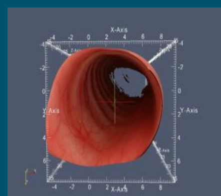
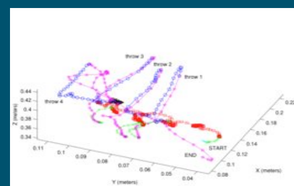
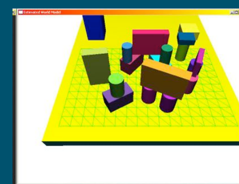


Quantitative Endoscopy

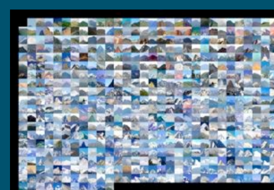


Language of Surgery

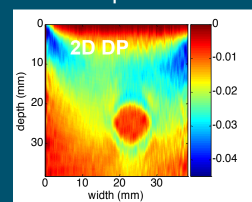


Scene Analysis and Manipulation

Human-Machine Collaborative Systems



Similarity Learning



Interventional Ultrasound

The **Computational Interaction and Robotics Laboratory (CIRL)** is devoted to the study of problems that involve dynamic, spatial interaction at the intersection of imaging, robotics, and human-computer interaction.

WHITING SCHOOL OF ENGINEERING
JOHNS HOPKINS UNIVERSITY

100 YEARS
JOHNS HOPKINS ENGINEERING

Human-Machine Collaborative Systems

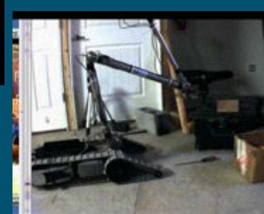
Gregory D. Hager
Professor and Chair
Department of Computer Science

LABORATORY FOR Computational Sensing + Robotics
THE JOHNS HOPKINS UNIVERSITY

What Is HMCS?

Augmentation of human **physical capability** by rendering **context appropriate** physical assistance to a user within a **recognized task**

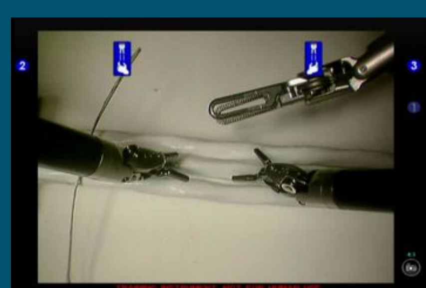
Courtesy Spirit Aerosystems



Courtesy Autonomous Solutions

What Is HMCS?

Augmentation of human **physical capability** by rendering **context appropriate** physical assistance to a user within a **recognized task**

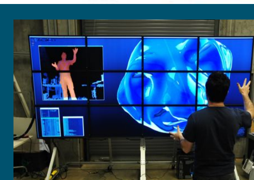


Courtesy Spirit Aerosystems

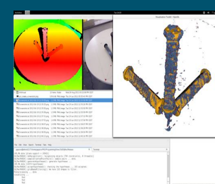
The Plan

- Human-Machine Collaborative Systems in surgery

- Human-Machine Collaborative Systems in VR



- Human-Machine Collaborative Systems for telemanipulation

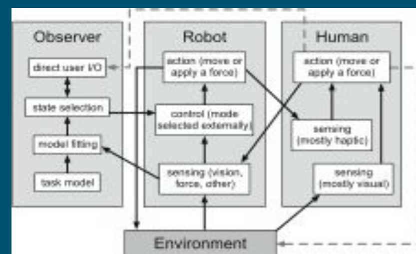


Why HMCS

- Increase skill and safety
- Reduce injury/improve ergonomics
- Extend working life
- Create new applications/opportunities for people and robotics

Major HMCS Problems:

- Recognition: What is going on?
  - Sensing and learning
- Differentiating stylistic and consequential variation
  - Latent variable analysis

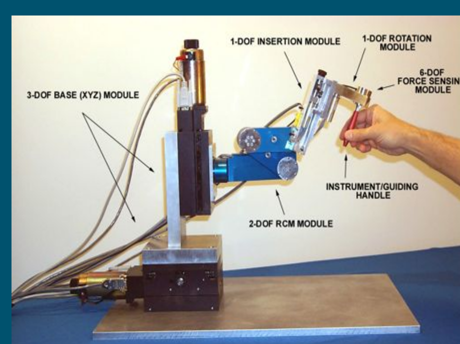


- Contextual Assistance: What to do to help
  - Virtual fixtures
  - Information augmentation/sensor substitution
  - Training/feedback

A Beginning: Retinal Surgery

S. Hundtofte, A. Okamura, and G. Hager. Building a task language for segmentation and recognition of user input to cooperative manipulation systems. In *Proc. 10th Int. Symp. on Haptic Interfaces for Virtual Environment and Teleoperator Systems, pages 225-230, 2002*

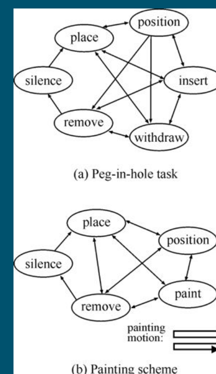
- Used SHR
  - All DOF except Z base stage
- Data recorded
  - Fx,Fy, Fz
  - Tx, Ty, Tz
  - ||translation||

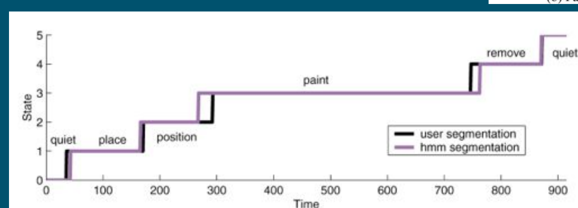


- Users pushed foot pedal to signal transitions for training HMMs

Recognizing Action from Kinematics

- Peg-in-hole
  - Place, Position, Insert, Withdraw, Remove
  - Model of cannulation
- "Painting"
  - Place, Position, Paint, Remove
  - Model of membrane removal
- 5-state HMM trained for each gesture
- Fully connected HMM for testing





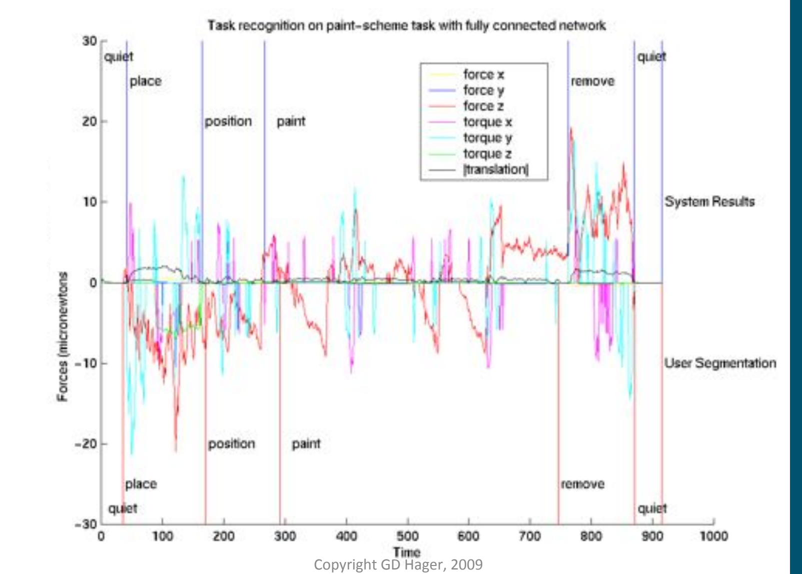
What is an HMM?

- Draw on the board Greg!

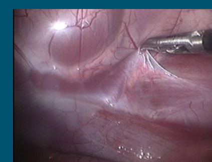
What is an HMM?

- Draw on the board Greg!
- What is a Markov model?
- What is a hidden Markov model?
- What are the two problems
  - Modeling
  - Inference

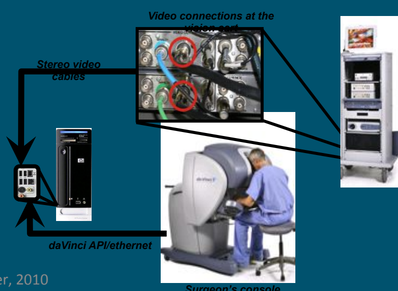
Recognition Results



Acquiring Motion Data at Scale

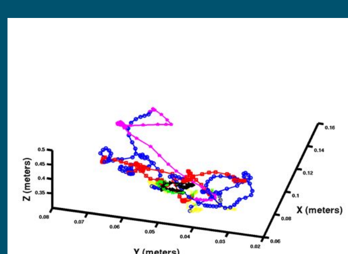


In-situ manipulation data at scale for free!

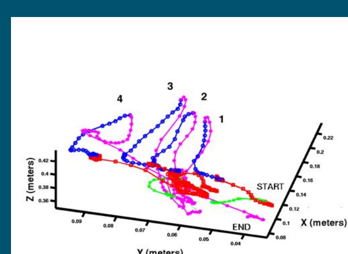


HMCS-Language Of Surgery: Objectives

1. Develop models for regularity of **manipulative** motion during surgery without reference to style, skill, or user.
2. Understanding the underpinning of skill -- system skill vs manipulative skill
3. Reflect models of skill back to improve training and performance.

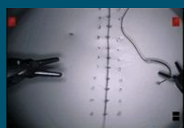


Intermediate Surgeon - trial 22

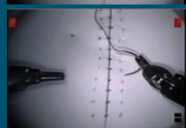


Expert Surgeon - trial 4

Suturing Gesture Vocabulary



1. Reach for needle



2. Position needle

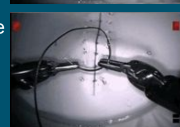
3. Insert and push needle through tissue

4. Move to middle with needle (left hand)

5. Move to middle with needle (right hand)

6. Pull suture with left hand

7. Pull suture with right hand

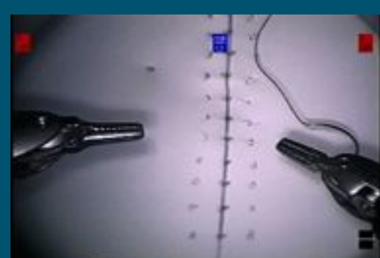


8. Orient needle with both hands

Early da VinciExperiments

Corpus

- 4-throw suturing task
- 72 motion variables
- 15 expert trials
- 8-motion vocabulary



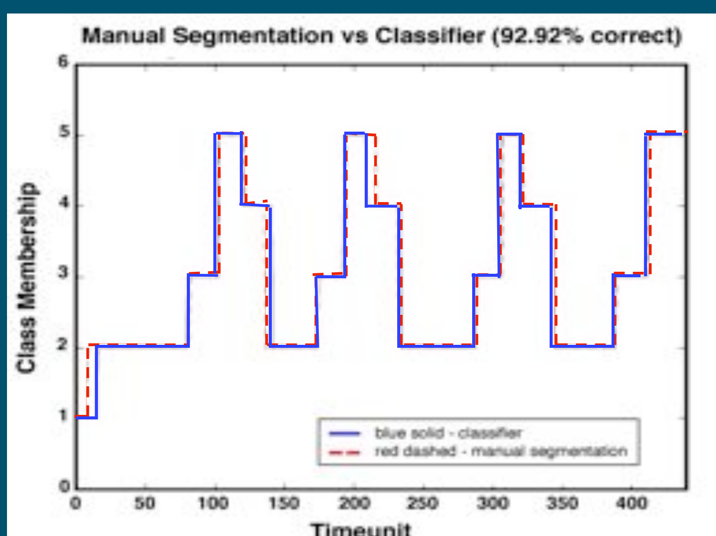
Classifier vs Manual Segmentation

Expectation Maximization + Bayes Classifier

n	Number of labeled classes	LDA output dimensions	% correct
1	6	3	91.26
2	6	4	91.46
3	6	5	91.14
4	5	3	91.06
5	5	4	91.34
6	5	3	92.09
7	5	4	91.92
8	4	3	91.88

Henry Lin

Classifier vs Segmentation



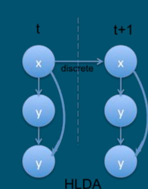
Second Data Collection At Intuitive Surgical

Subject ID	Medical Background	Da Vinci Training	Hours?
A	-	-	<1
B	-	-	10-15
C	-	-	100+
D	X	X	100+
E	X	X	100+
F	-	X	100+
G	-	X	<10
H	-	X	<10
I	-	-	<1

Each subject performs >= 5 reps of 3 tasks

Results of Recognition State Labeling

LDA Dimension	Setup I	Setup II	Setup III
10	83%	82%	**73%**
15	86%	82%	71%
20	**87%**	**83%**	70%



- Setup I: Good trials; mixing of subjects with training
- Setup II: Trials with errors; mixing of subjects while training
- Setup III: Train on one subject, test against the rest

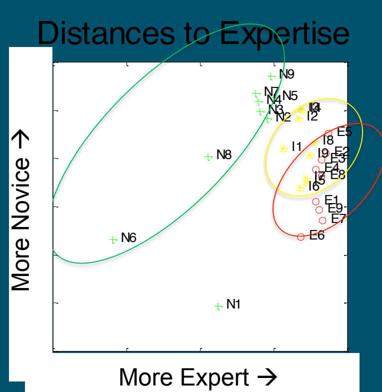
Data-Derived Models for Segmentation with Application to Surgical Assessment and Training, B Varadarajan , Carol Reiley, H Lin, S Khudanpur, G Hager, Proc. MICCAI 2009

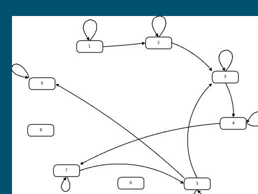
How Do We Recognize Skill?

1: the ability to use one's knowledge effectively and readily in execution or performance
2: dexterity or coordination especially in the execution of learned physical tasks
3 : a learned power of doing something competently : a developed aptitude or ability

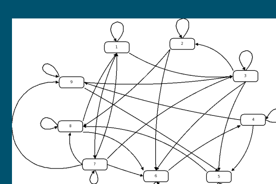
Data-Driven Assessment

Task versus Subtask Surgical Skill Evaluation of Robotic Minimally Invasive Surgery Carol E. Reiley and Gregory D. Hager, Proc. MICCAI 2009



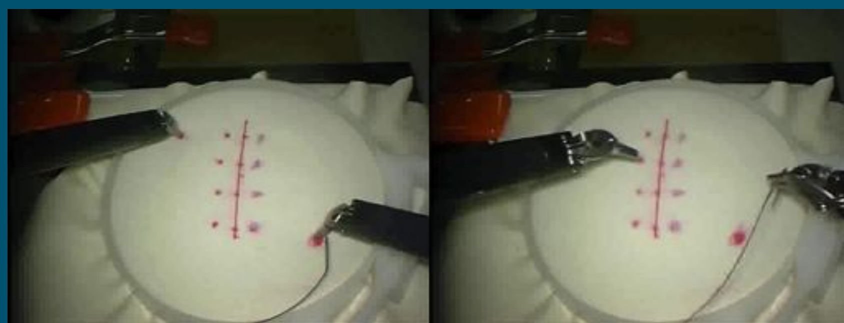


Expert

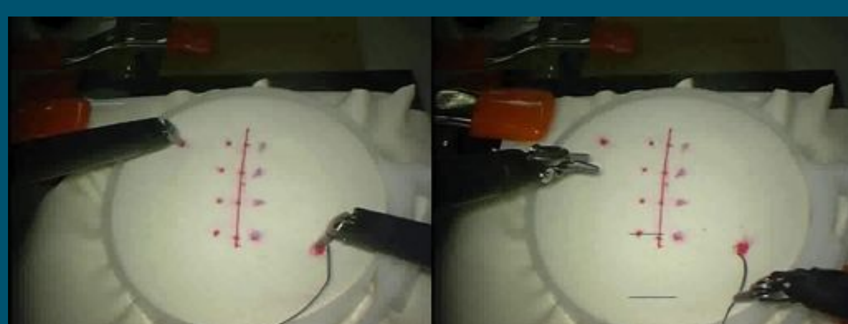


Novice

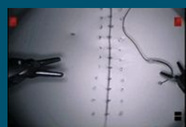
Expert-Expert



Expert-Novice



Recall the Language of Motion Idea



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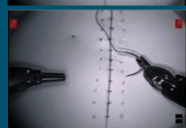

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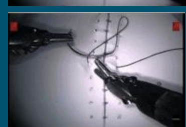

4. Move to middle with needle (left hand)

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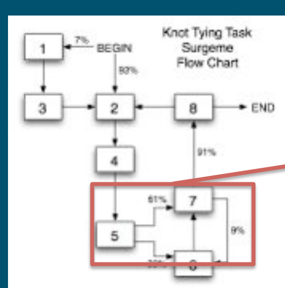
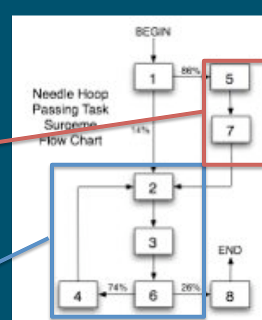
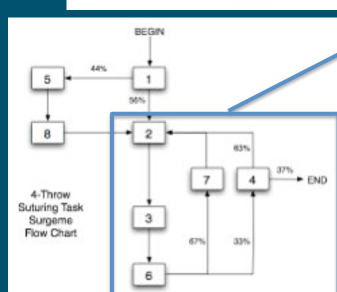
8. Orient needle with both hands

Recall the Language of Motion Idea







3 Tasks describable with 8 surgemes based on manual annotations of experts

Noticeable common substructures

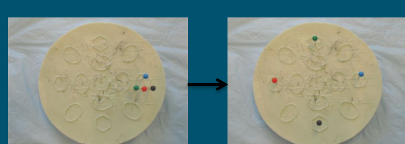
HMMs

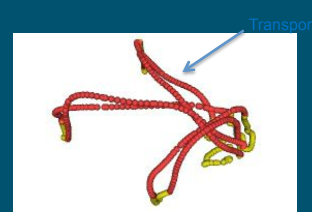
- Composed of a sequence of “hidden” states (gestures)
- Observe something correlated with the hidden state (in our case motion)
- See http://videolectures.net/hltss2010_eisner_plm/video/2/

Learned Human-Machine Performance

(Nicolas Padoy)

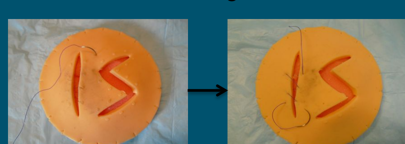
Pin Task

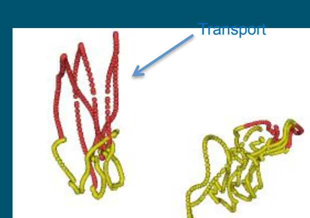




PSM Trajectory

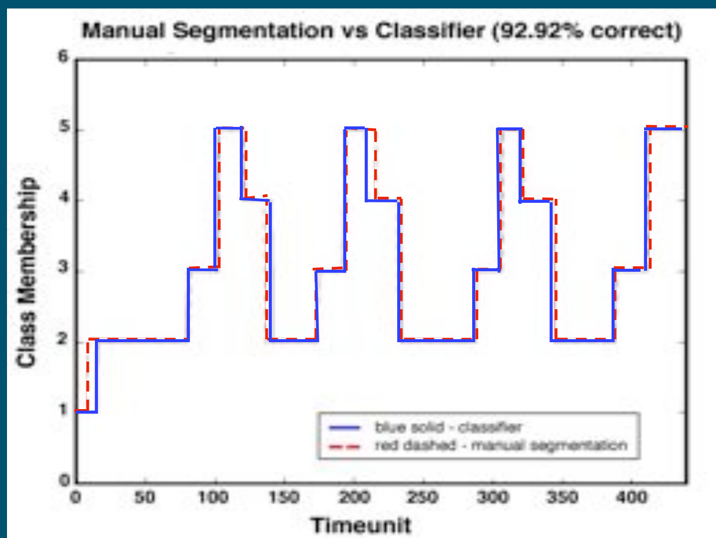
Suturing Task



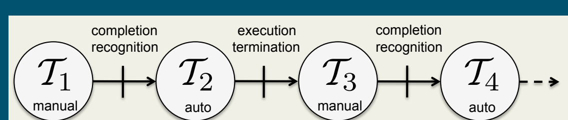


PSM Trajectories

Classifier vs Segmentation



Augmentation Using a Task Model



Pin Task

#	Name	#	Name
1	Grab *pin1* from East	7	Pin *pin2*
2*	Move *pin1* to North	8*	Move tool back to East
3	Pin pin1	9	Grab *pin3*
4*	Move tool back to East	10*	Move *pin3* to South
5	Grab *pin2*	11	Pin *pin3*
6*	Move *pin2* to West	12*	Move tool back to East

* = automated

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)

Two Examples

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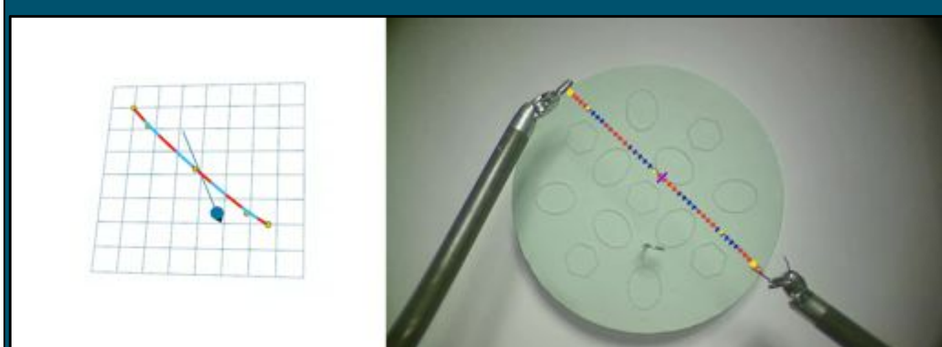
Adding Context



(Padoy, Hager - Patent pending; To appear, BMVC'12)

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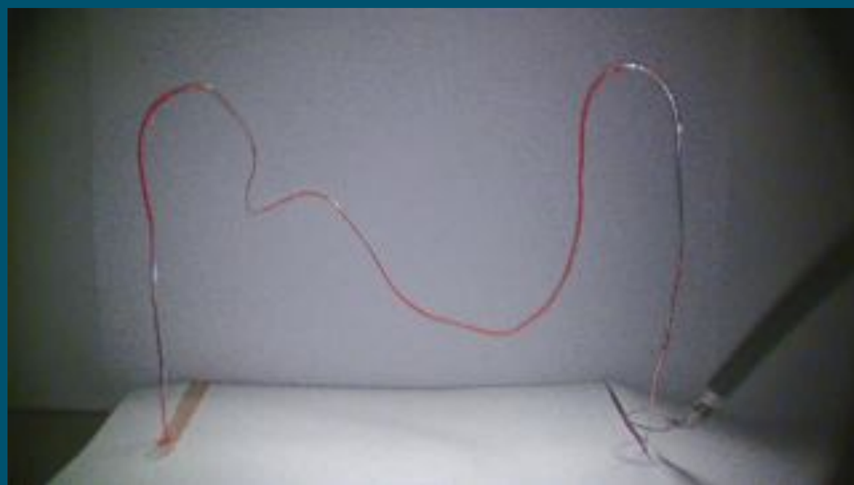
Adding Context



(Bodenstedt, Padoy, Hager – To appear, AIFS)

Combining Perception with Tasks: Transatlantic Telemanipulation

- > ¼ second time delay
- Limited perception
- Complex manipulation

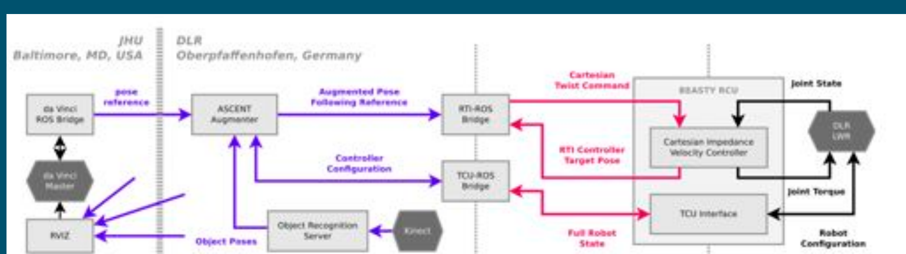
Look and move strategy

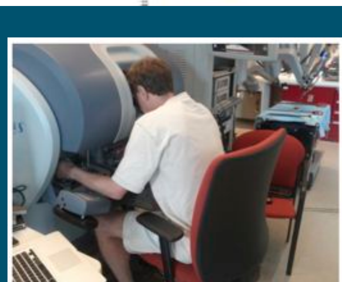
How do we solve this problem?

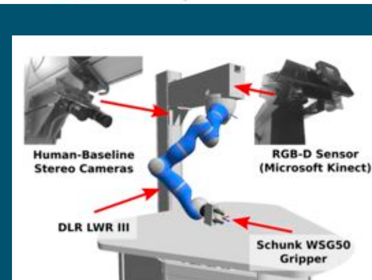
Combining Perception with Tasks: Transatlantic Telemanipulation

- Ground action in perception of objects
- Define canonical manipulation trajectories
- Detect intent relative to plan

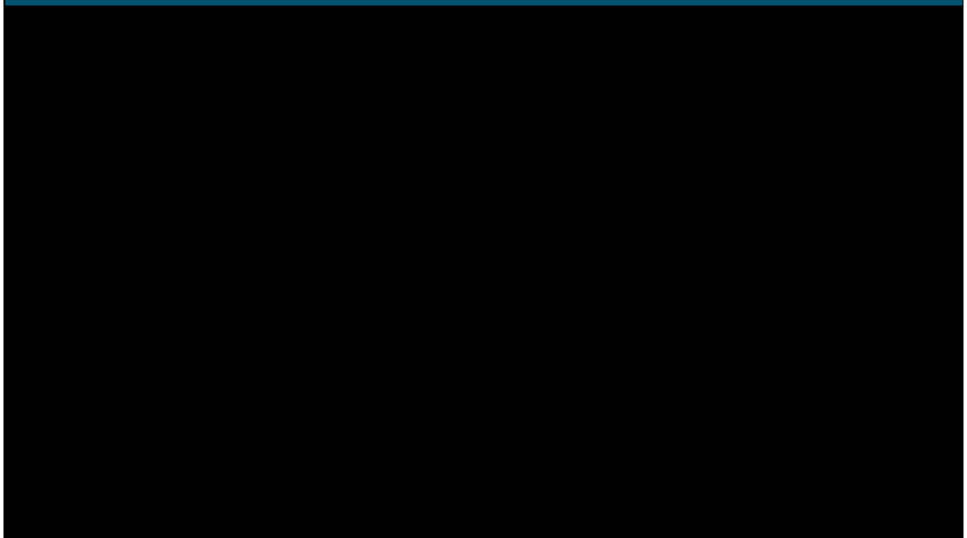
Combining Perception with Tasks







In Action



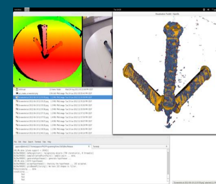
HMCS: New Platforms

- Raven II™ was funded by a NSF equipment grant to build an open source surgical robotics platform for use in a research setting.

- Intuitive Surgical Skills Simulator is a key ingredient to next steps in developing active learning and assistive technologies for surgery

HMCS Projects/Collaborations

- DLR-LiveTime-JHU transatlantic telemanipulation
  Burschka, Haddadin, Amir, Whitcomb, Bohren
- Balaur interactive wall with JHU library
  Guerin, Choudhury
- NRI Collaborations
  Okamura, Blake, Abbeel, Goldberg, Rosen
  Howe, Pfister
- Autonomous Solutions SBIR



Summary

- Robotics is about more than autonomous execution of rudimentary tasks
- Robots will interact with people – they will have to understand and react to them
- CS will be at the core of this effort – it will be about the software, not the hardware!

http://www.cccblog.org/2012/08/24/what-computer-science-can-teach-us-about-robotics/#more-8941

Summary

Rethink Robotics just announced today!

100 YEARS
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