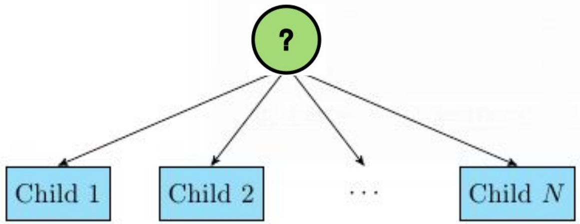
- *Selector* Pass the tick to each child in turn
  Return Success when first child returns Success
  (try each child).

- *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.

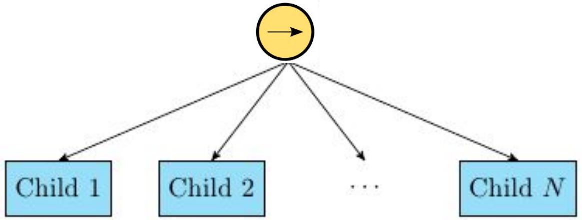
Diagrams:

Selector



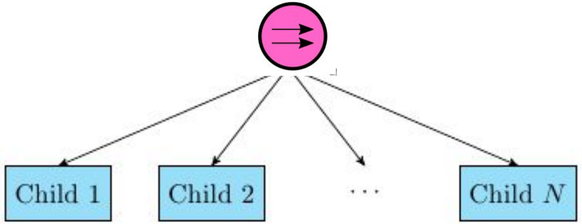
In order, Succeed when the FIRST child succeeds

Sequence



In order, Succeed when all children succeed

Parallel

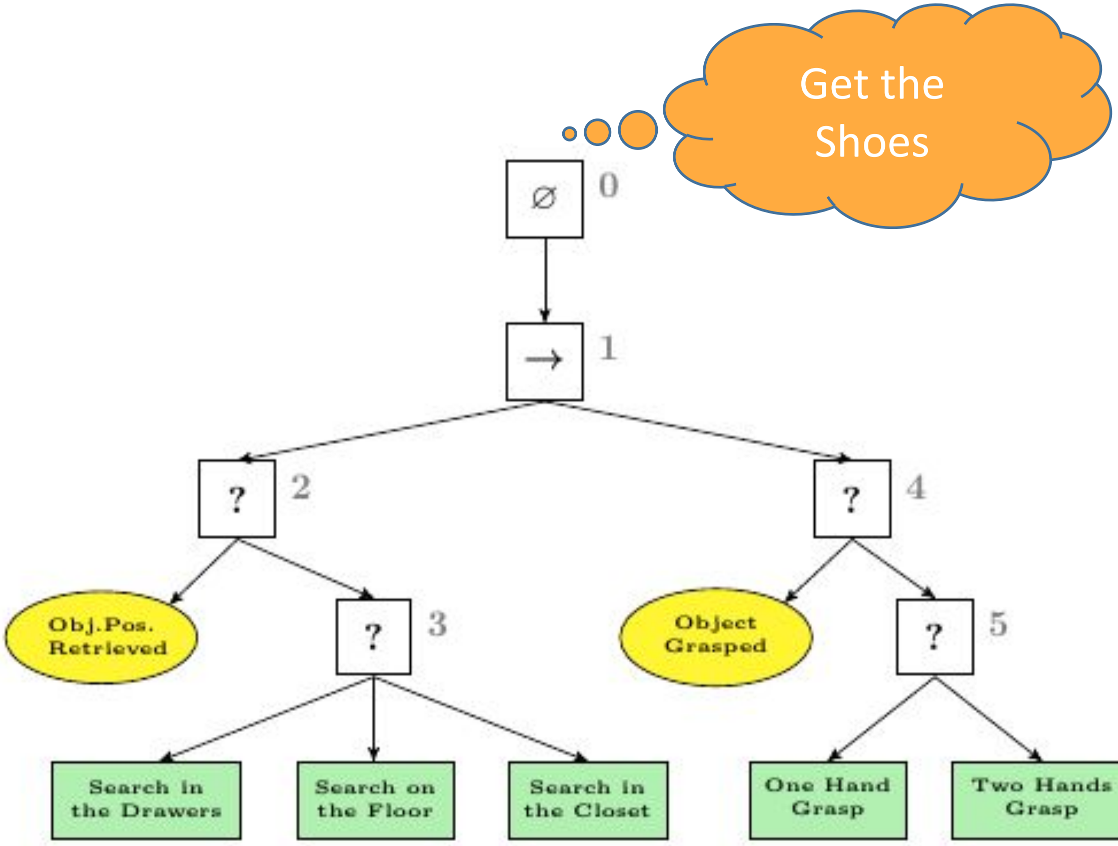


Simultaneous: Succeed when xx% of children succeed

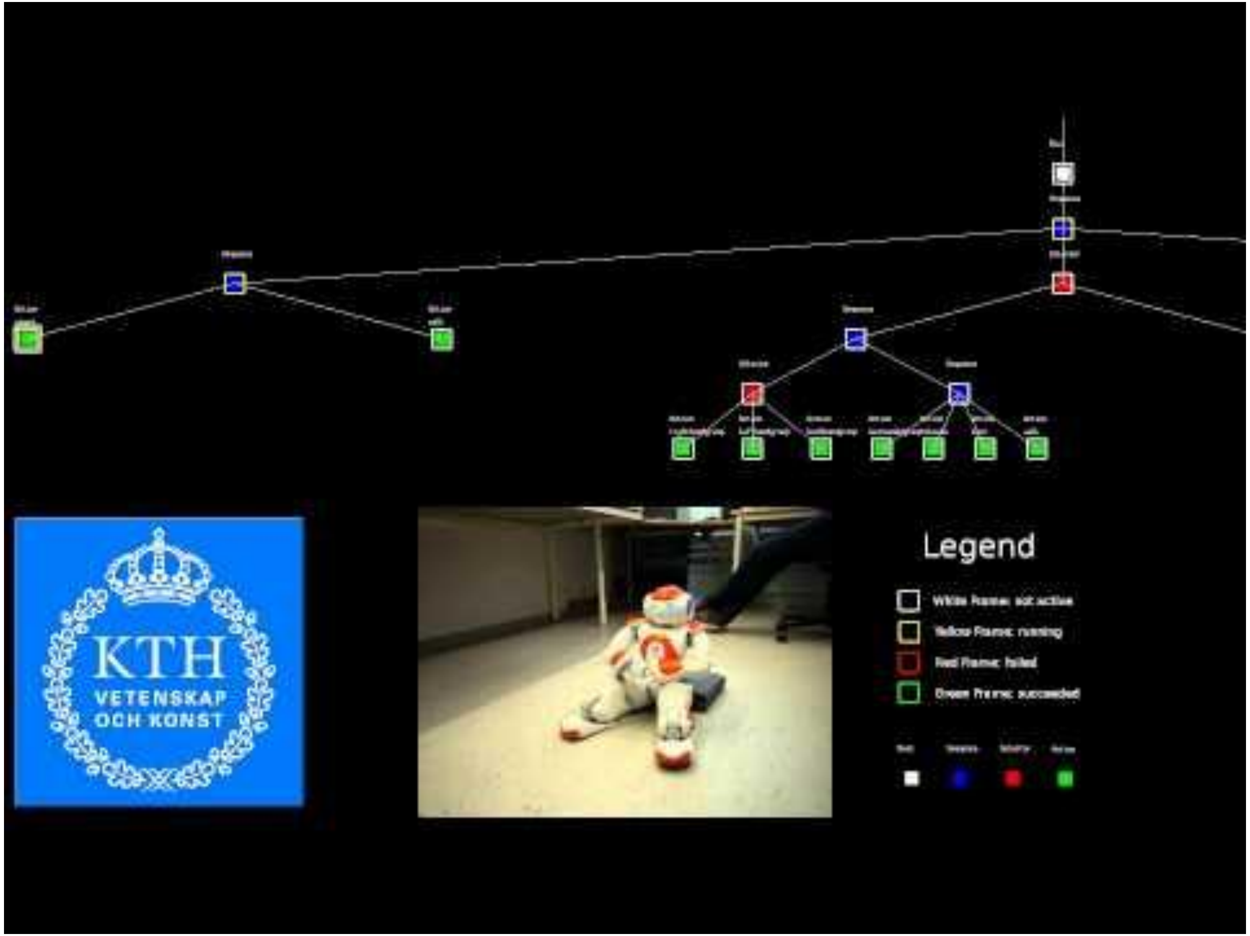
Leaves


Get the
Shoes

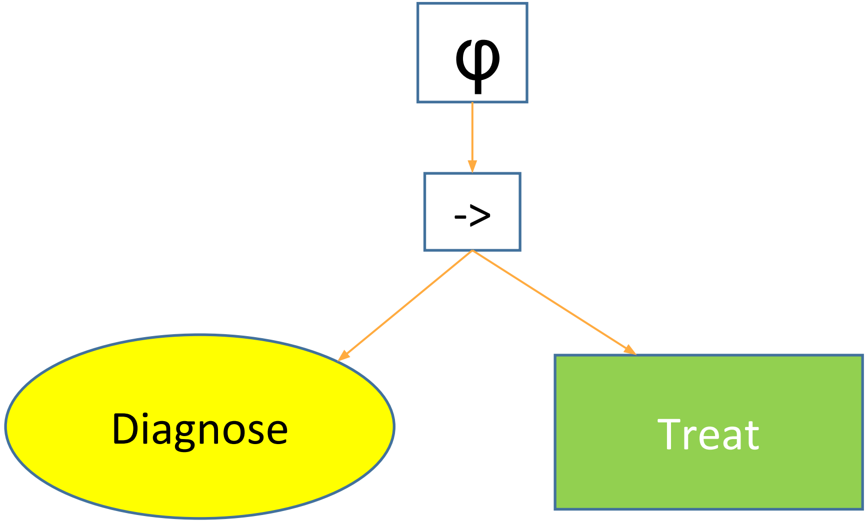
Example



Get the Shoes
∅
0
→
1
?
2
?
4
Obj.Pos. Retrieved
?
3
Object Grasped
?
5
Search in the Drawers
Search on the Floor
Search in the Closet
One Hand Grasp
Two Hands Grasp


KTH
VETENSKAP
OCH KONST
Legend
White Frame: not active
Yellow Frame: running
Red Frame: failed
Green Frame: succeeded

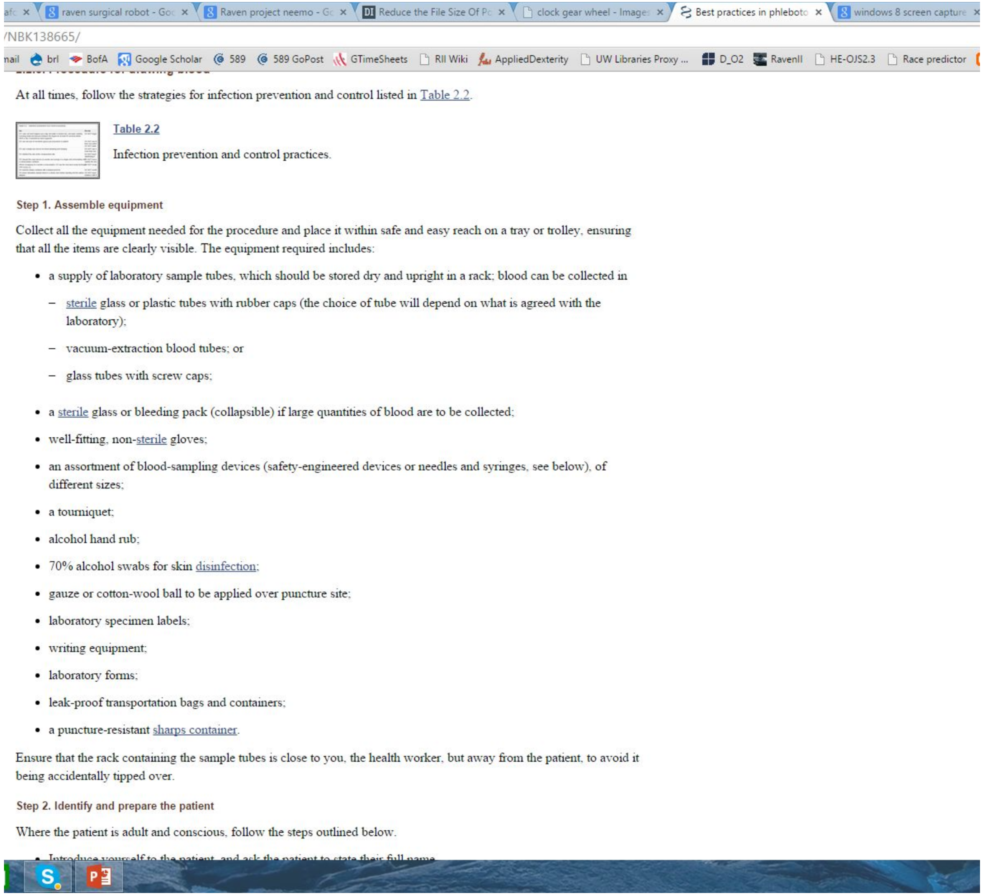
Medical Behavior Trees



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!)



At all times, follow the strategies for infection prevention and control listed in Table 2.2.

Table 2.2

Infection prevention and control practices.

Step 1. Assemble equipment

Collect all the equipment needed for the procedure and place it within safe and easy reach on a tray or trolley, ensuring that all the items are clearly visible. The equipment required includes:

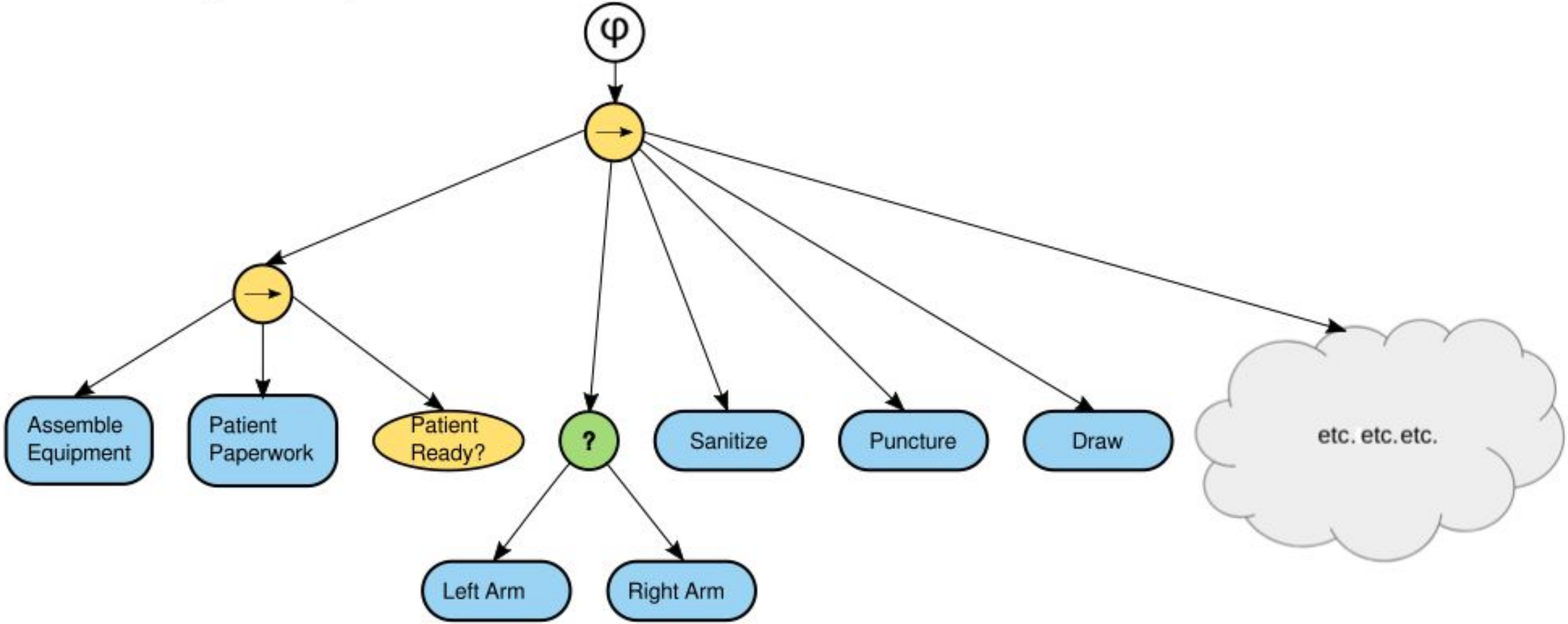
- a supply of laboratory sample tubes, which should be stored dry and upright in a rack; blood can be collected in
  - sterile glass or plastic tubes with rubber caps (the choice of tube will depend on what is agreed with the laboratory);
  - vacuum-extraction blood tubes; or
  - glass tubes with screw caps;
- a sterile glass or bleeding pack (collapsible) if large quantities of blood are to be collected;
- well-fitting, non-sterile gloves;
- an assortment of blood-sampling devices (safety-engineered devices or needles and syringes, see below), of different sizes;
- a tourniquet;
- alcohol hand rub;
- 70% alcohol swabs for skin disinfection;
- gauze or cotton-wool ball to be applied over puncture site;
- laboratory specimen labels;
- writing equipment;
- laboratory forms;
- leak-proof transportation bags and containers;
- a puncture-resistant sharps container.

Ensure that the rack containing the sample tubes is close to you, the health worker, but away from the patient, to avoid it being accidentally tipped over.

Step 2. Identify and prepare the patient

Where the patient is adult and conscious, follow the steps outlined below.

Blood Draw (W.H.O.)

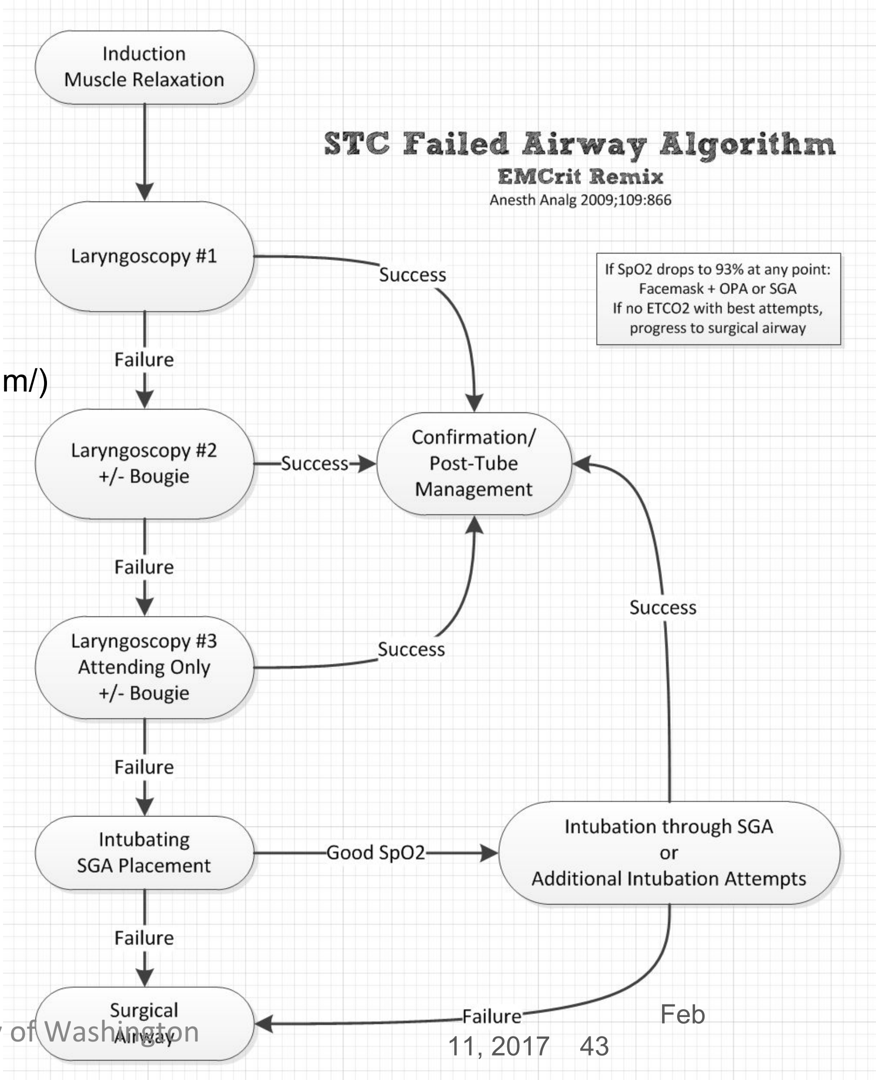


Emergency Airway Algorithm

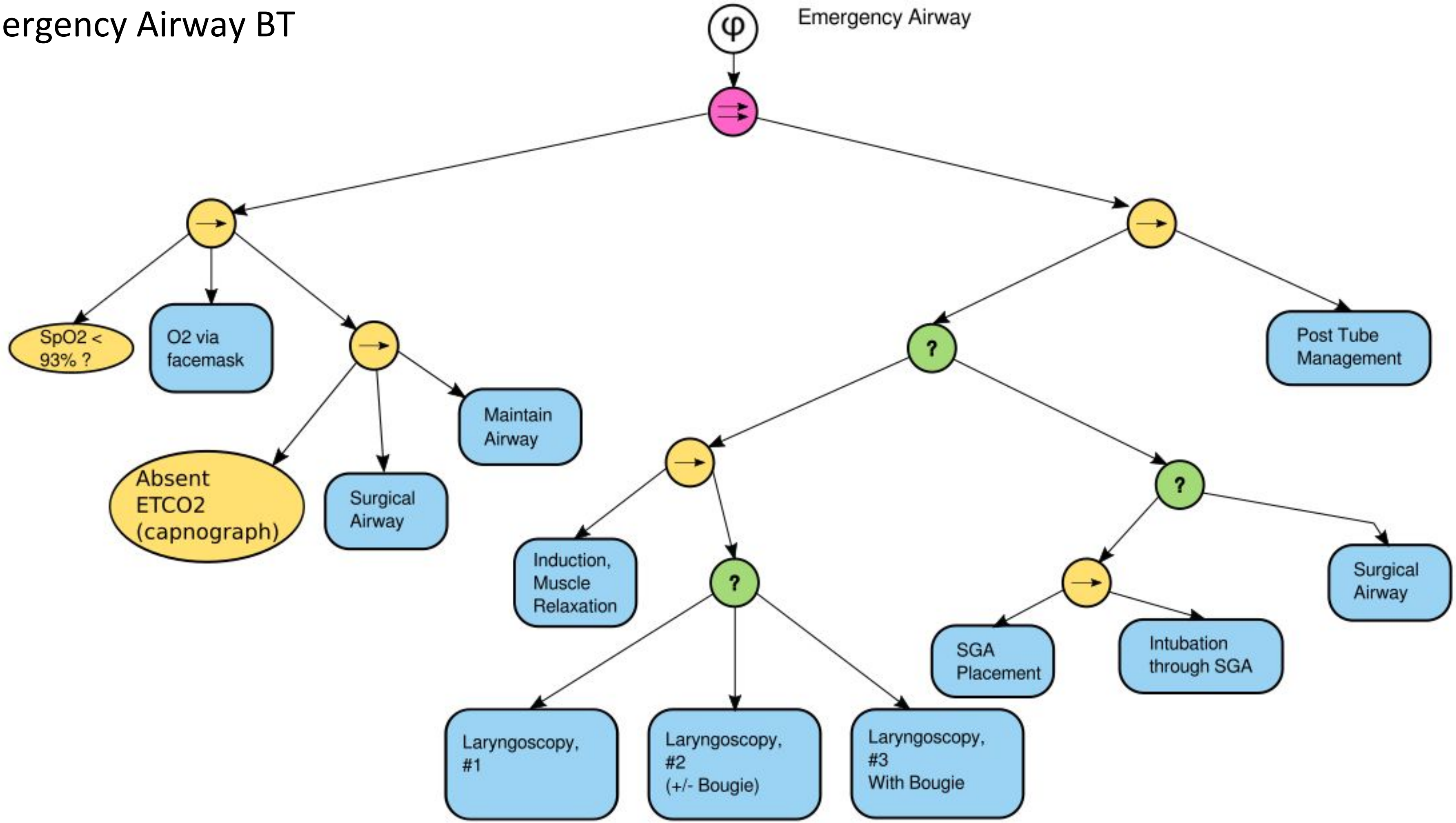
- Source: emcrit.org

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

http://orangecountyfl.net/emsref/



Emergency Airway BT



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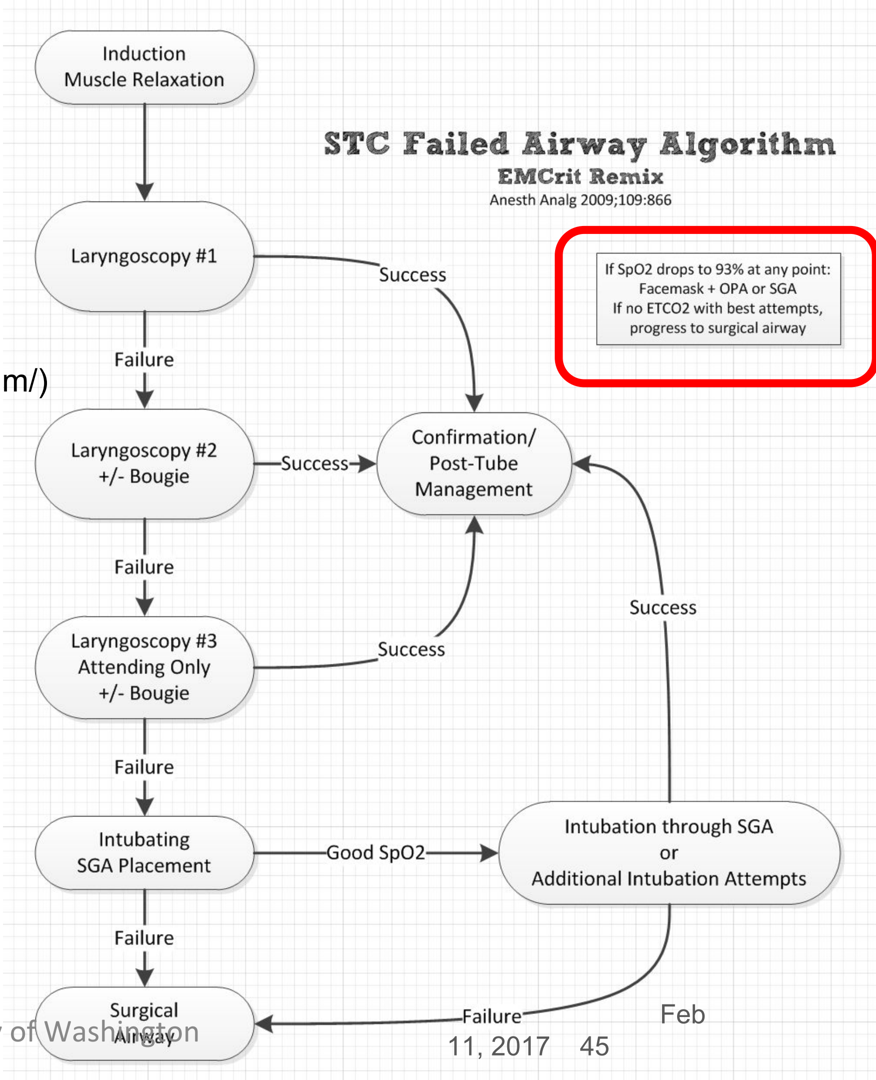
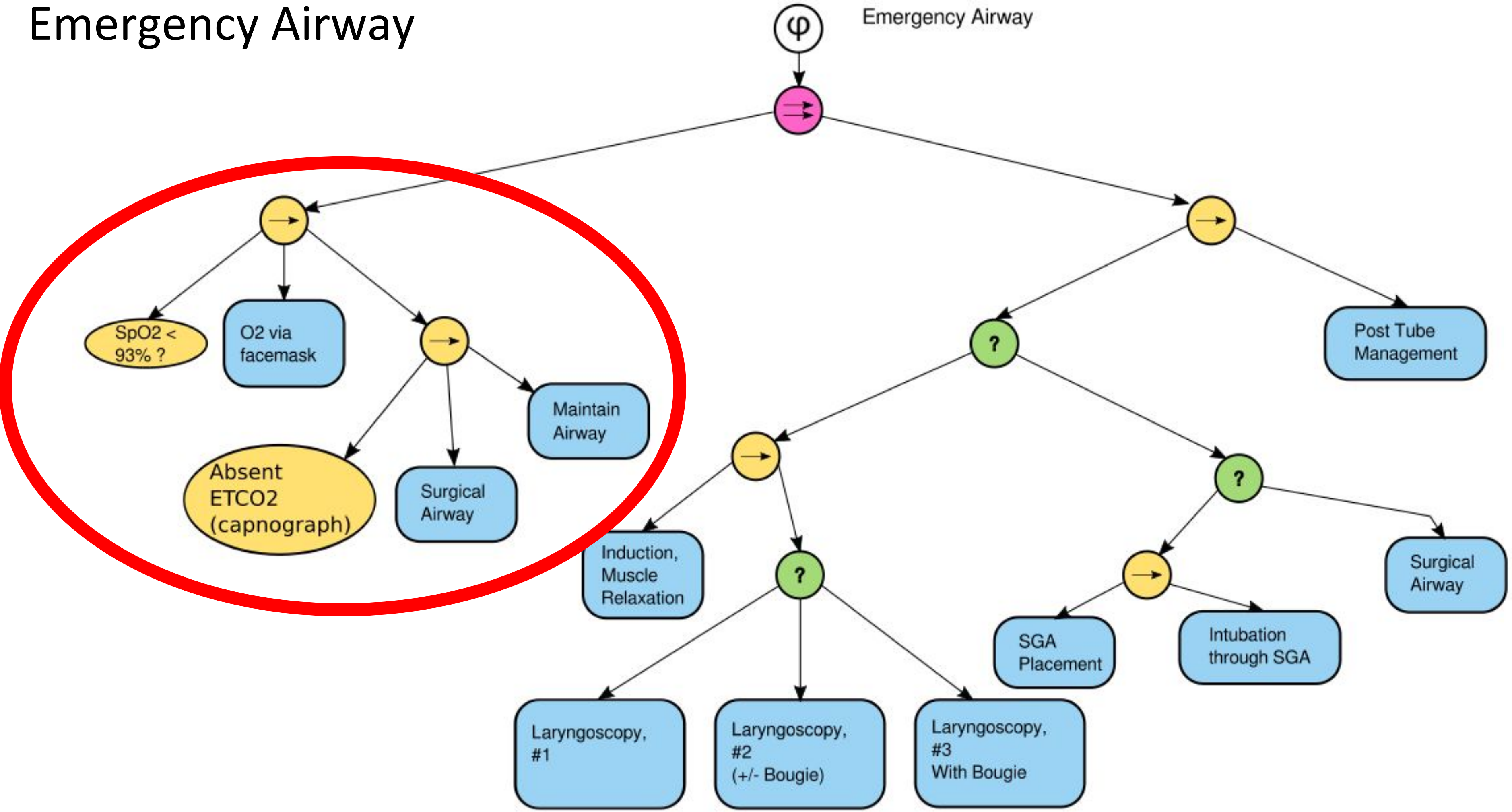


If SP02 drops to 93% at any point:

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

Emergency 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

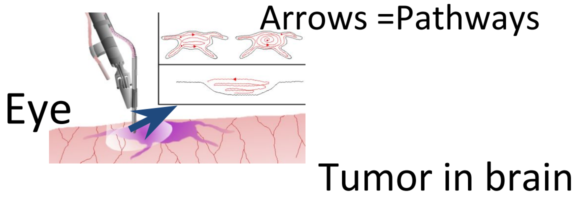
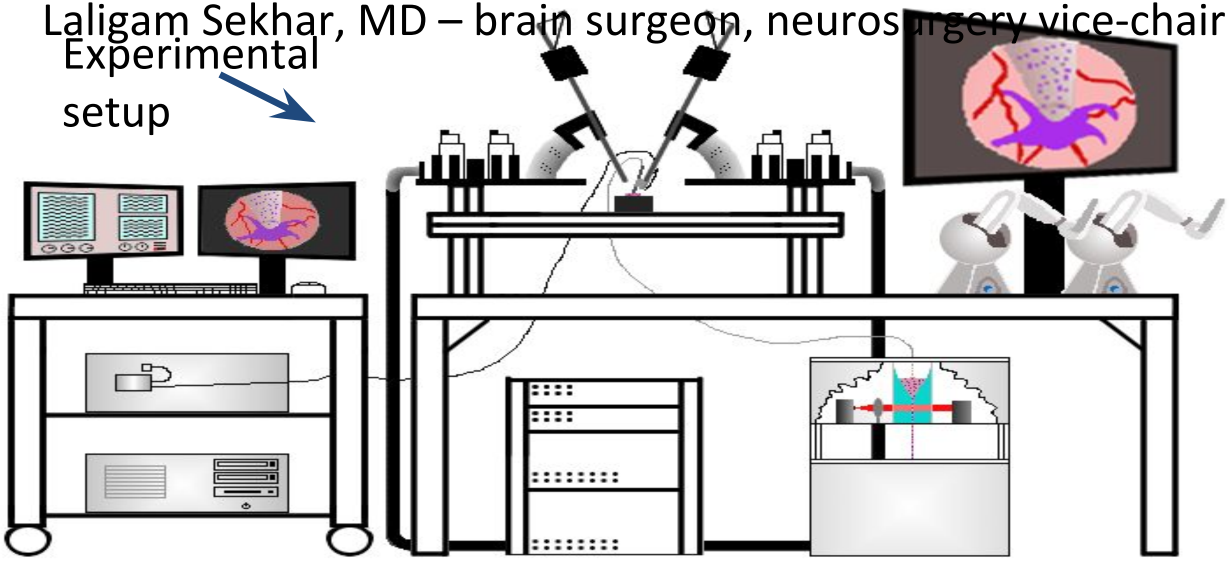


Image-guided miniature robotic tool to surgically remove tumors (pathways top-right).

Experimental setup



Laser imaging (left) on robot arms (center) manipulated by surgeon's console of display and hand controls (right).

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

- # Behavior Tree Modeling of the Tumor Ablation Procedure

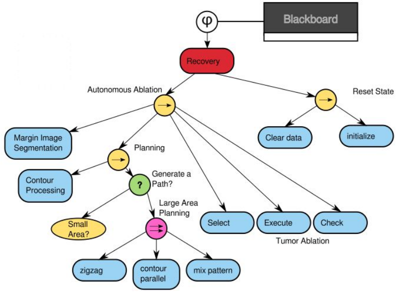


Figure: BT representation of the tumor ablation procedure

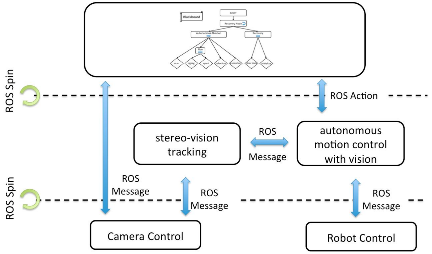
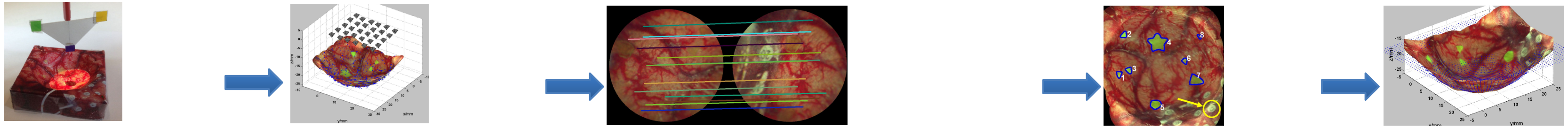


Figure: Software Architecture

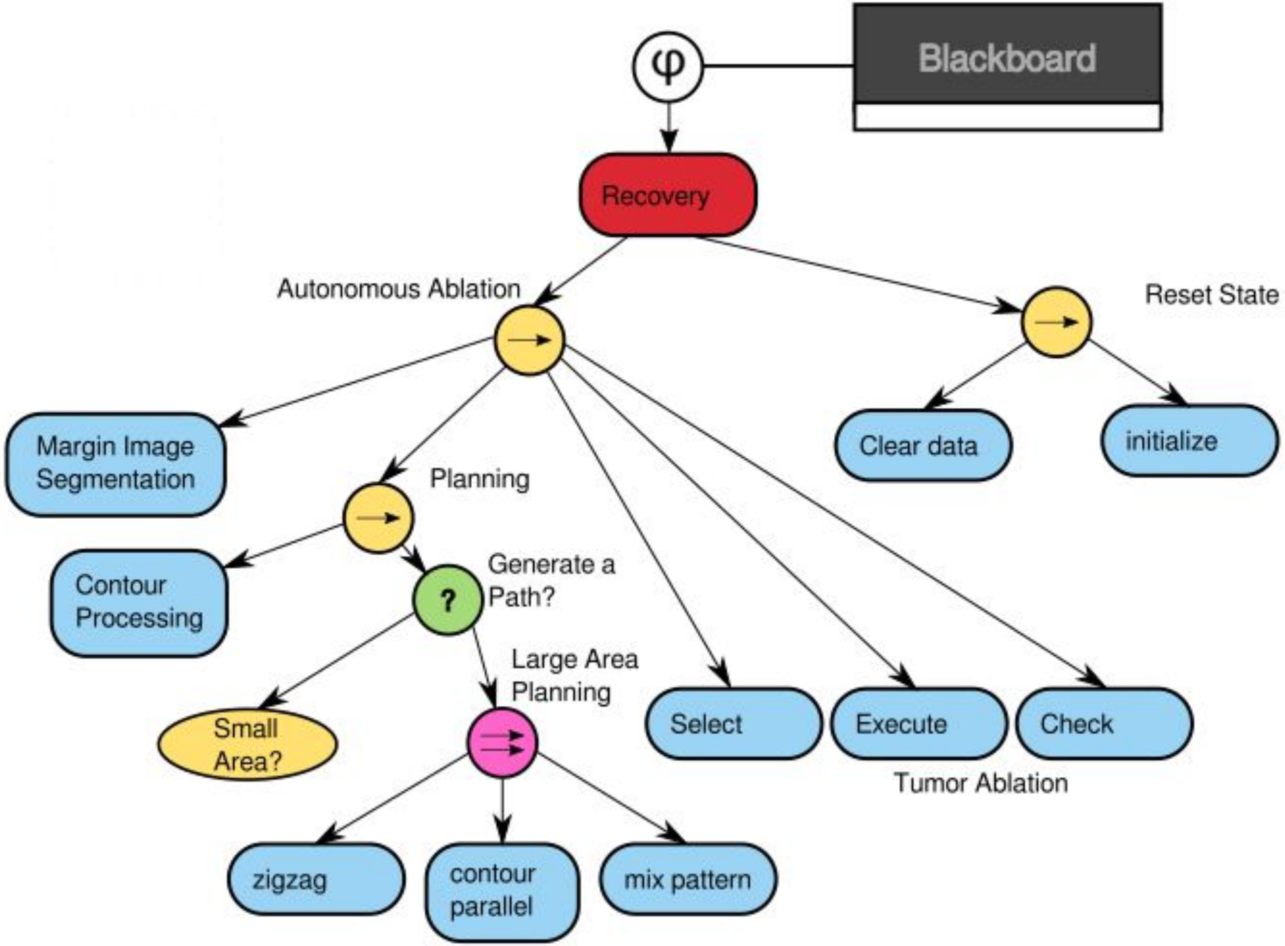
- # 3D virtual reconstruction of surgical field



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

- # Ablation path planning (in the planar surgical field)

- **Behavior Tree Modeling of the Tumor Ablation Procedure**

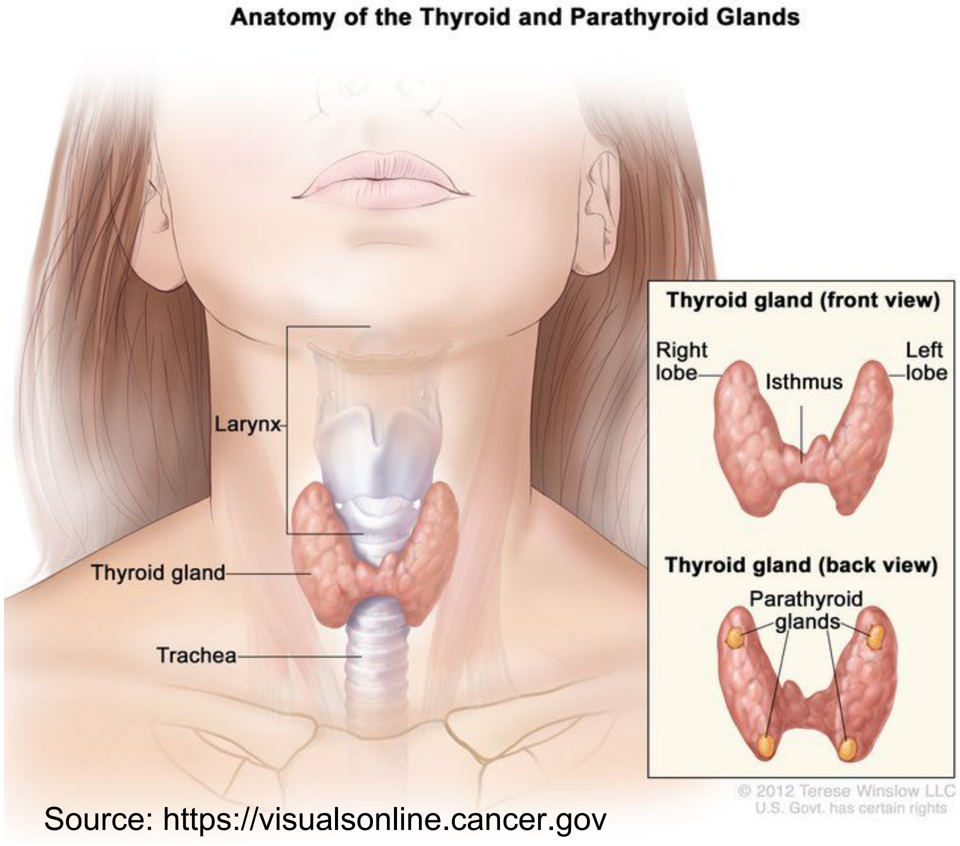


Post Operative Patient Mangement: Pediatric Total Thyroidectomy

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



Source: https://visualsonline.cancer.gov

Source: (Randy Bly M.D. co-author) -->

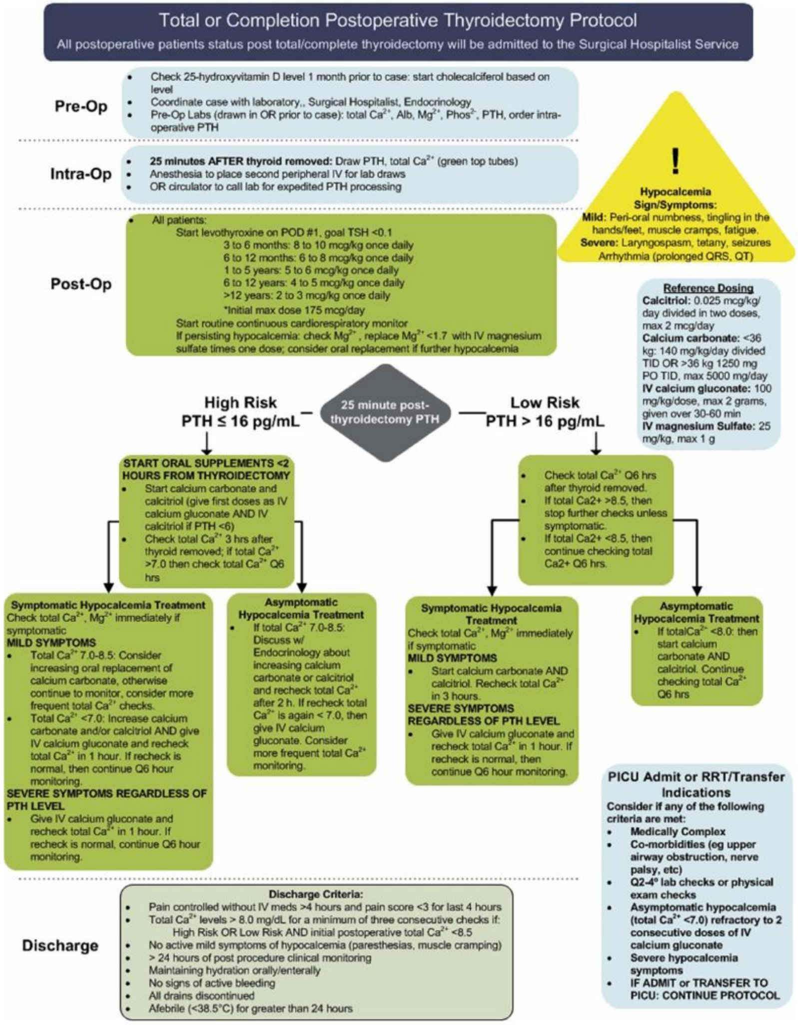
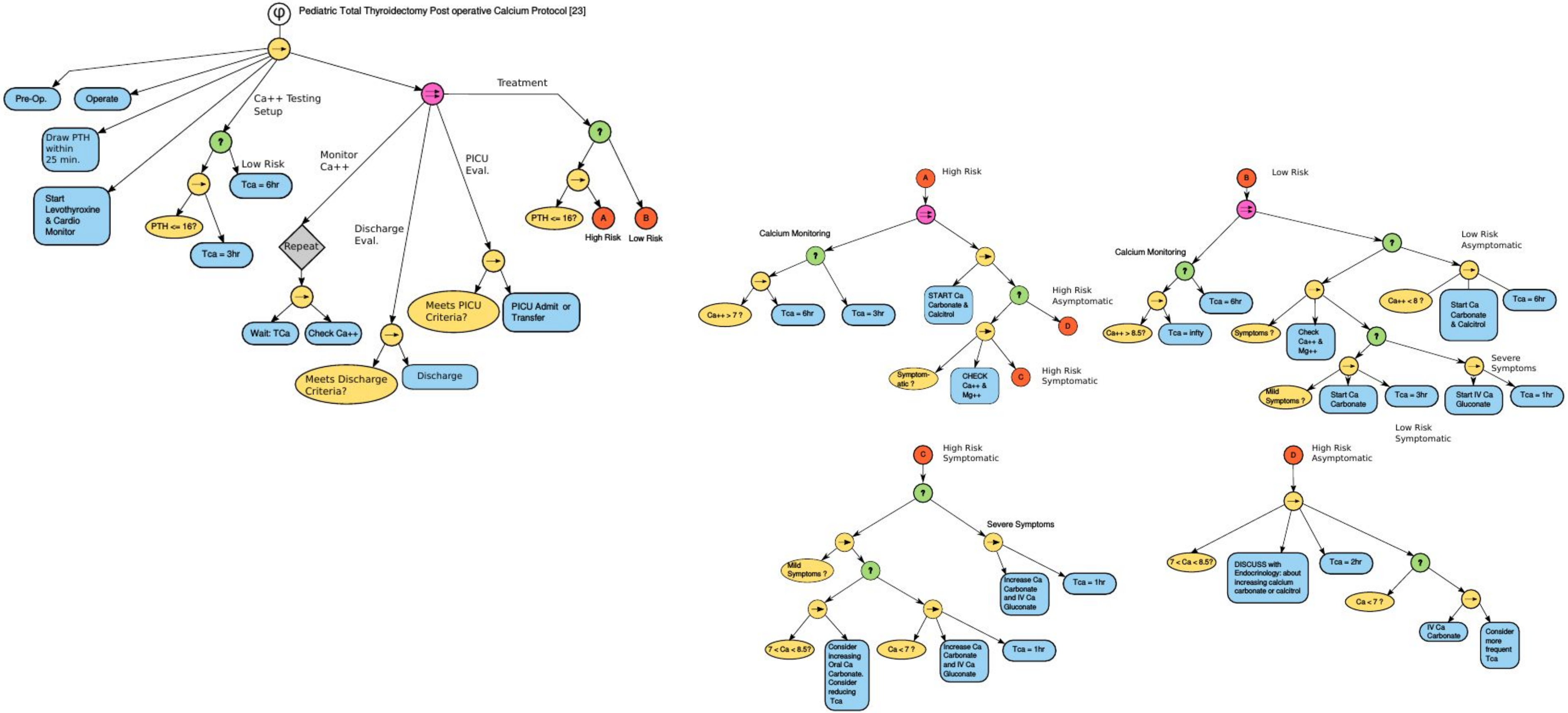


Fig. 1. Postoperative thyroidectomy protocol (total or completion thyroidectomy).

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.

*Bio*Robotics Lab

非常感谢你

Thank you very much!