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Move Better with a Robot

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Manipulation Execution:
Toward Human Dexterity

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What can be done with robotics?

Retraining

Robotic Rehabilitation
Home-Based Therapy

Augmentation

Dexterous Prosthetics
Exoskeleton

Remote Assistance

Home-Based Assistance

Home-Based pHRI

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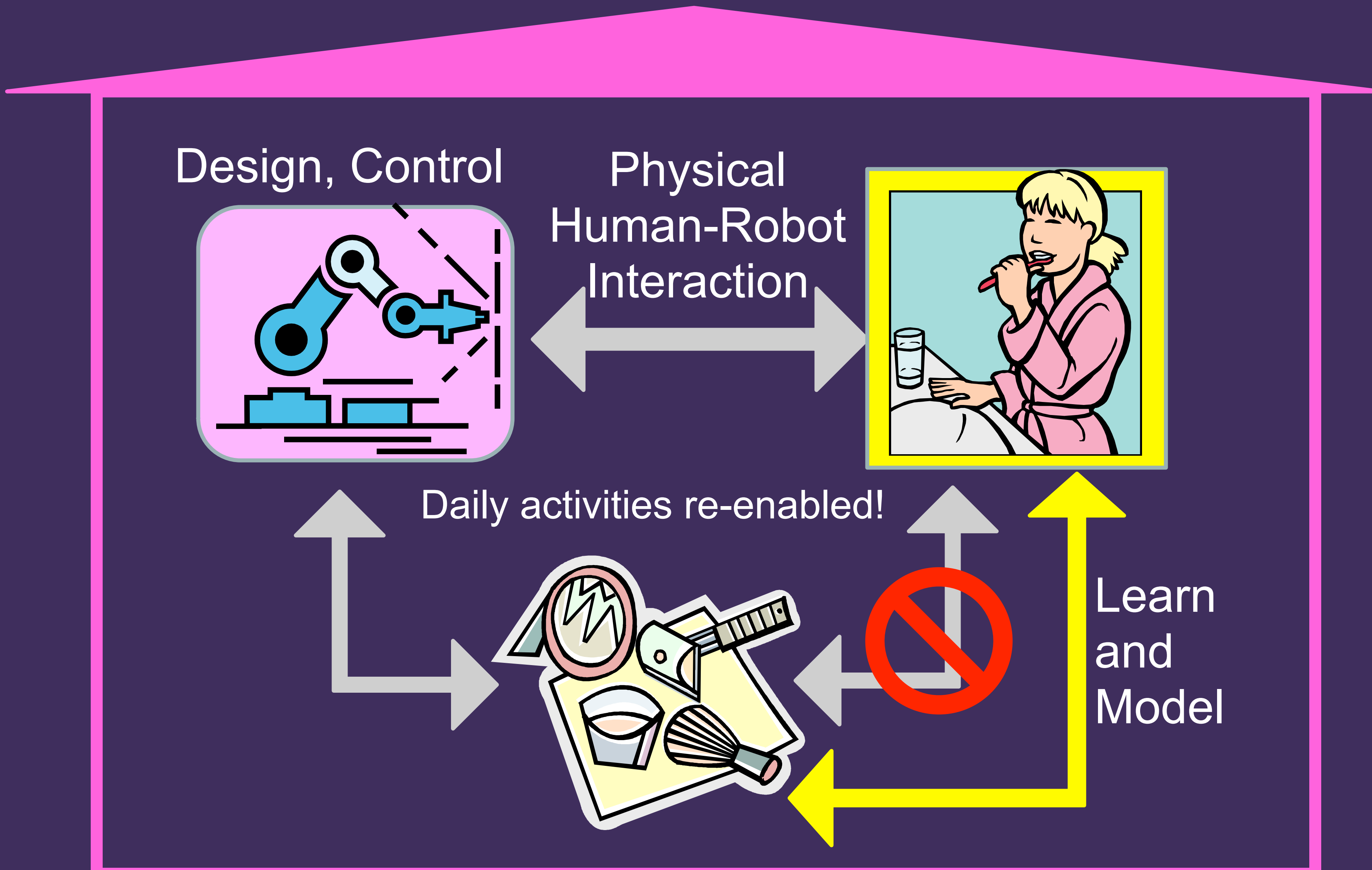

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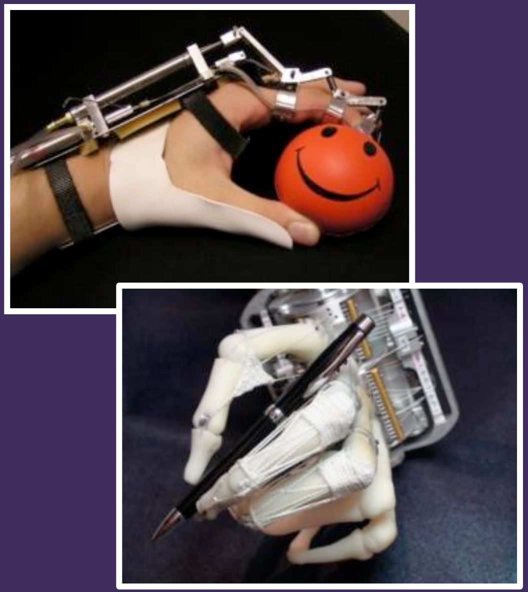
Retraining

Robotic Rehabilitation
Home-Based Therapy

Augmentation



Dexterous Prosthetics
Exoskeleton

Remote Assistance

Home-Based Assistance

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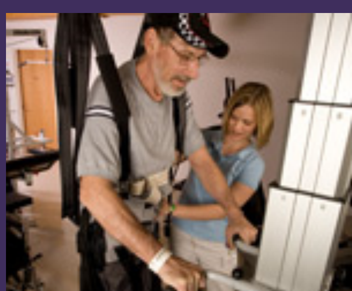
Retraining Movements



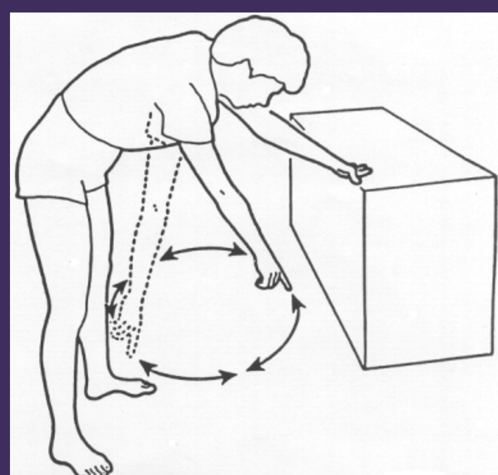


TABLE 1

Therapy Session Check Sheet [TSCS]

Patient ____________________ Date ______________ Therapist ________________ Session# __________

(FILL OUT DURING OR IMMEDIATELY AFTER SESSION!!)

	None-Slight	*Some*	*Mod.*	*Much*	*Very Much*	*Notes:*
PATIENT:						
Reflective	1	2	3	4	5	____ Technical Problems
Receptive	1	2	3	4	5	
Anxiety	1	2	3	4	5	____ Symptoms
Depression	1	2	3	4	5	
Hostility	1	2	3	4	5	____ Therapeutic Change
Other Affect	1	2	3	4	5	
Specify:						____________
TRANSFERENCE:						
Amount	1	2	3	4	5	
Manifest	1	2	3	4	5	
Latent	1	2	3	4	5	
Positive	1	2	3	4	5	
Negative	1	2	3	4	5	

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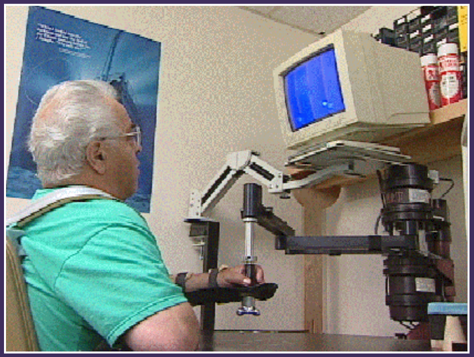
Robotic Rehabilitation

MIME
VA/Stanford

LOCOMAT



MIT-MANUS

Advantages:
•Multiplication without fatigue
•Repetitive movements shown to have efficacy

Challenges:
• Hospital use only because the robots are dangerous/expensive
• Lack of bio/neural feedback or monitoring progress
• Patients have learned-nonuse

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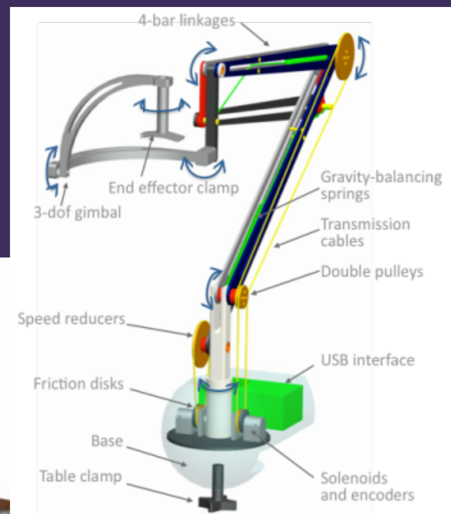
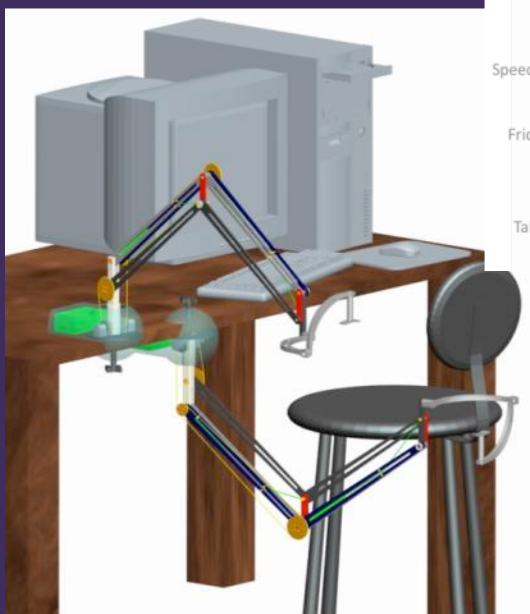
Robotic Rehabilitation:
Safer & Cheaper





Just funded from NSF:
cheaper home-based therapy robot

Part	Quantity	Price	Sub Total	Total
Base including plates	1	8	8	112.95
Electronics/connectors	1	10	10	
Pulleys	7	1	7	
Solenoid	2	8	16	
Linkage	11	1.2	13.2	
Spring	2	4	8	
Cables	5	1.5	7.5	
Clamp screw	1	2	2	
Gimbal linkages	3	1	3	
Plastic mold for attachment	1	1.5	1.5	
Bearings	10	1.5	15	
Low-resolution Encoders	3	7.25	21.75	

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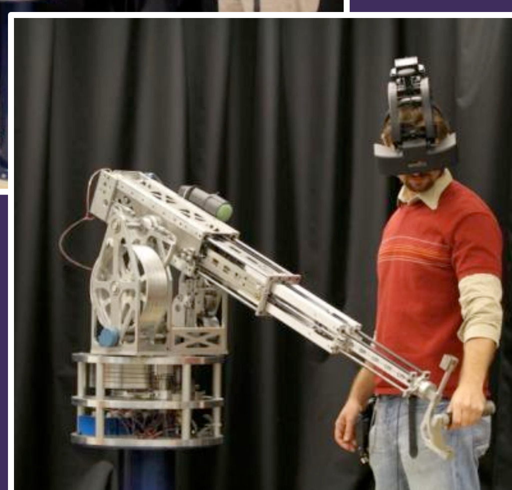
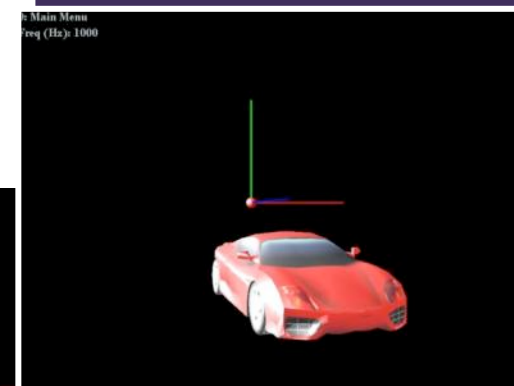
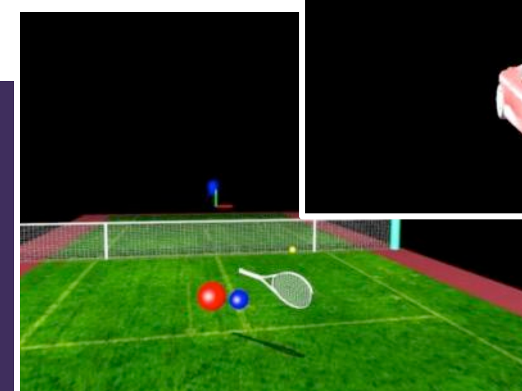
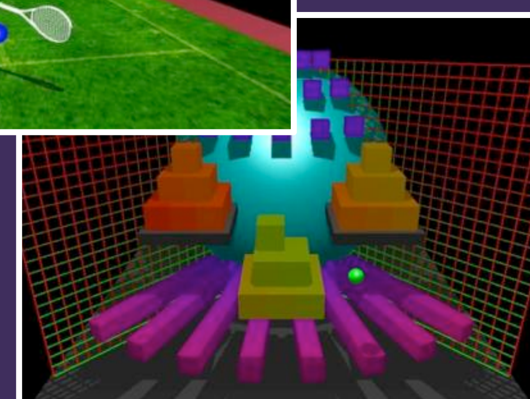
Robotic Rehabilitation: Safer & Cheaper







Brake
Actuated
Manipulator
(BAM)
US Patent#5,755,645

Large Workspace

[Matsuoka & Townsend, 2001]
[Vande Weghe et al. 2004]

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Robotic Rehabilitation: Safer & Cheaper

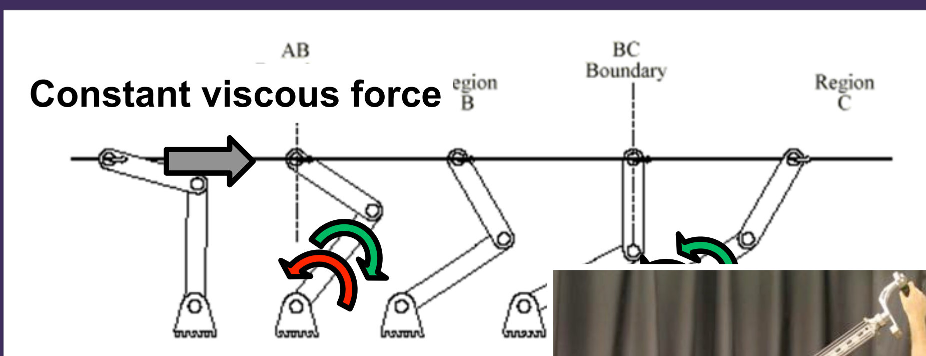
Passivity $v^T f = v^T(-cv) = -cv^2 < 0$

$$v^T f = \dot{\theta}^T J^T (J^T)^{-1} \tau = \dot{\theta}^T \tau < 0$$

Revolute kinematic robots violate this eqn

$$\dot{\theta}^T \tau = \sum_i^n \dot{\theta}_i \tau_i < 0 \qquad \dot{\theta}_i^T \tau_i < 0$$

Creates swiss-cheese environment



Orthogonal kinematic robots:

Swiss-cheese never occurs

[Matsuoka & Townsend, 200
[Dellon & Matsuoka, 2008]

Kinematic arrangement	# of revolute joints	# of prismatic joints
Cartesian	0	3
Cylindrical	1	2
Sphere	2	1

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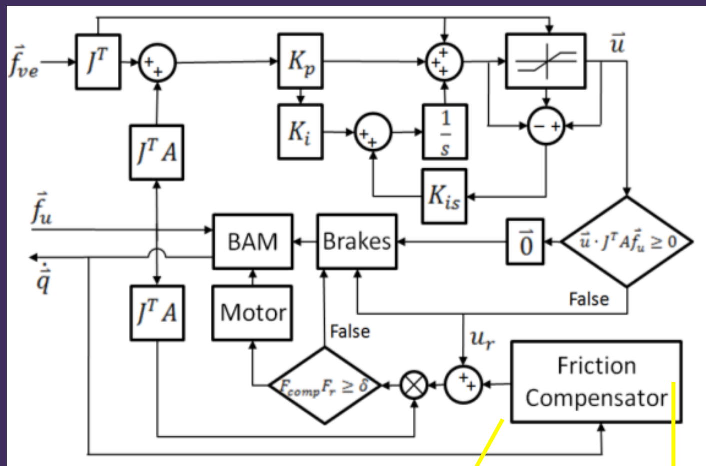
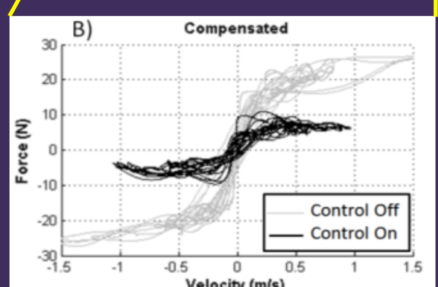
Robotic Rehabilitation: Safer & Cheaper

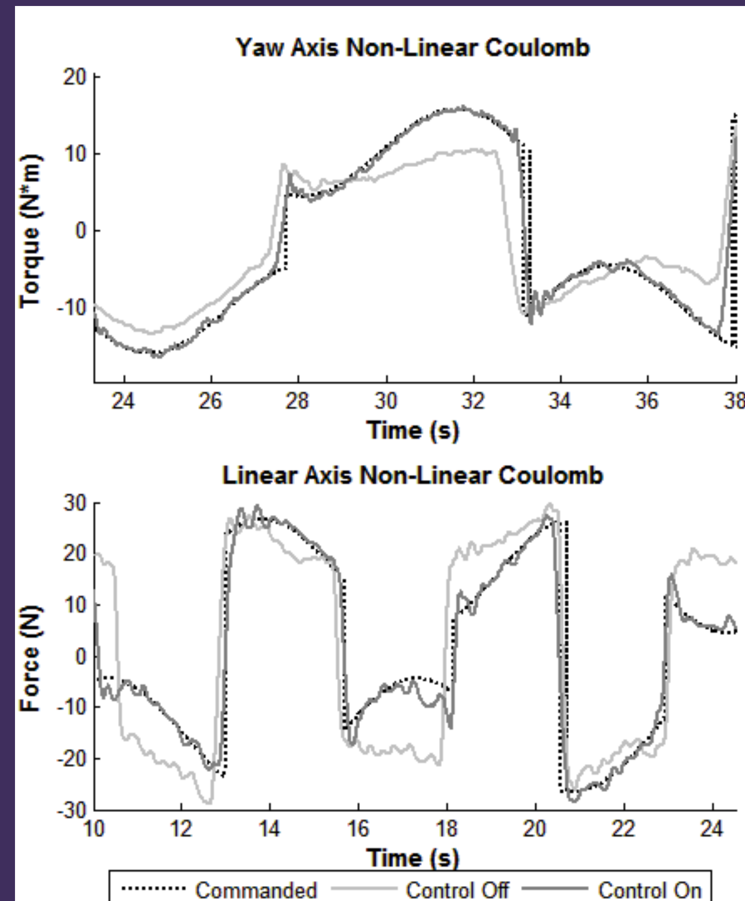


$$\vec{u} = J^T\vec{f}_{ve} + K_p\left\{J^T(\vec{f}_{ve} - A\vec{f}_u) + K_i\int_0^t J^T(\vec{f}_{ve} - A\vec{f}_u)\,d\zeta\right\}$$

$$\vec{u} = J^T\vec{f}_{ve} + K_p\left\{J^T(\vec{f}_{ve} - A\vec{f}_u) + K_i\int_0^t J^T(\vec{f}_{ve} - A\vec{f}_u)\,d\zeta\right\} + K_{is}\int_0^t \vec{e}_s\,d\zeta$$

$$\vec{e}_s = \begin{cases} 0, |\vec{u}| \in \left\{\eta\,|J^T\vec{f}_{ve}|, (I+\eta)\,|J^T\vec{f}_{ve}|\right\} \\ J^T\vec{f}_{ve} - \vec{u}, otherwise \end{cases}$$





BAM interaction controller

[Dellon & Matsuoka, 2010]

Robotic Rehabilitation: Safer & Cheaper

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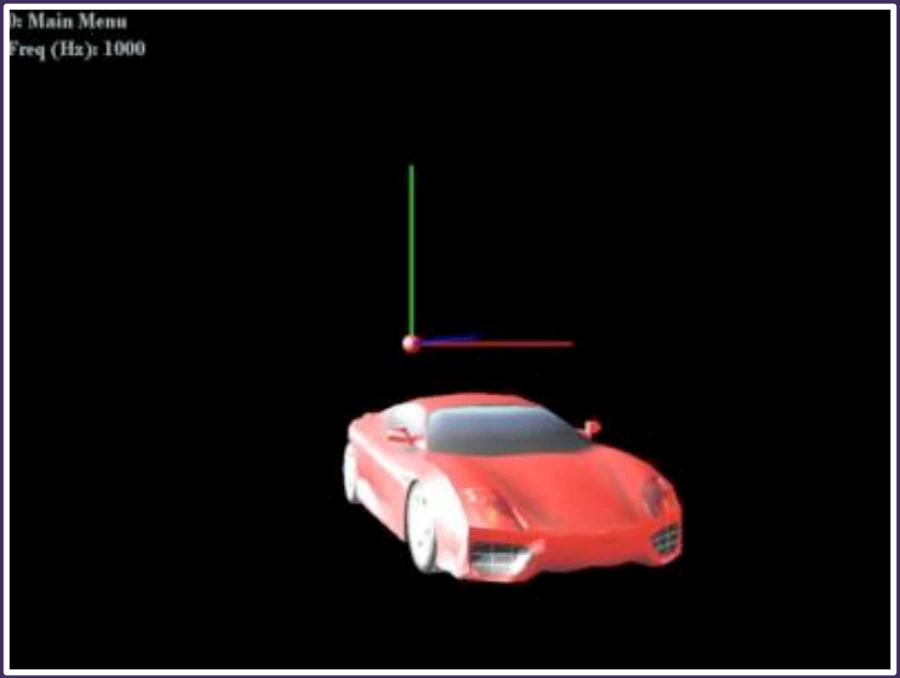

Active robots can push back but not passive robots

Optic illusion changes body movements [NIH funded --- experiments just conducted]

Another optic illusion changes arm movements [preliminary test conducted]

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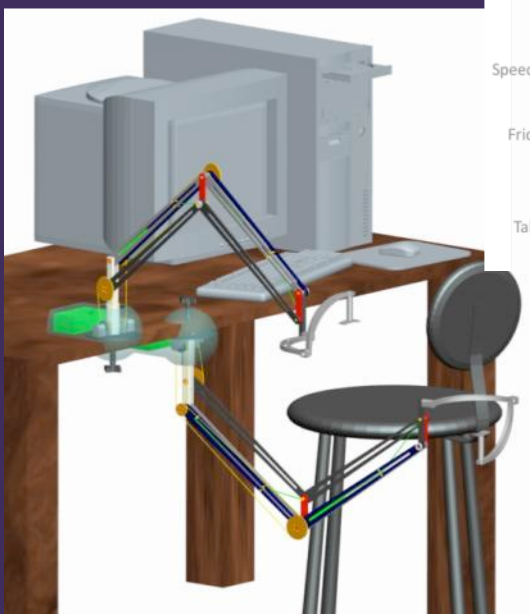
Robotic Rehabilitation: Safer & Cheaper



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Challenges:

- ~~Hospital use only because the robots are dangerous/expensive~~
- Lack of bio/neural feedback or monitoring progress
- Patients have learned-nonuse

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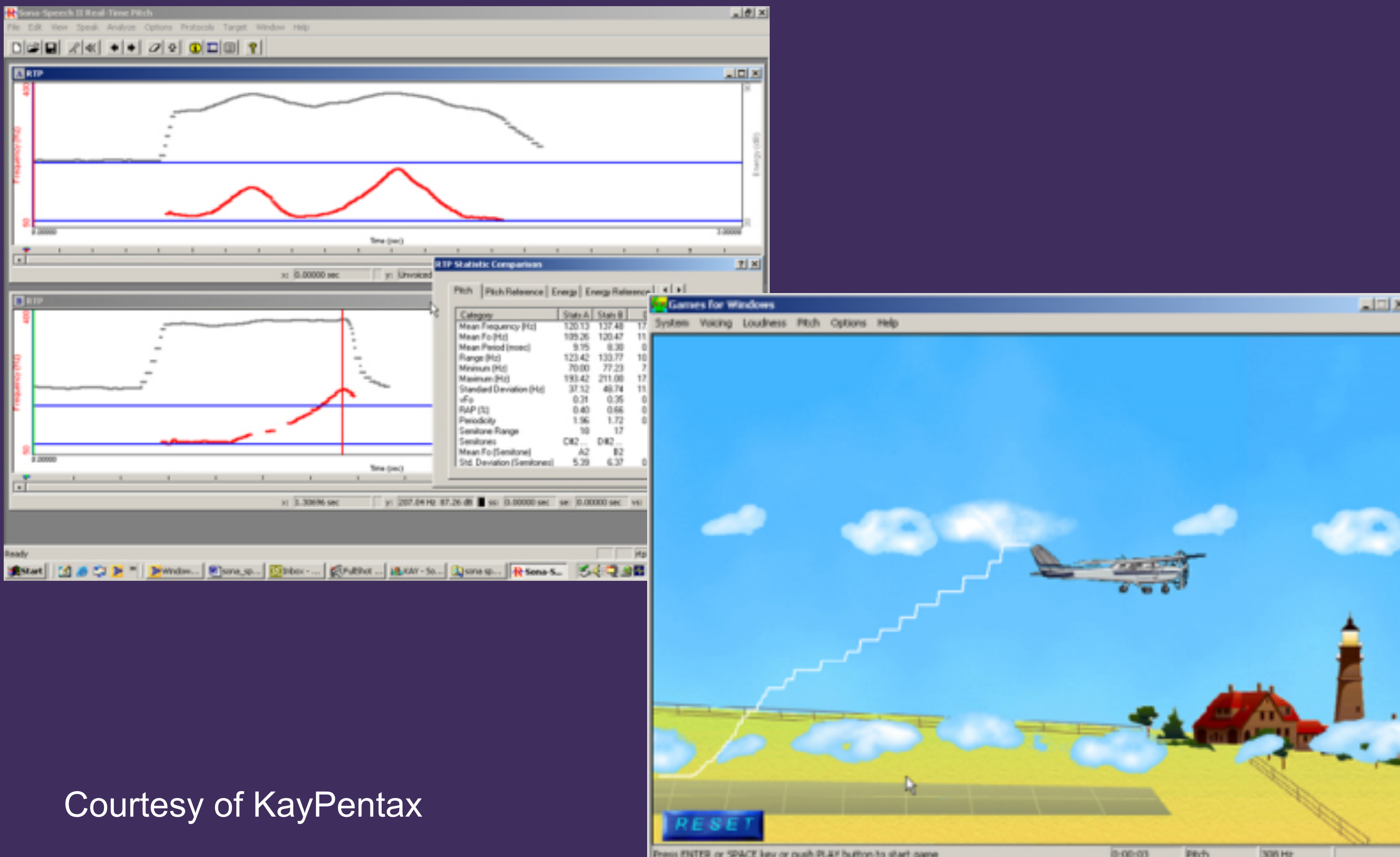
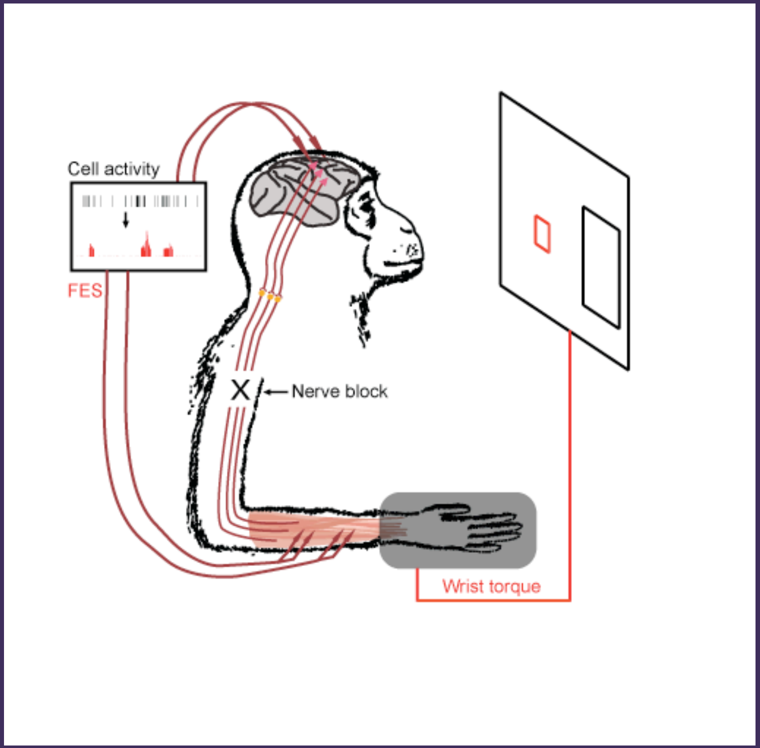
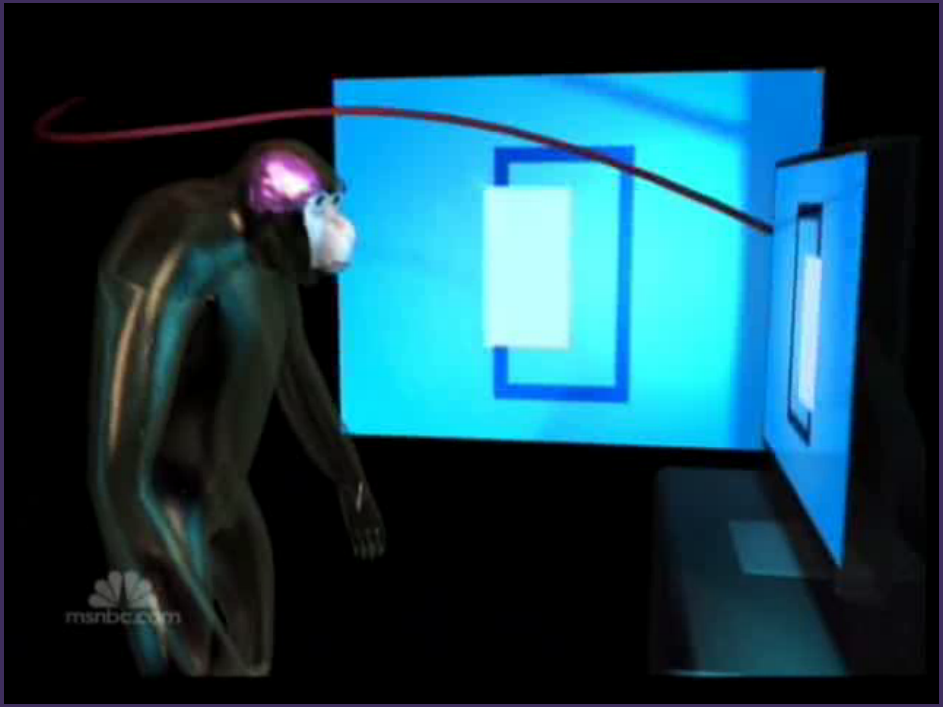
Robotic Rehabilitation: Feedback & Monitoring



Courtesy of KayPentax

Robotic Rehabilitation: Feedback & Monitoring





[Moritz, Perlmutter & Fetz, 2008]

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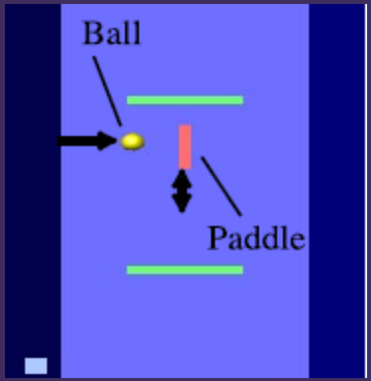
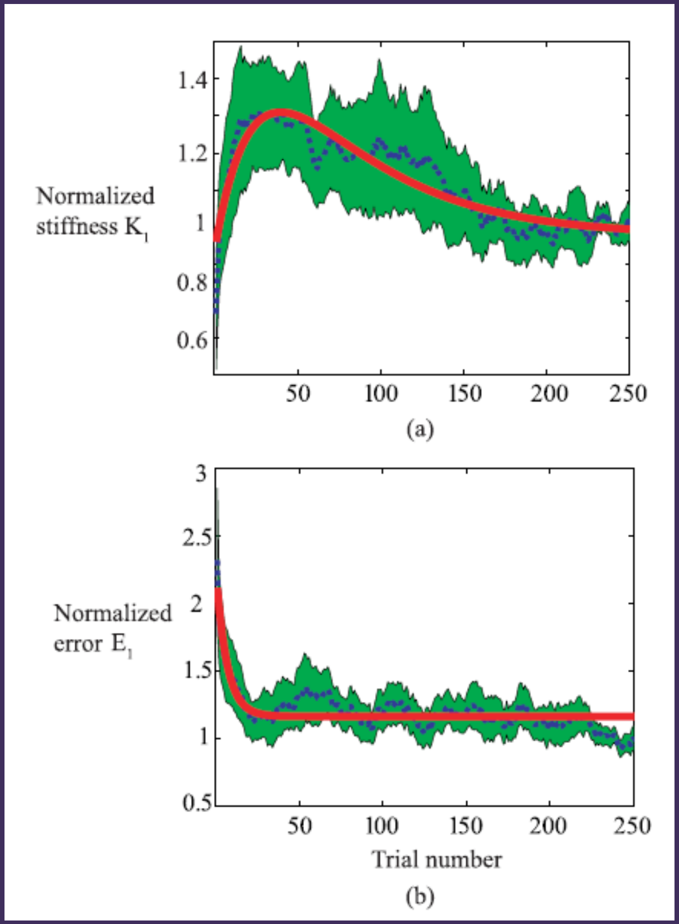
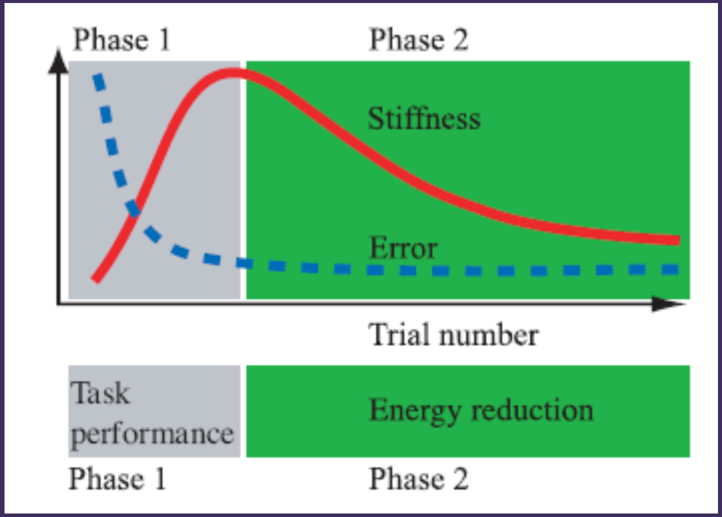
Robotic Rehabilitation: Feedback & Monitoring







[Balasubramanian, Howe & Matsuoka, 2009]

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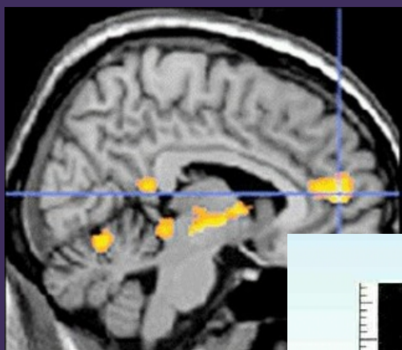
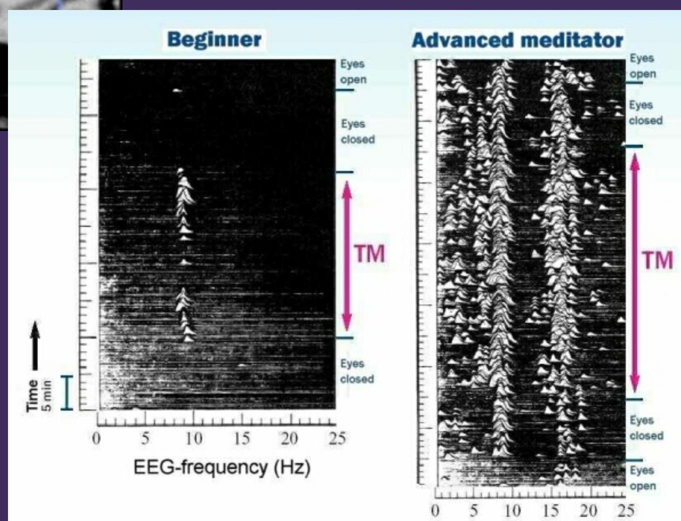
Robotic Rehabilitation: Feedback & Monitoring

Neural (and physiological) coherence





More coherence observed while learning (EEG, EEG & EMG, etc)

<u>Hypothesis:</u>
If bio/neural feedback can modulate the level of coherence, can the learning rate be changed?

<u>Qualitative evidence:</u>
Listening to music
Learns better

<u>Quantitative evidence:</u>
1-2 weeks away…

Challenges:

- ~~Hospital use only because the robots are dangerous/expensive~~
- ~~Lack of bio/neural feedback or monitoring progress~~
- Patients have learned-nonuse

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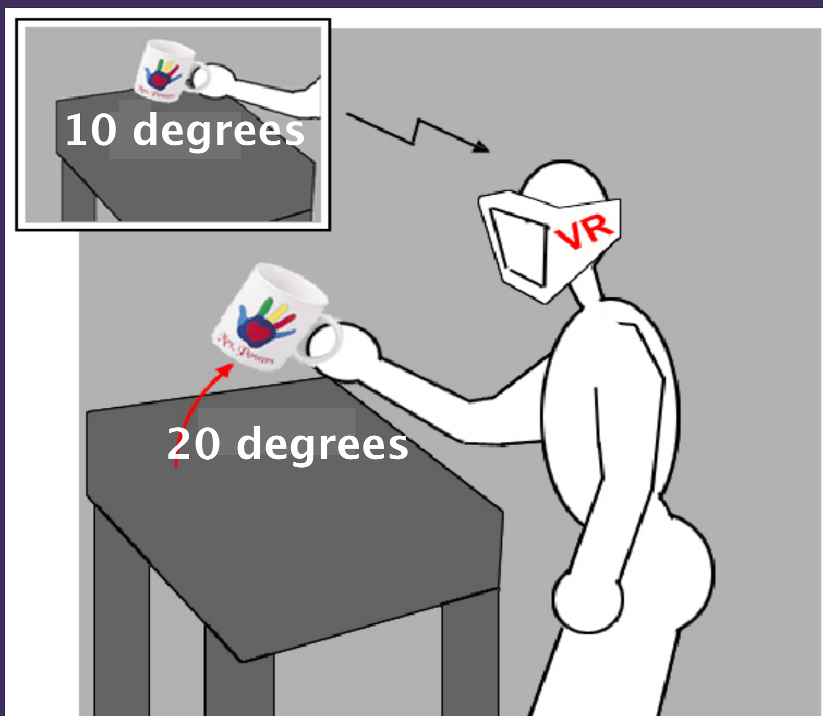
Robotic Rehabilitation:
Overcoming Learned-Nonuse



Proprioceptive sensors not as sensitive as vision.

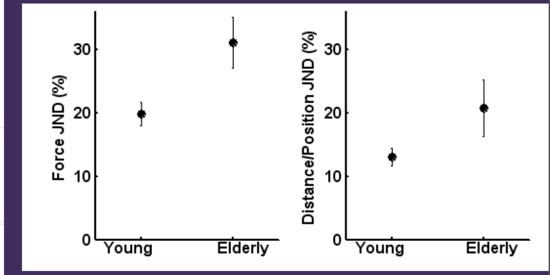
“Rehabilitation by Distortion”

Other feedback manipulation in rehabilitation [Pisella, 2002; Rode 2004; Patton, 2005]

Robotic Rehabilitation:
Overcoming Learned-Nonuse

- Quantification of Imperceptible Distortion Size

	Younger subjects (age 18-35)	Elderly subjects (age 61-80)	Motor disabled subjects
Force JND	19.7%	31.0%	46.0%
Distance JND	13.0%	21.1%	45.0%



[Brewer, Fagan, Klatzky &Matsuoka, 2004]

- The distorted feedback in force/distance is not reliably detected till up to 3 JNDs.

[Matsuoka, Allin & Klatzky, 2002]

- Perceived physical effort follows distortion.

[Fagan, Klatzky & Matsuoka, 2003]

Robotic Rehabilitation: Overcoming Learned-Nonuse

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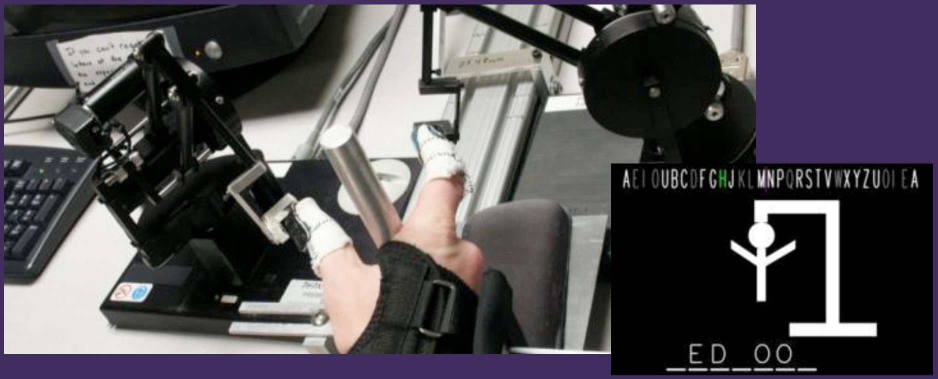
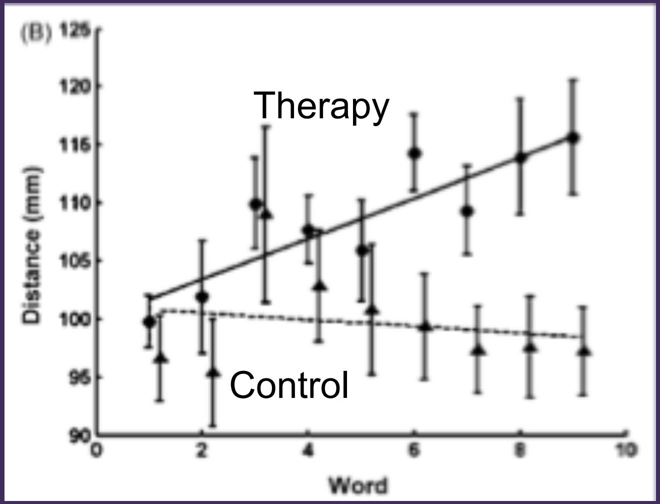
Preliminary study

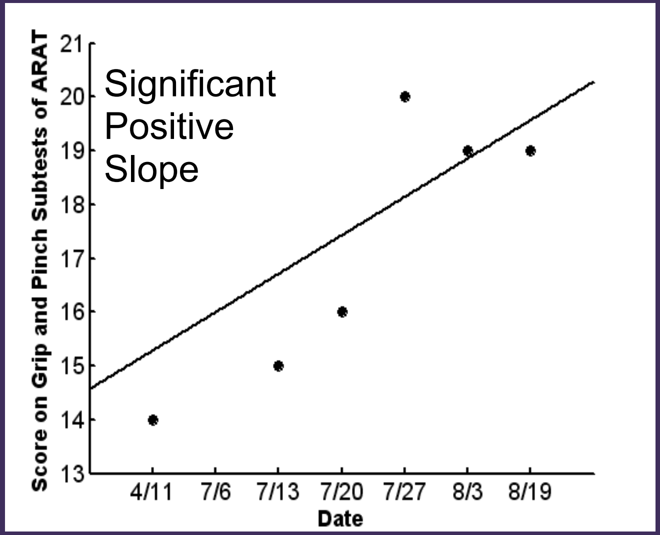


- Focused on finger pinching movement
- 6-week therapy with feedback distortion
- 1 stroke (age 71), 2 TBI (ages 25, 34)
- Between 2 to 8 years post-injury

Example improvements:

- Index MCP active range of motion: 40° to 68°
- Reduced hypertone in index and thumb (Ashworth 2/3 to 1)
- Increase in maximum exertable force
- improvement on ARAT
- Retention shown after 12 weeks





[Brewer, Klatzky & Matsuoka, 2006, 2008]

Robotic Rehabilitation: Moving Forward

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Home based therapy

Other ongoing projects:

- Cheap, safe, online home-based therapy
- Parkinson's diagnostic and monitoring
- Multi-finger movement coordination therapy

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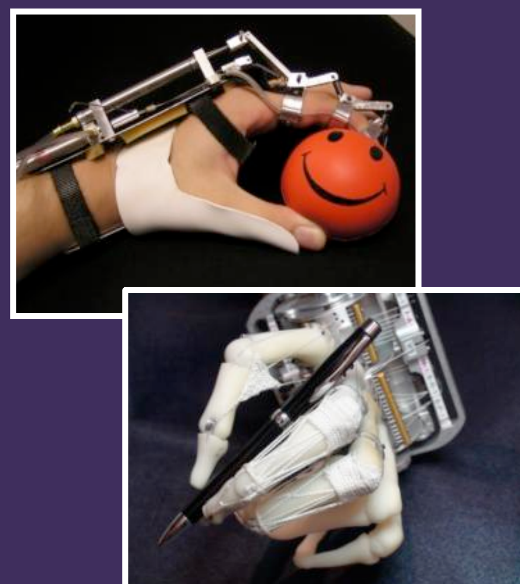
Retraining

Robotic Rehabilitation
Home-Based Therapy

Augmentation



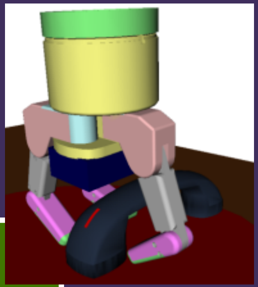
Dexterous Prosthetics
Exoskeleton

Remote Assistance

Home-Based Assistance

Chronic Manipulation Assistance

Intention



Planning

Execution

Grasping --- minimum
Manipulation --- critical

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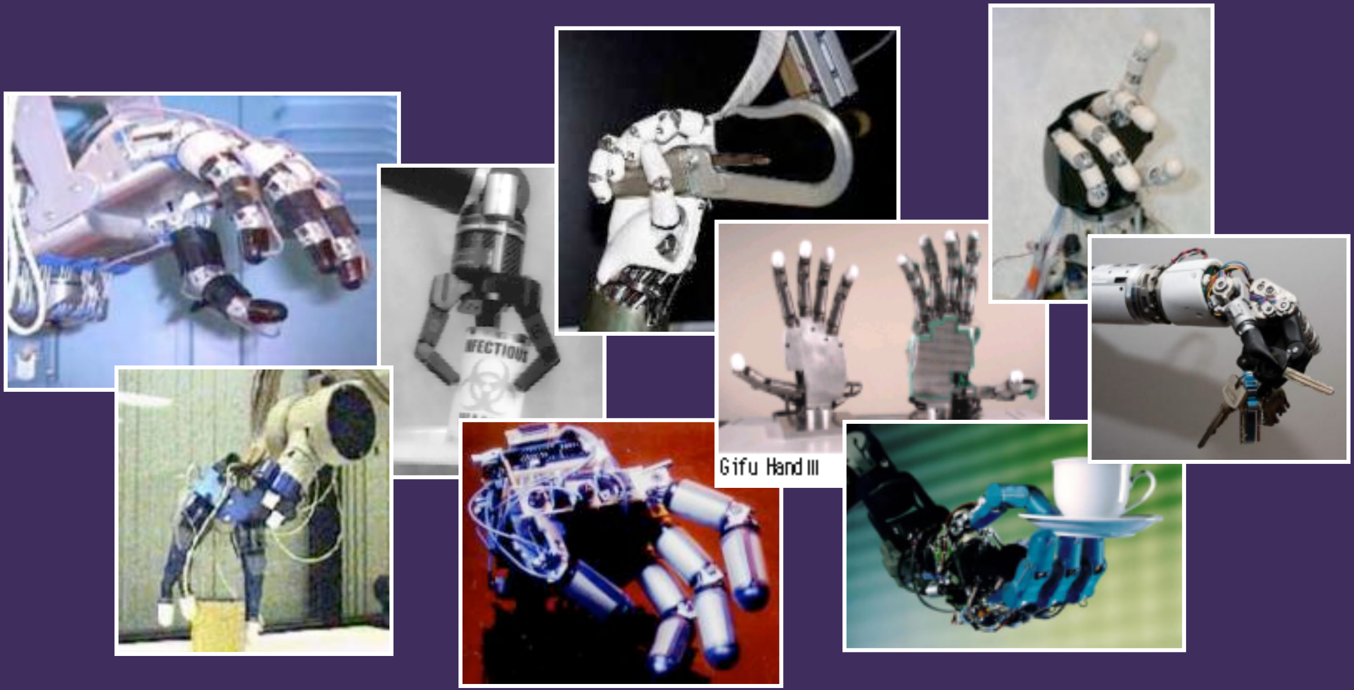
Execution

Prosthetics on the market



Robotic hands 1983 to 2009

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Manipulation Execution:
Toward Human Dexterity

Understand
- musculoskeletal details
- neural control of movement
- robust behavior execution

That enable human level dexterity

Provide solutions to those with injuries

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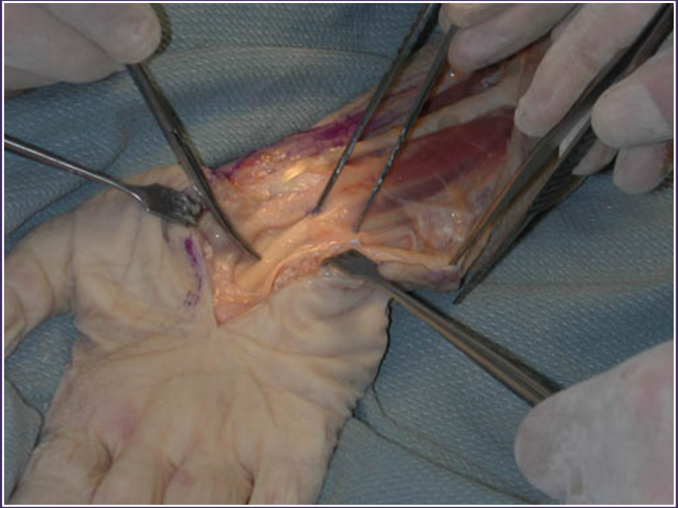
Manipulation Execution:
Toward Human Dexterity

Anatomically Correct Testbed



© Yoky Matsuoka 2001

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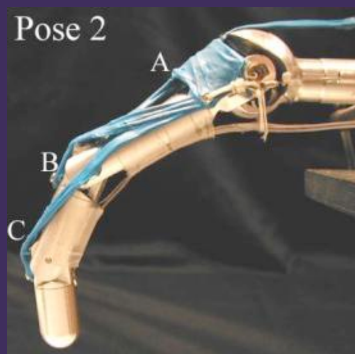
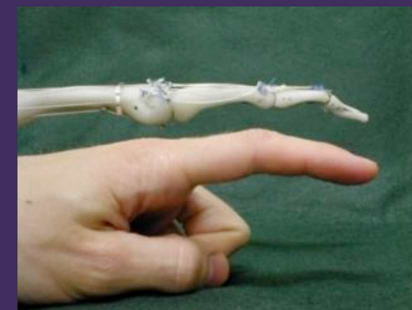
Manipulation Execution:
Toward Human Dexterity

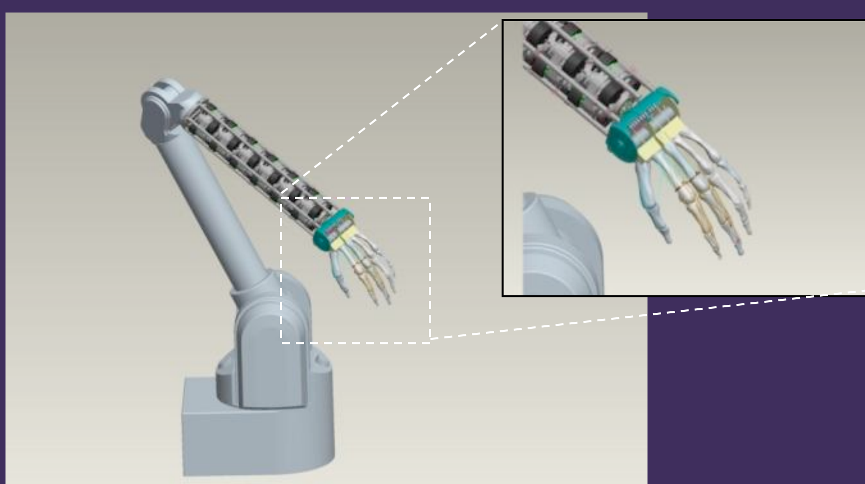


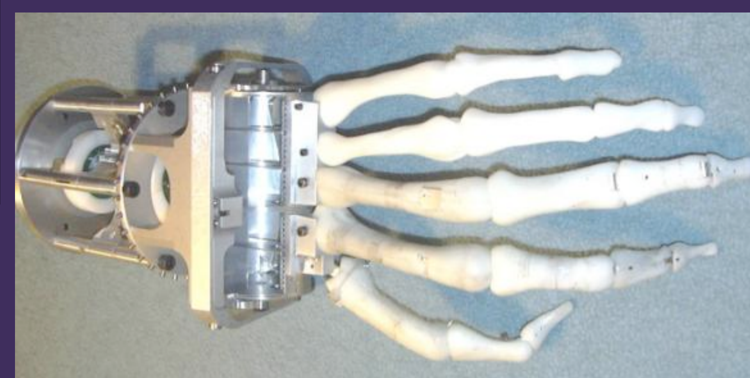
v2.4

v3.1



v4.0 and current





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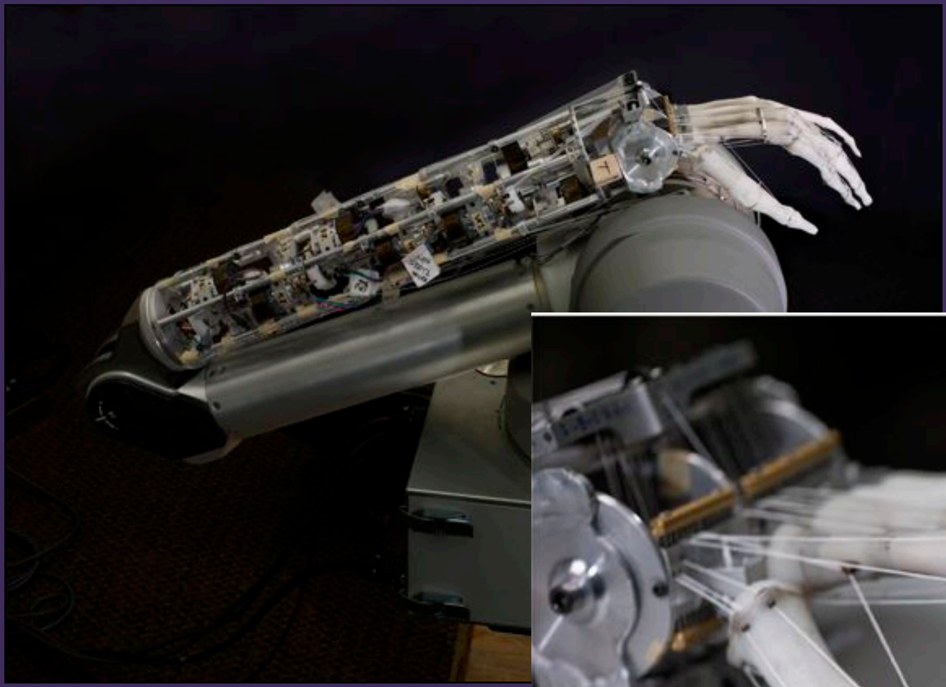
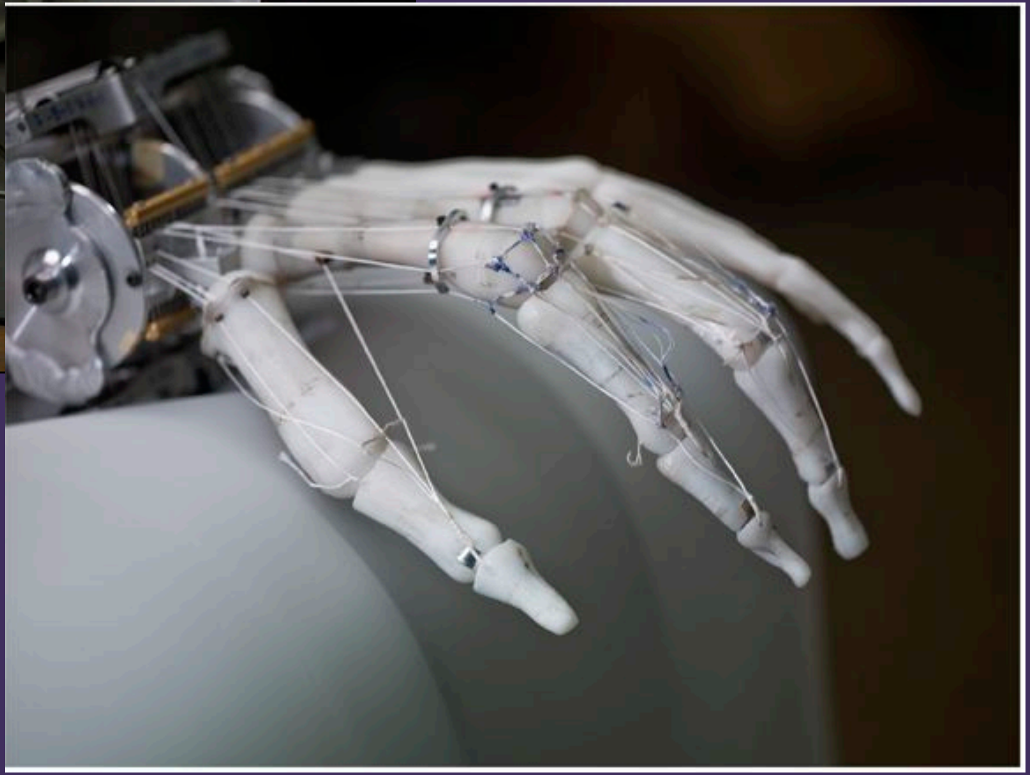
Manipulation Execution:
Toward Human Dexterity



© Ellen Garvens 2008



# Muscles = # actuators
Thumb = 8
Index = 7
Middle = 6

Wrist moves anthropomorphically but not anatomically.

Manipulation Execution:
Toward Human Dexterity

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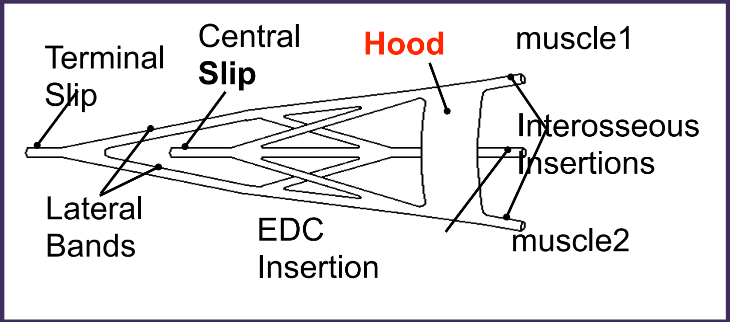
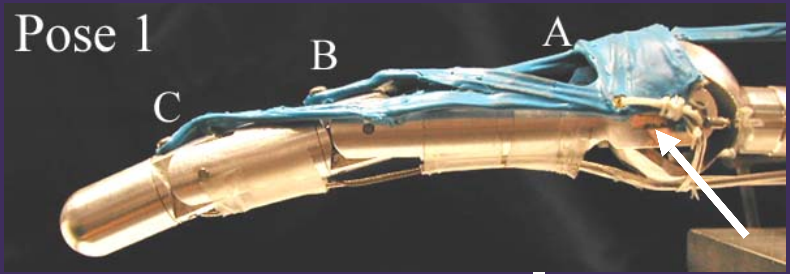
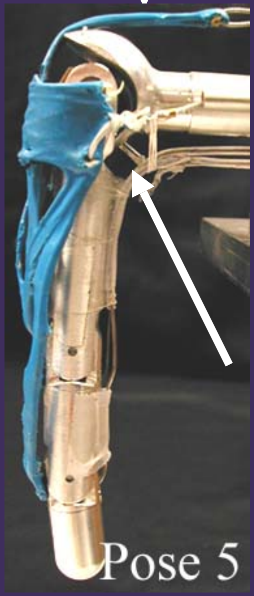
Complex tendon routing reduces muscles





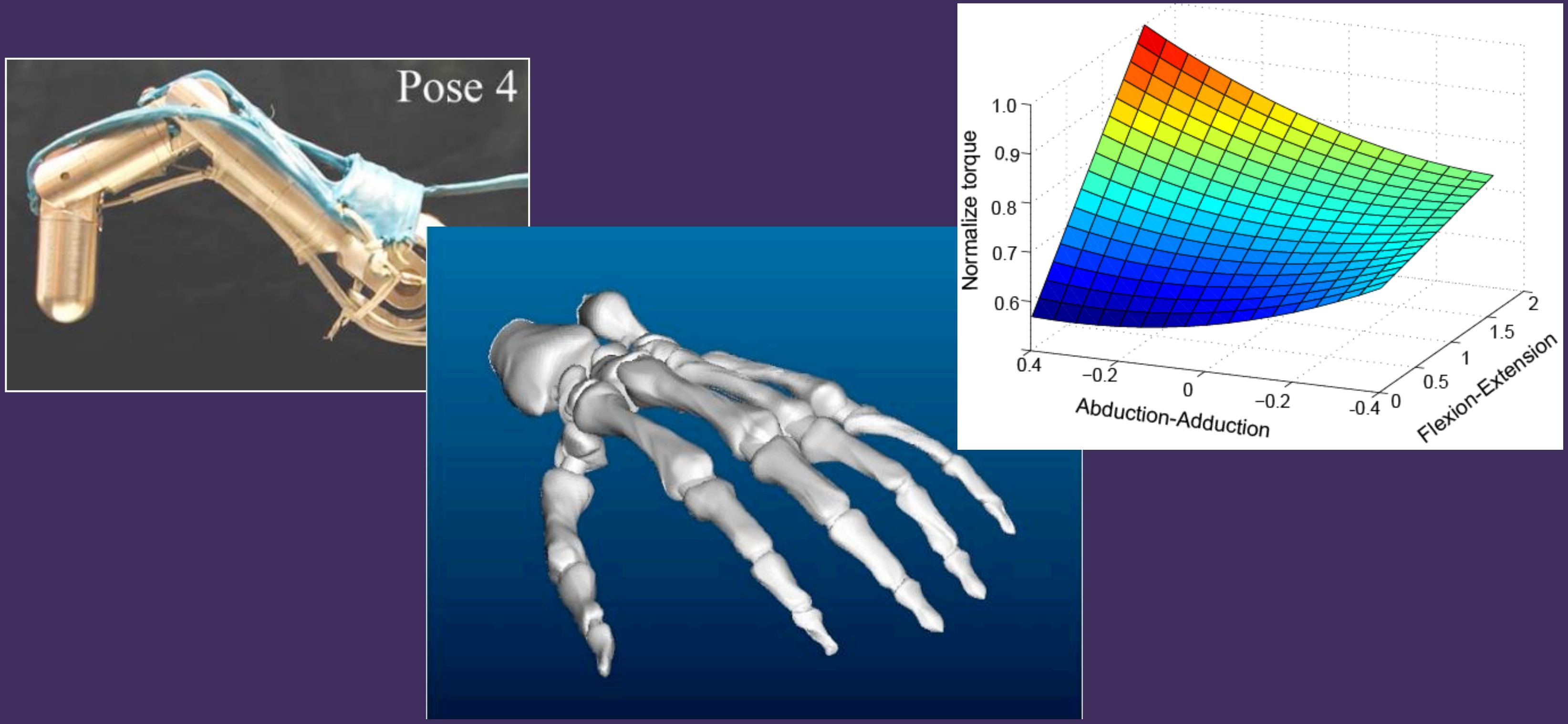


- Complex web of tendons
  - Evolutionary marvel or baggage?
  - Allow special finger posture with limited number of muscles

[Wilkinson, Vande Weghe & Matsuoka, 2003]
[Valero-Cuevas et al. 2007]

Manipulation Execution:
Toward Human Dexterity

Shape of the bones saves neural effort



[Vande Weghe, Rogers, Weissert, & Matsuoka, 2004]
[Deshpande, Balasubramanian, Lin, & Matsuoka, 2008]

Manipulation Execution:
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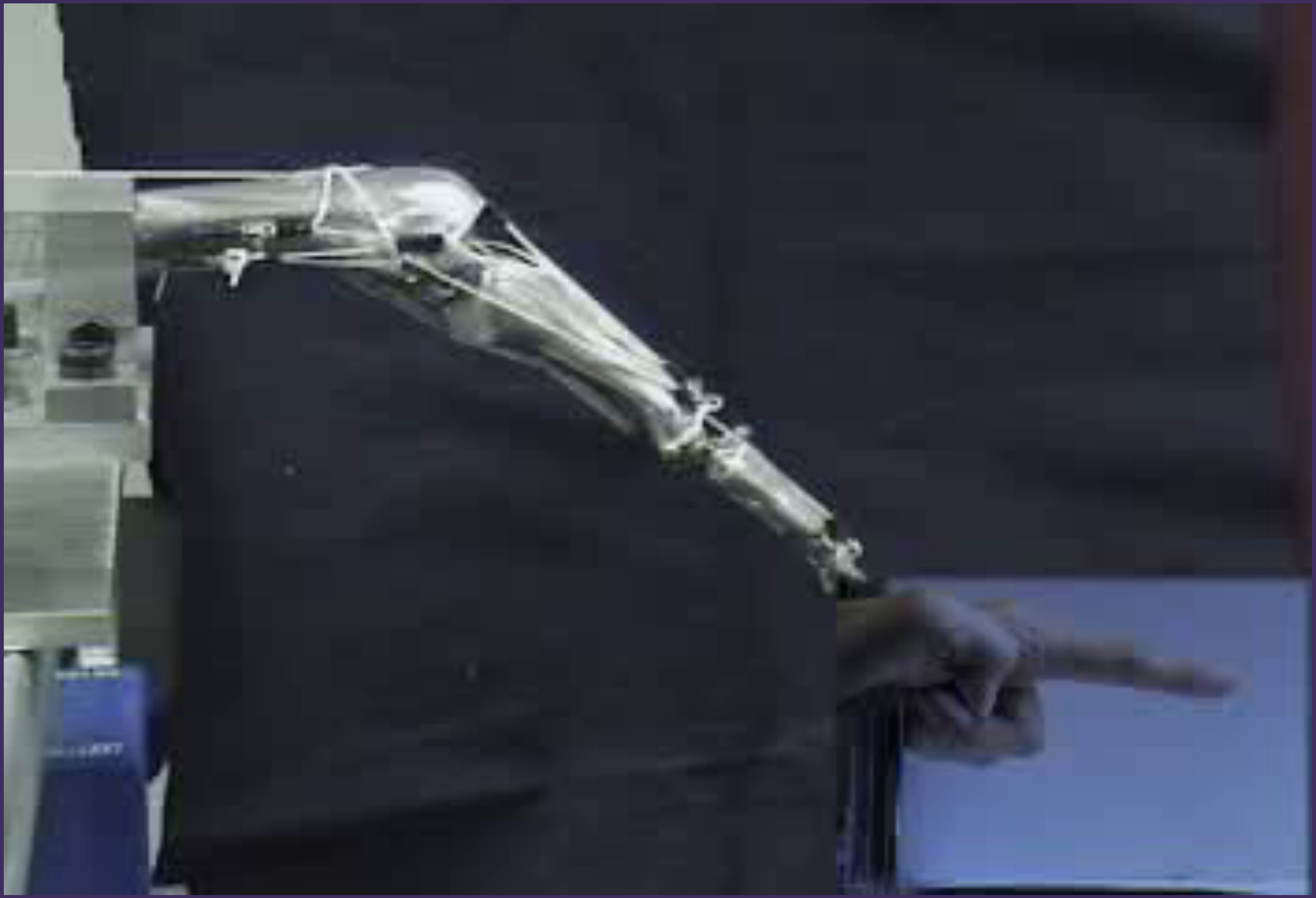

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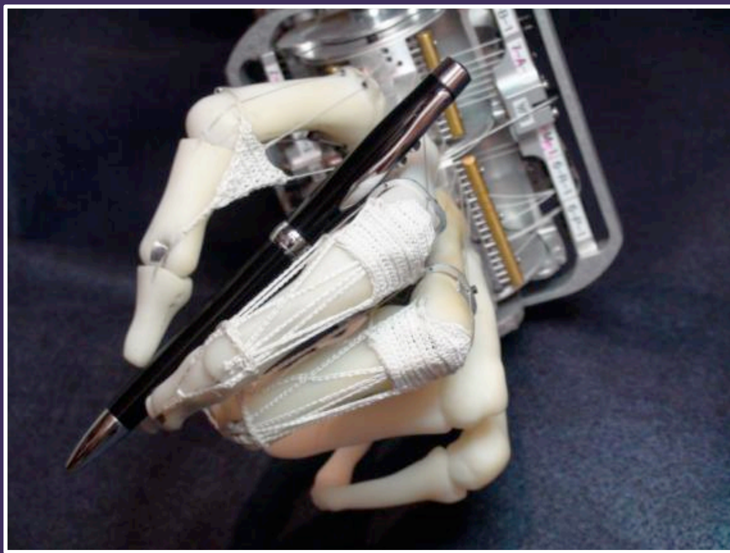
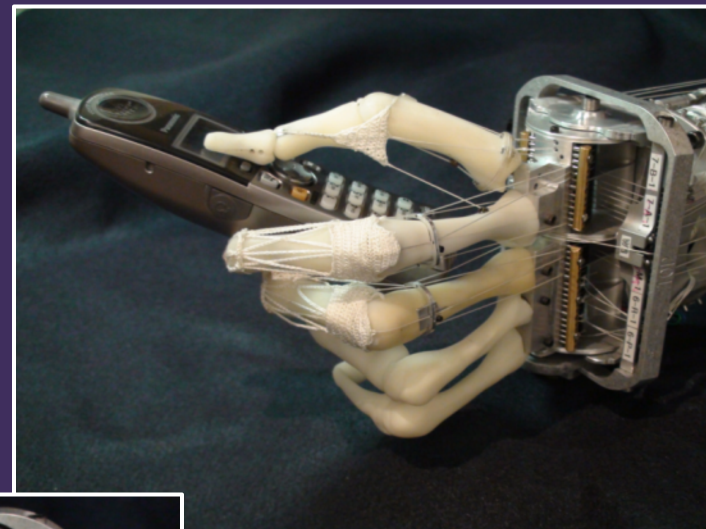
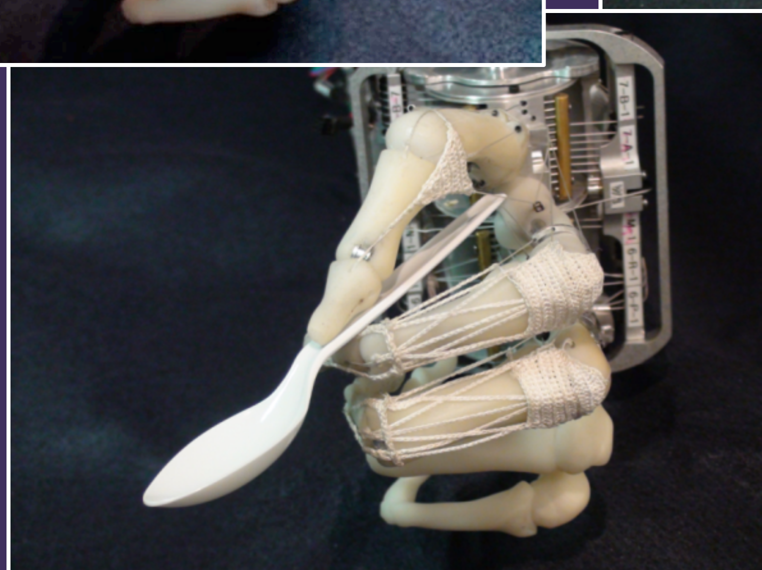
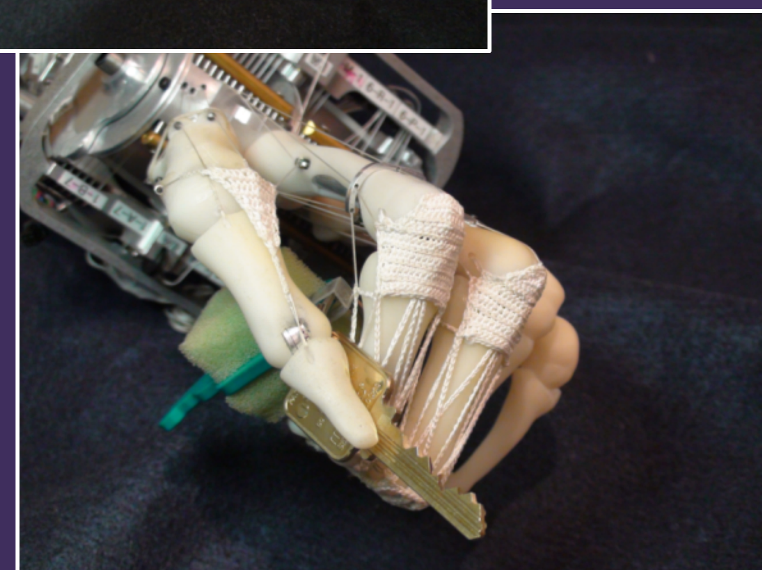
Manipulation Execution:
Toward Human Dexterity

What we can do now!









Manipulation Execution:
Toward Human Dexterity

Hand writing video

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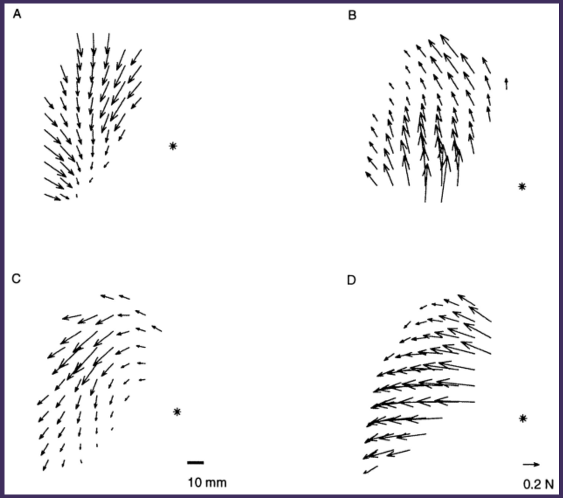
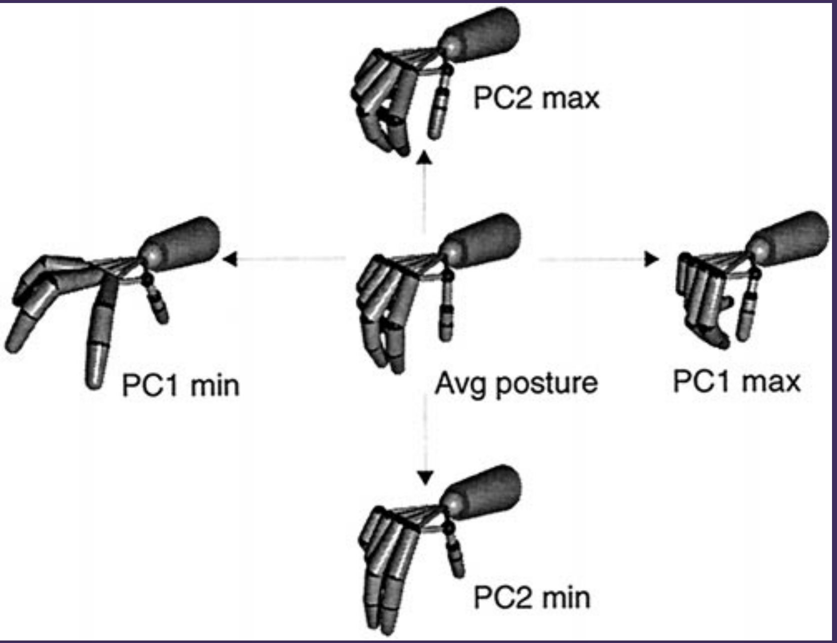
Manipulation Execution:
Toward Human Dexterity

How does the nervous system control a whole bunch of muscles elegantly?





[Bizzi, et al. 80’s & 90’s]

[Santello et al. 1998]

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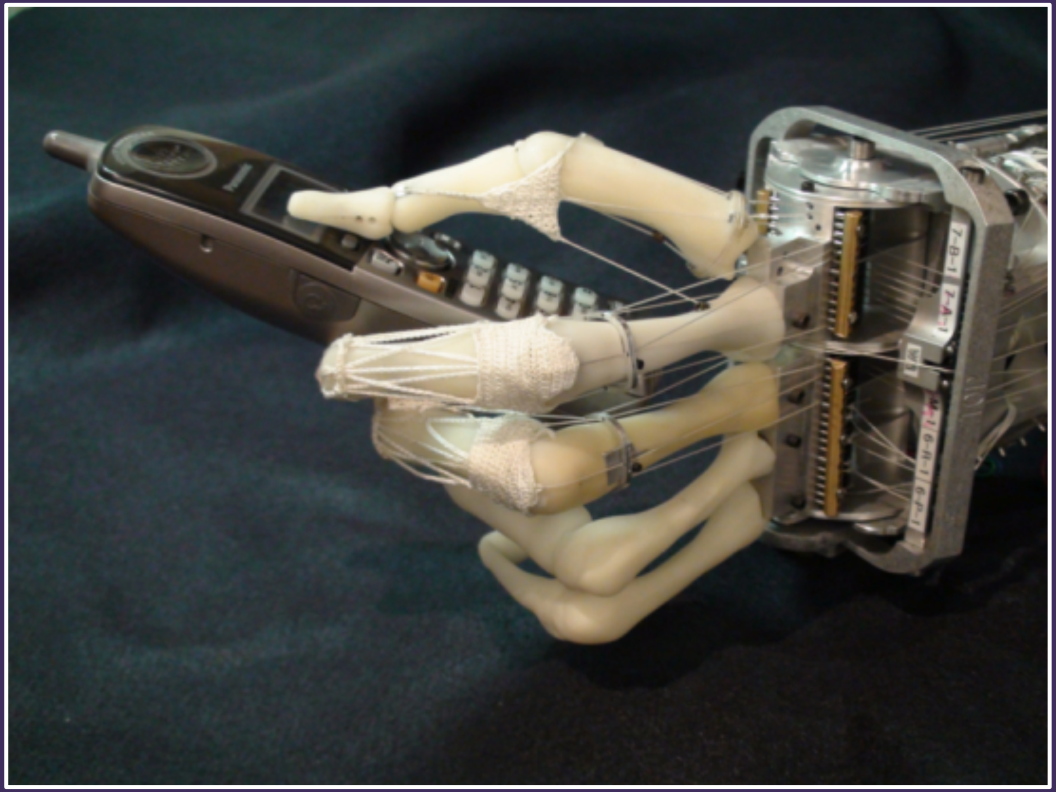
Manipulation Execution:
Toward Human Dexterity

Starting to give out copies of the ACT hand

Mechanical simplification is good if not investigating details



Full Human Scale

Thumb	8
Index	7
Middle	6

97% range of motion

Thumb	6
Index	4
Middle	4

Compromise on force vector, and stiffness ellipsoid

[Malhotra & Matsuoka, 2010]

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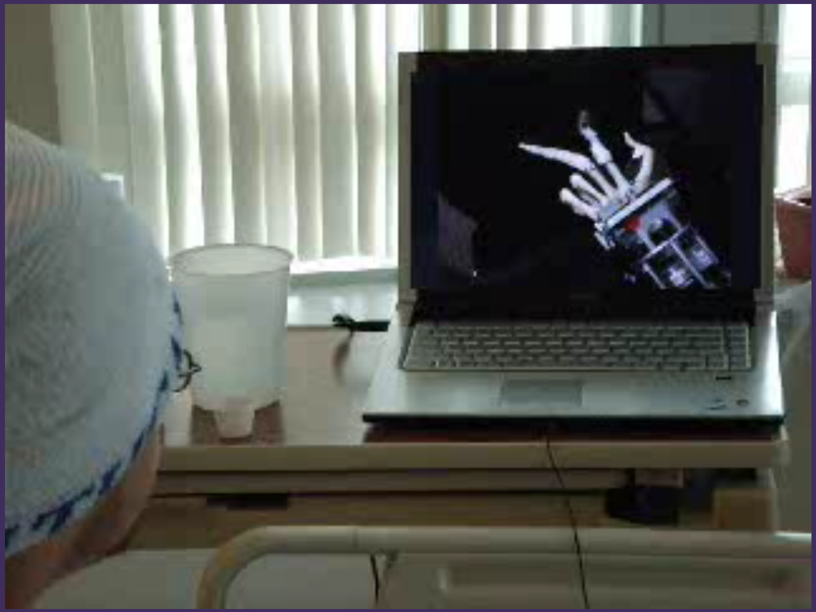
Manipulation Execution: Toward Human Dexterity

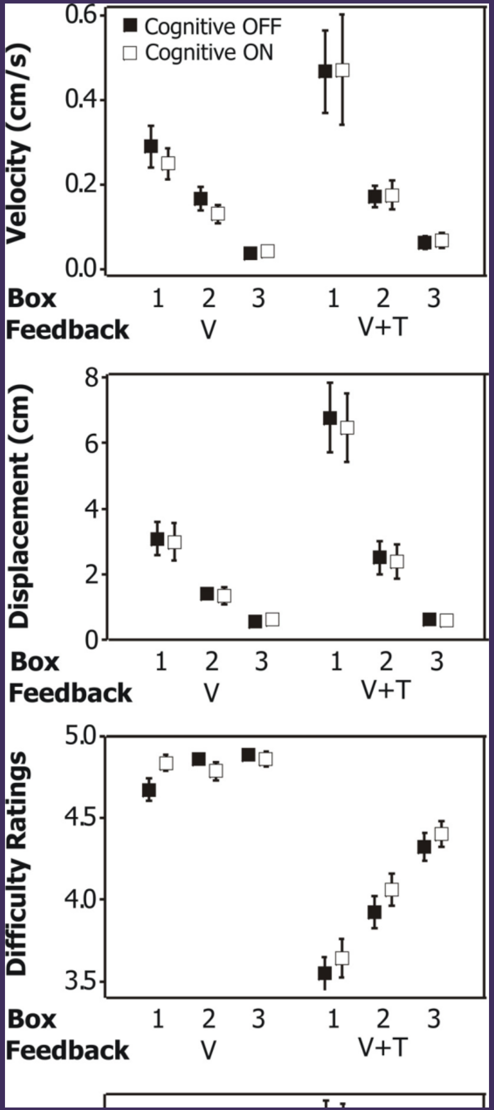
ECoG human control of the ACT hand



Finger movements decoded video

Manipulation Execution:
Toward Human Dexterity

Tactile feedback augmentation



[Stepp & Matsuoka, 2010]

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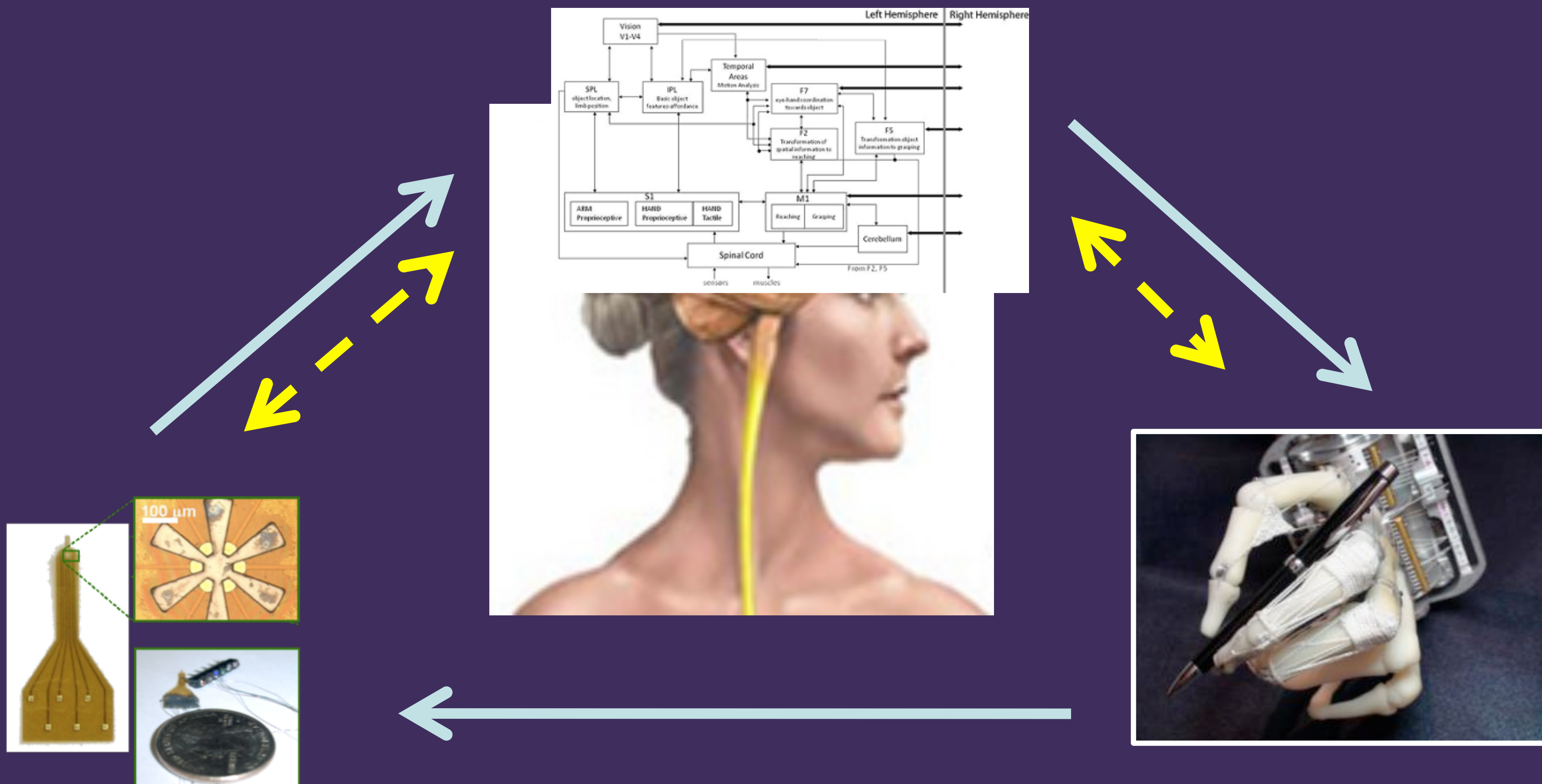
Sensorimotor Neural Engineering



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Center for Sensorimotor Neural Engineering

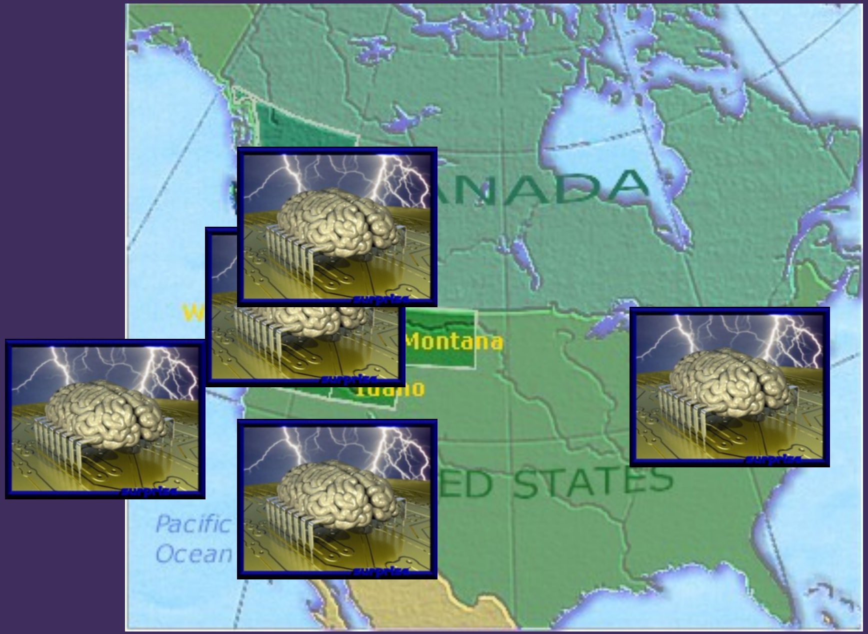

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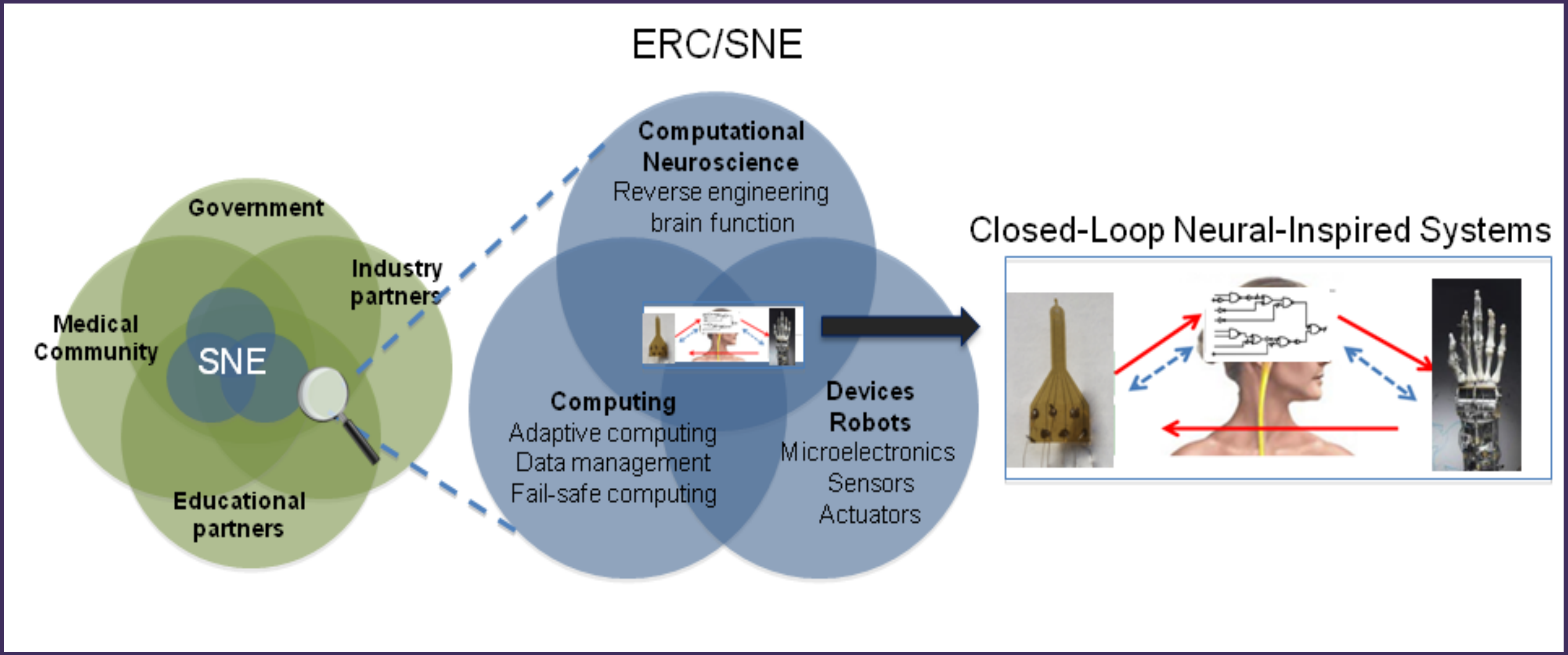
Diagram from the NSF ERC proposal



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ENGINEERING FOR THE HUMAN EXPERIENCE

CS/Engineering students

Middle/High School Students

"Re-launchers"

and more…

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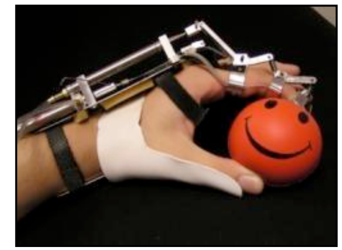

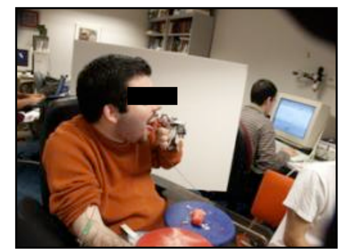

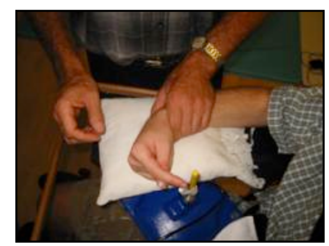

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Thank you to current and past students

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To learn more:

http://neurobotics.cs.washington.edu/

http://www.cs.washington.edu/homes/yoky/

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