# DARPA Revolutionizing Prosthetics 2009


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*January 2009*

**Presented to the**
**MORS Personnel and National Security Workshop**




The Johns Hopkins University
APPLIED PHYSICS LABORATORY

# Report Documentation Page

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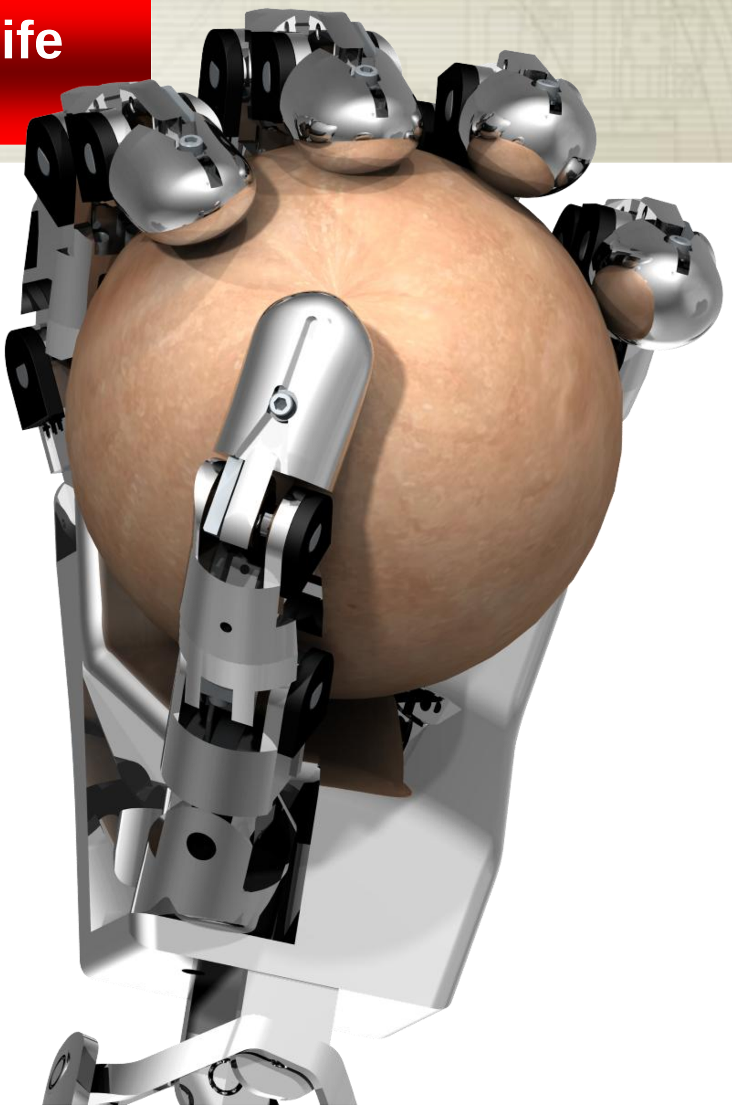
# DARPA Revolutionizing Prosthetics 2009 Program

- **Vision**
  - **Produce a fully neurally integrated upper extremity prosthetic with appropriate documentation for clinical trials, FDA approvals, and manufacturing transition.**

- **Mission**
  - **Apply an understanding of the underlying function and control of the human arm and hand when performing the basic functions of reaching, pointing, grasping, and coordinated finger movements to the design of this prosthetic.**
  - **Understand and address the amputees' needs to promote and enhance quality of life issues – comfort, cosmesis, natural control, integrated sensory feedback**

***This vision enabled APL to rapidly assemble a world-class team of neural scientists, clinicians, technology developers, and commercial organizations for the Revolutionizing Prosthetics program***

# Restoring function and improving quality of life for our injured warfighters



- Modular to suit range of Upper Extremity Patients
  - Suitable for Range of Injury Levels
    - (Modular Mechanical Design)
- Dexterous control of 22+ degrees of freedom
  - – mimics natural limb
- Natural Control
- Natural Performance
  - Anthropomorphic, speed, dexterity, force
  - Supports Activities of Daily Living
- Sensory Perception of Environment
  - Pressure, Force
  - Temperature
  - Tactile Discrimination
- Proprioception
- Natural Appearance
- Comfortable
- Durable, Reliable
- Provides Suitable Function at Varying Degrees of Invasiveness

# Revolutionizing Prosthetics 2009 Collaborative Partners

***> 30 Participating organizations; 4 year, $70+M program***

## APL
- Program Management
- System Engineering & Integration
- Signal & Image processing
- Virtual Reality & Controls

## JHMI
- PI for Medicine
- Human Subjects
- Brain Computer Interface

## New World Assoc
- Mechanical Design
- Prototype Development
- Test & Integration

## UCI
- Sensory Integration

## Otto Bock
- Prosthetic Components
- Control Bus Architecture
- Clinical Support

## Kinea
- Mechanical design
- Controls

## Duke
- Intelligent Grasp Control
- Sensory Stimulation

## Northwestern
- Non/Low Invasive Strategies
- Enhanced Haptics
- Mechanical Design

## RIC
- Virtual Reality Environment
- Targeted Reinnervation
- Patient Needs

## USC
- Virtual Reality Environment

## U of Rochester
- Cortical Control for Hand Movement

## Rutgers Univ
- Peripheral Nerve Interfaces
- Bio-Materials

## Stanford Univ
- Cortical Signal Extraction
- Signal Analysis & Control

## CalTech
- Higher Cortex Signal/Intent Extraction

## Orthocare
- SMART socket
- Haptics Patient Interface

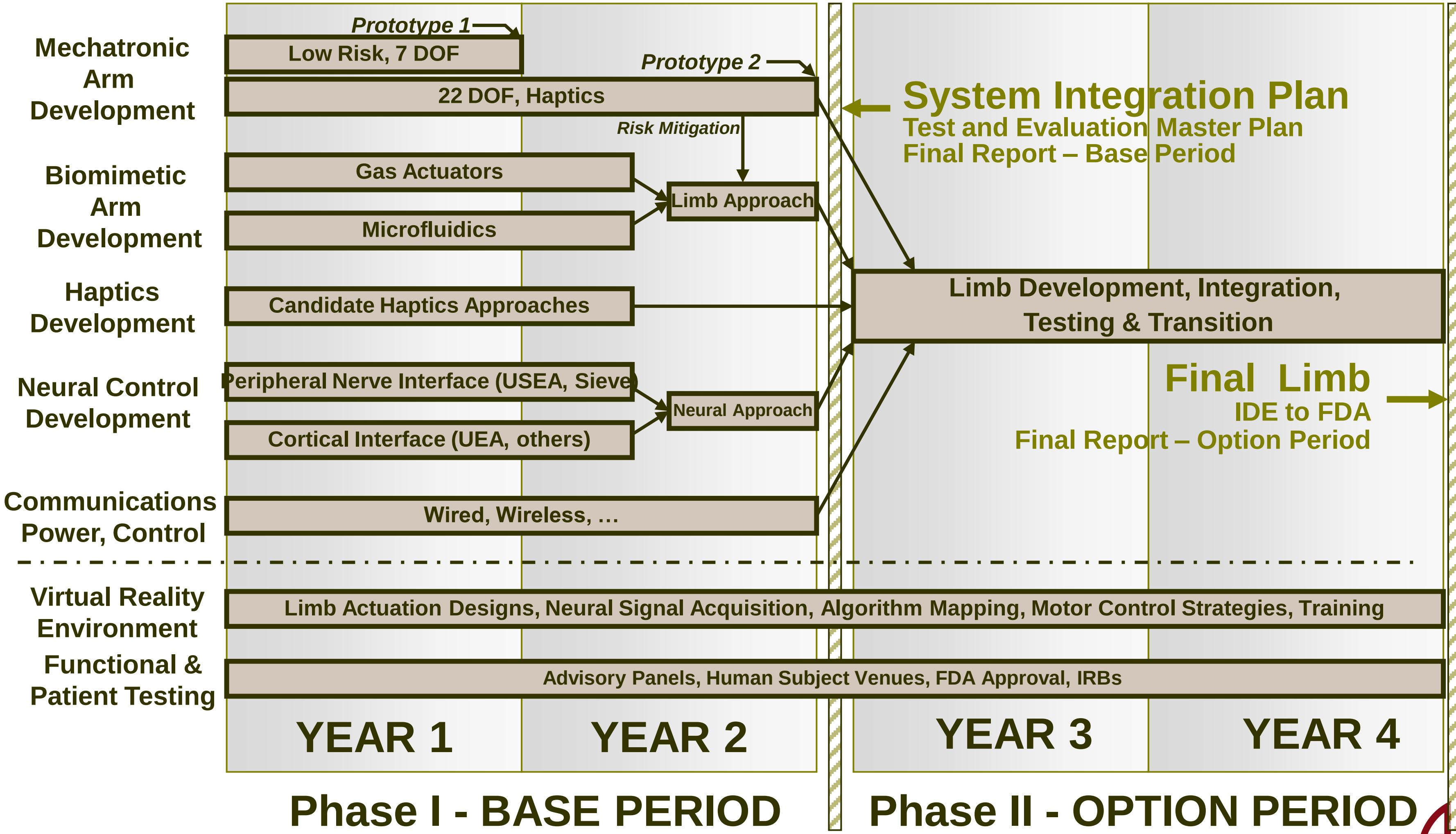
## UNB
- Neural Integration
- Grasp coding

## Utah
- Peripheral Nerve Arrays
- Neural Integration
- Wireless Electronics

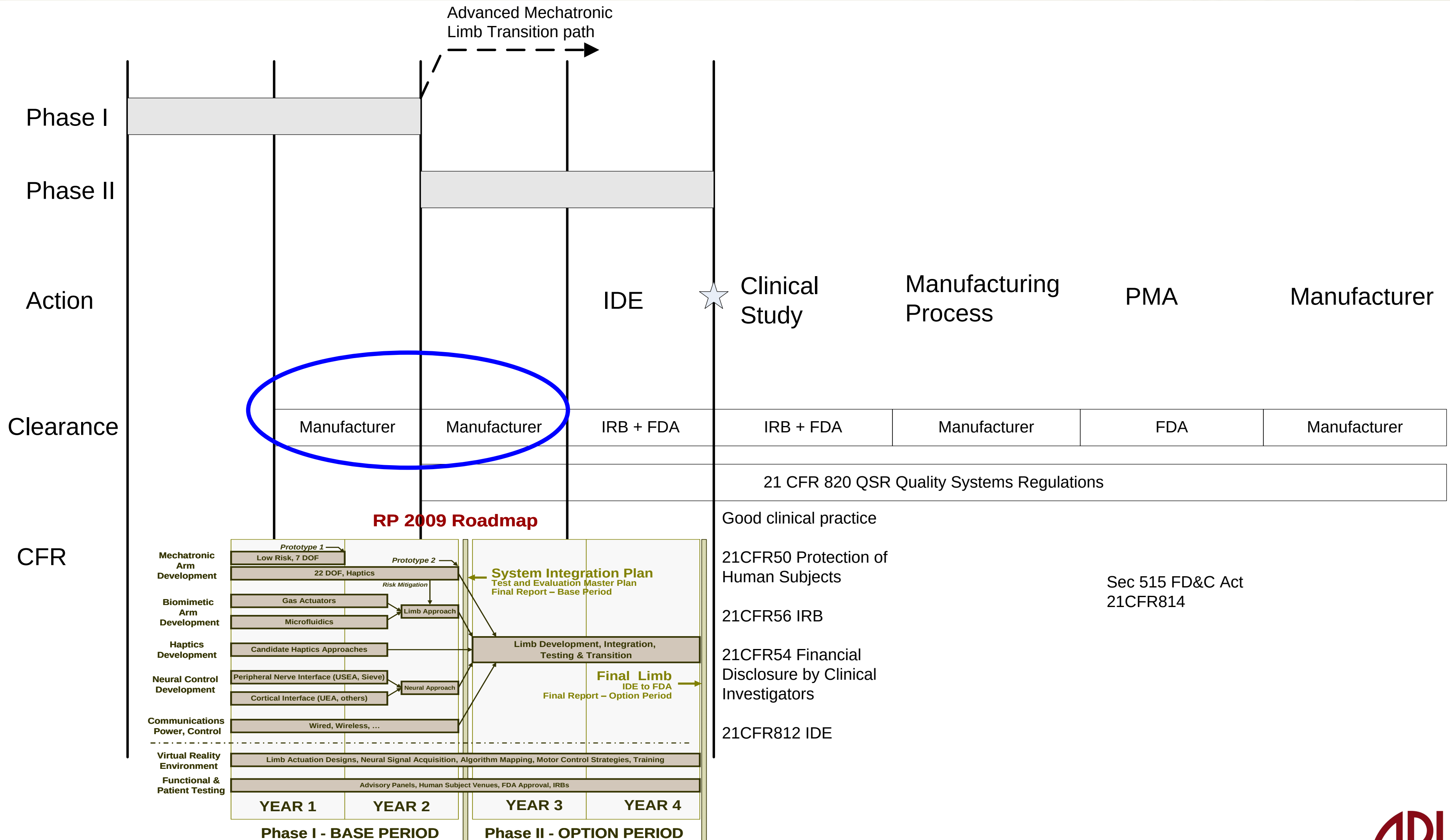
## Sigenics
- IMES Implants
- Integrated Electronics

# Program Plan

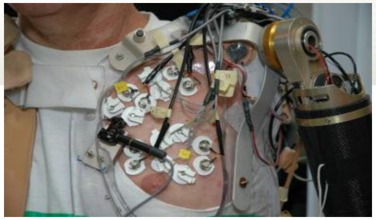
## RP 2009 Roadmap



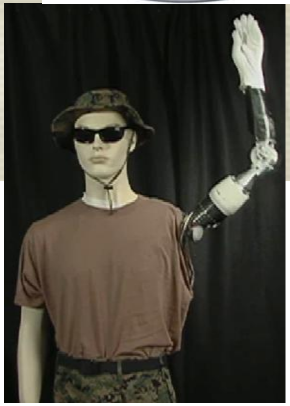
# Transition Plan Clarification: R&D through Production



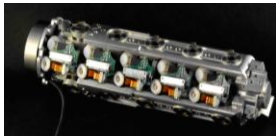
# Revolutionizing Prosthetics
# Phase 1 Highlights

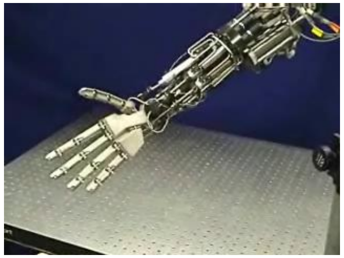


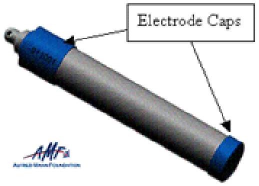
Proto 2 Intrinsic



Proto 2 Extrinsic





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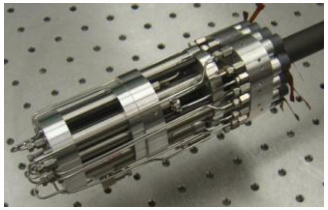
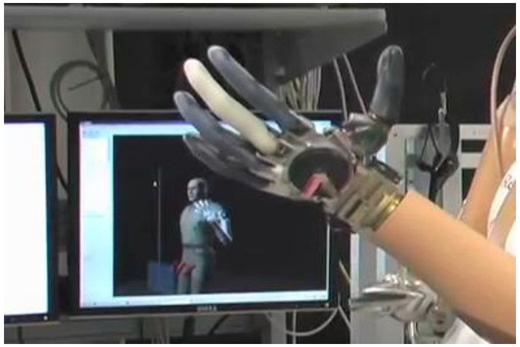
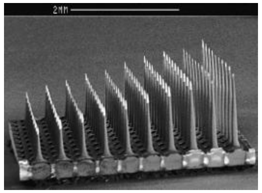
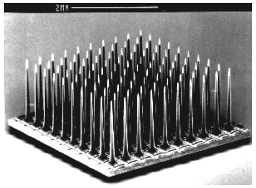
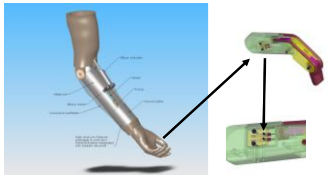






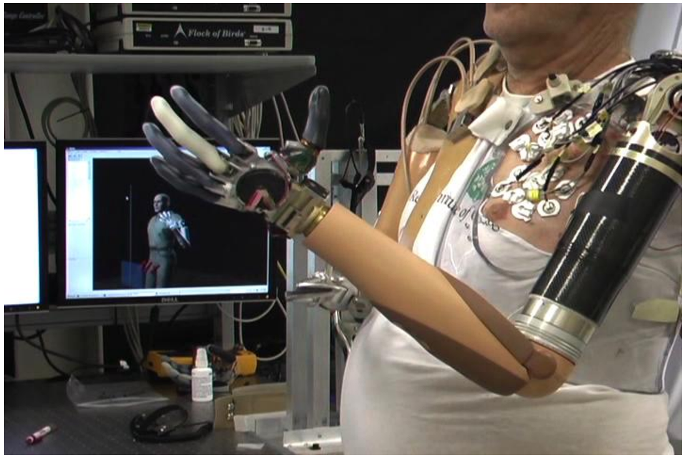




http://www.sci.utah.edu/~gk/abstracts/bisti03/img/slant-array.png

http://www.bioen.utah.edu/cni/projects/blindness_files/image004.gif

# Revolutionizing Prosthetics 2009 - Prototype 1

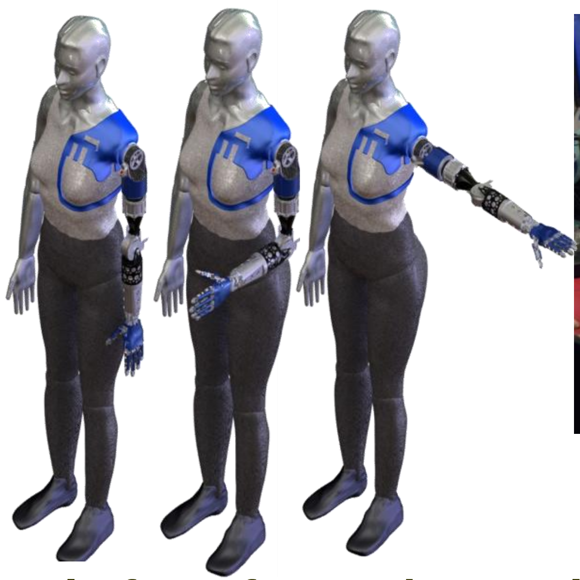

Pictures courtesy of RIC

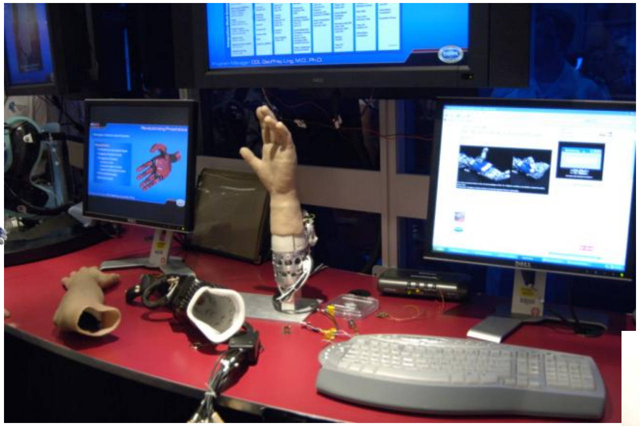
# Prototype 1 at RIC – January 2007

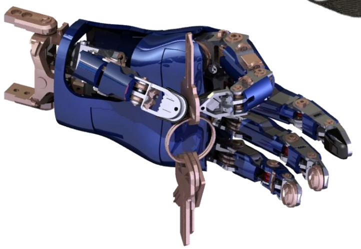

*Images Courtesy of RIC Collaboration*

# Prototype 2 Objectives – Addressing DARPA Requirements Early

- Phase I risk reduction path to final limb
  - Electromechanical actuation
  - All degrees of freedom, speed, torque





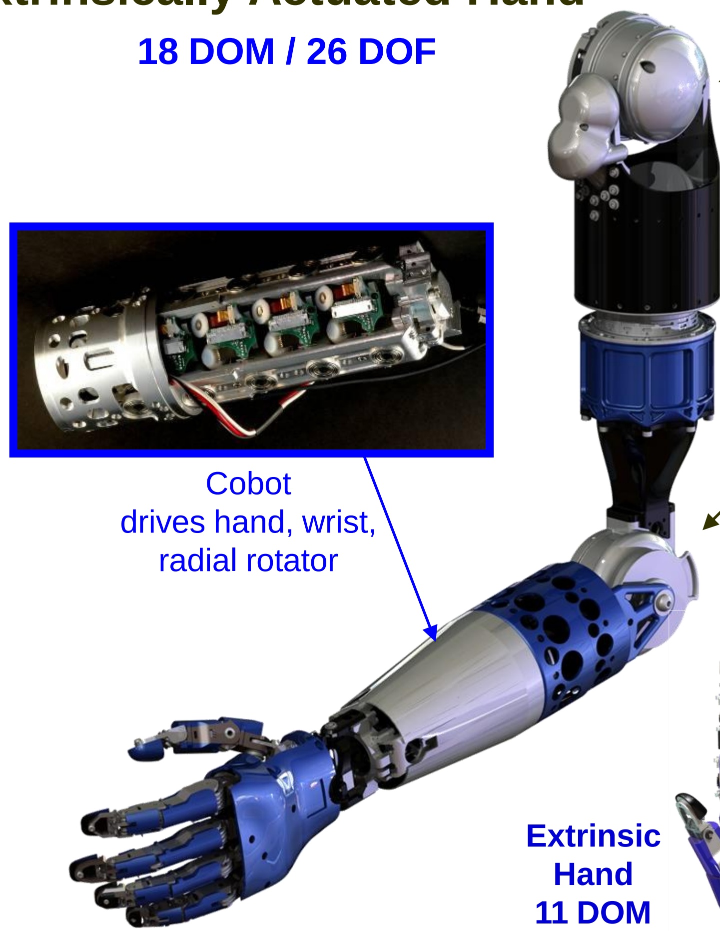


- Platform for testing evolving neural control during Phase II
  - Evaluate emerging Control strategies
  - Explore sensory feedback
  - Understand limb design trade-offs for final limb

# Proto 2 Arm Architectures

## Extrinsically Actuated Hand

**18 DOM / 26 DOF**



Cobot
drives hand, wrist,
radial rotator

Shoulder
2 DOM/F

Humeral
Rotator
1 DOM/F

Elbow
1 DOM/F

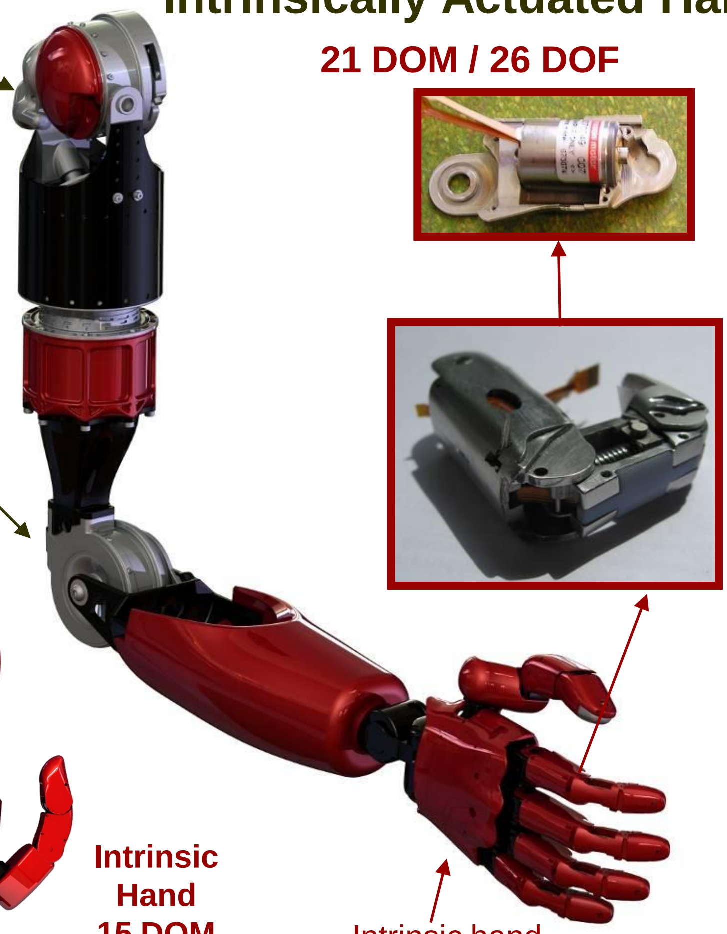
Wrist
3 DOM/F

**Extrinsic Hand**
**11 DOM**
**21 DOF**

**Intrinsic Hand**
**15 DOM**
**19 DOF**

## Intrinsically Actuated Hand

**21 DOM / 26 DOF**



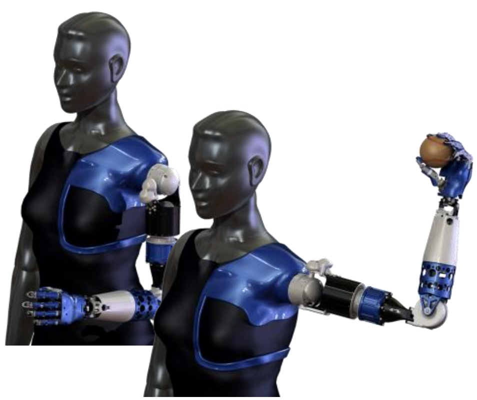
Intrinsic hand
contains motors

# Proto 2 Upper Arm Performance

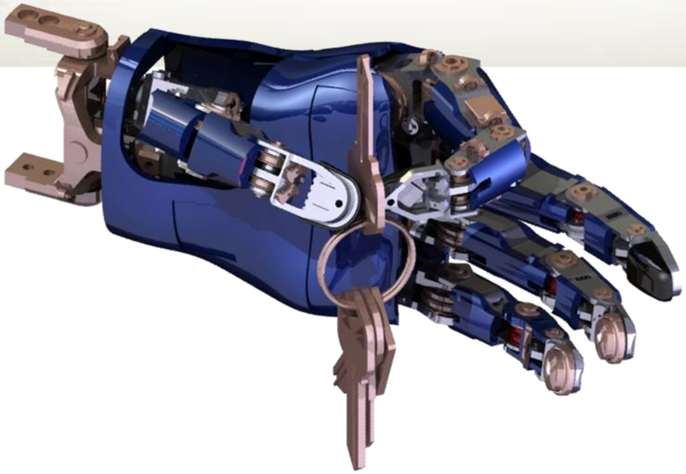
- Shoulder
  - Flex / Extend
  - Abduct / Adduct
  - Humeral Rotation
  - 45 ft-lbf, 120º/sec

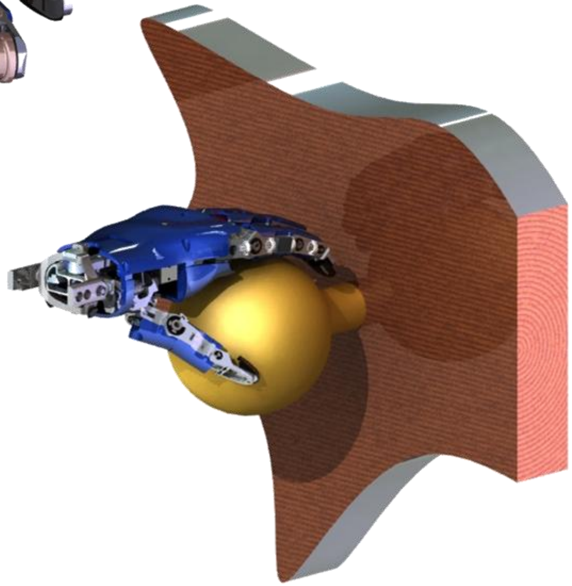
- Elbow
  - Flex / Extend
  - 60 ft-lbf, 120º/sec

- Wrist
  - Flex /Extend
  - Pronate / Supinate
  - Radial / Ulnar Deviation



# Hand Grasps

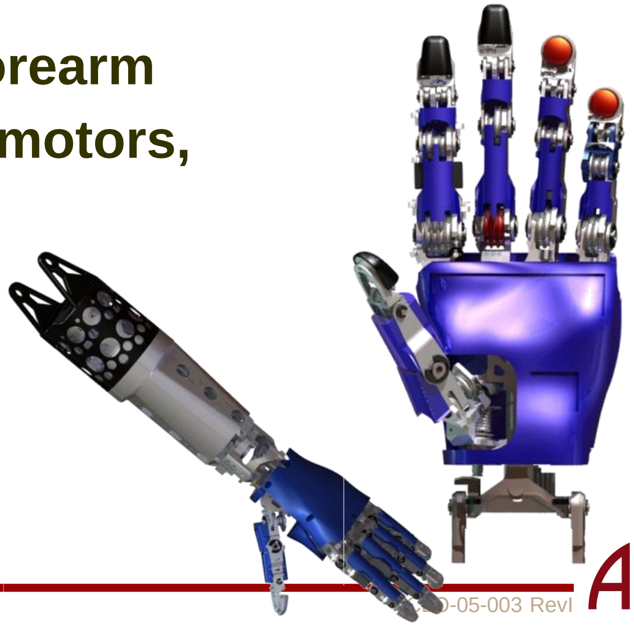




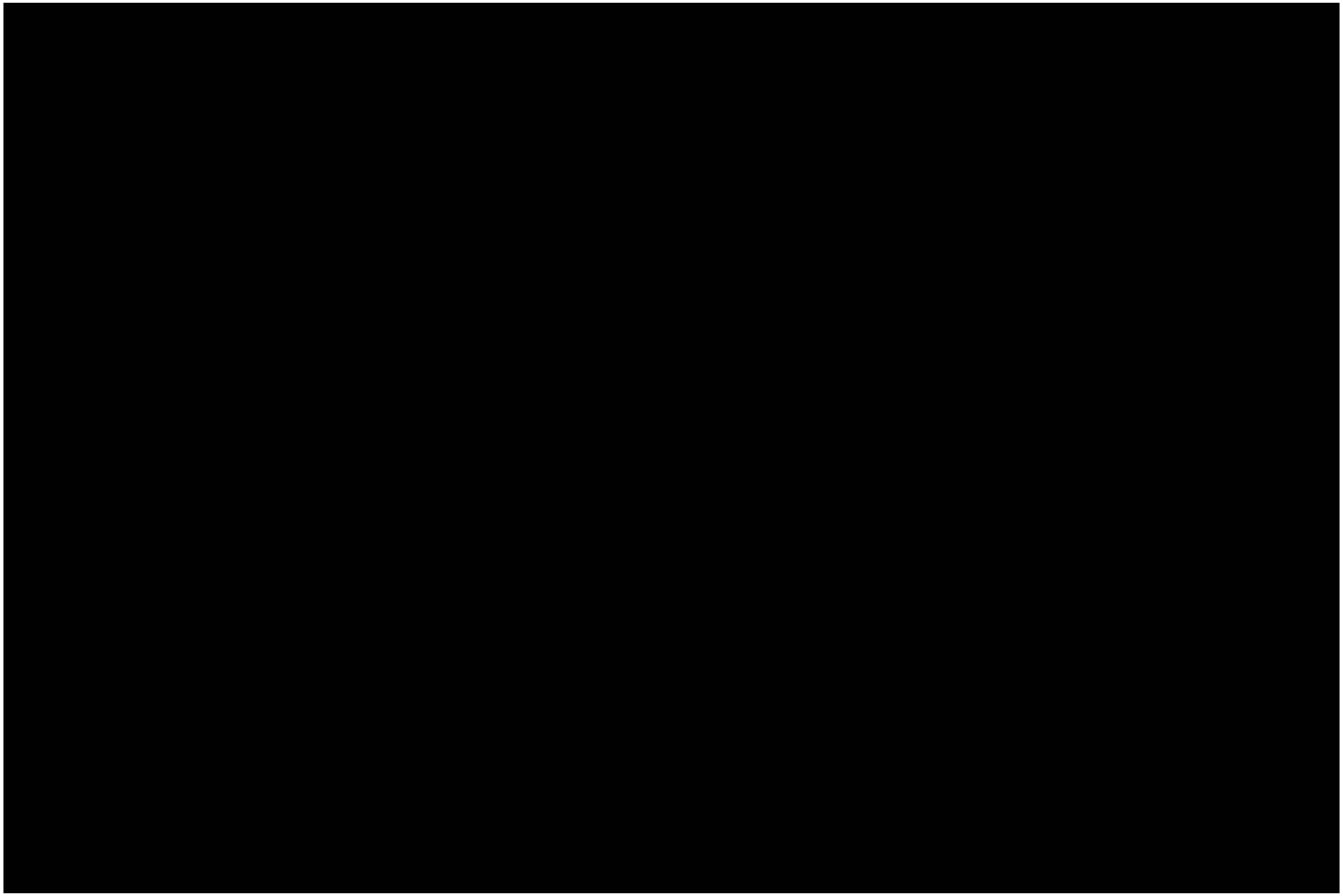
# Proto 2 Hands

- Intrinsic
  - 15 motors in hand
  - 15 actuated degrees of motion
  - 4 underactuated degrees of motion
  - 19 degrees of freedom

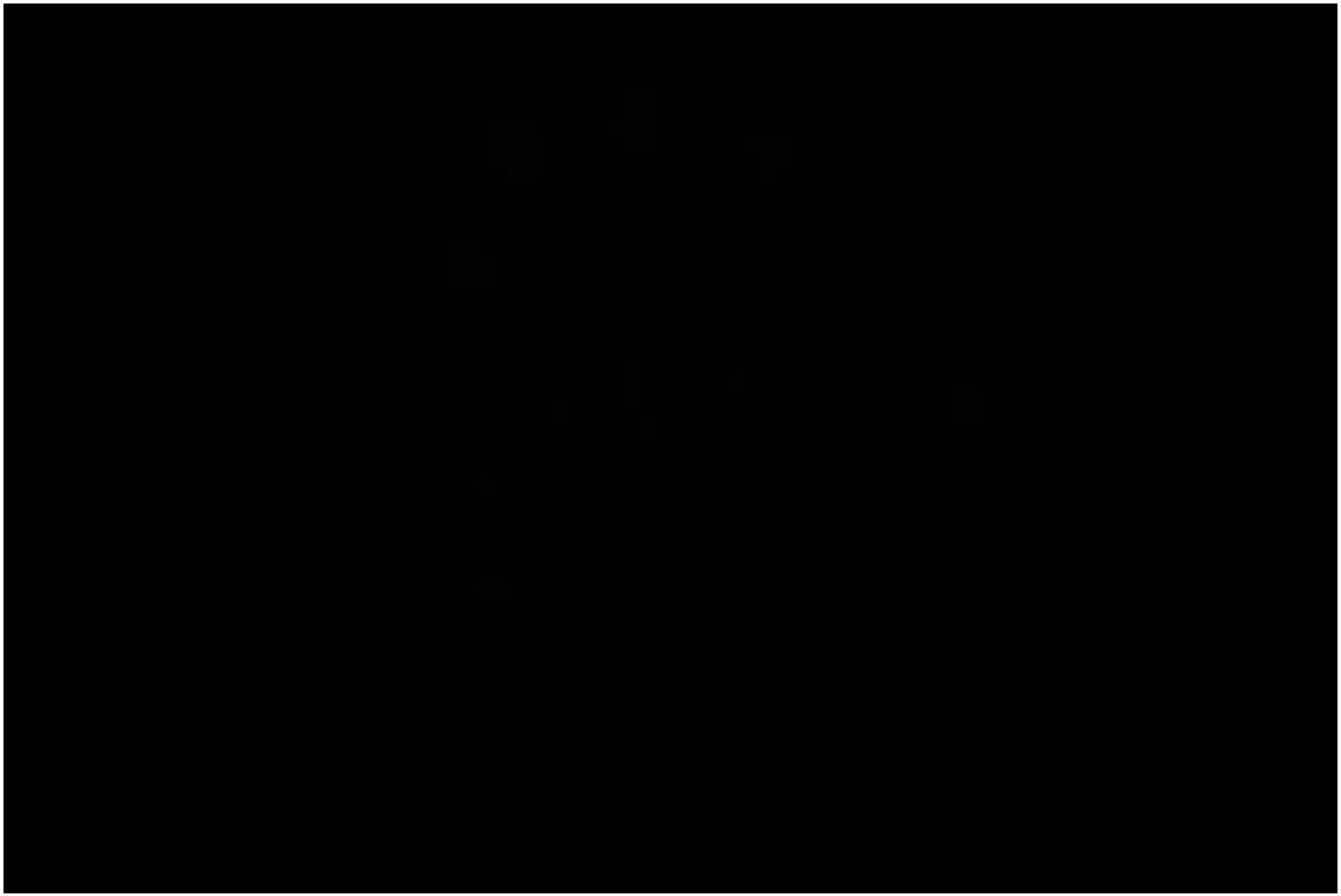
- Extrinsic
  - Motors and transmission (cobot) in forearm
  - Cobot: one power motor, 15 steering motors, 15 outputs
  - 11 actuated motions with 11 tendons
  - 7 underactuated degrees of motion
  - 21 degrees of freedom



# Prototype 2 Extrinsic Hand Dexterity

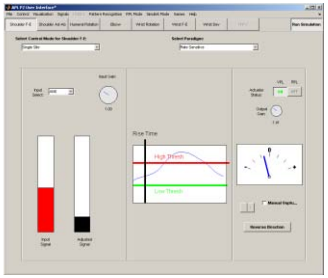


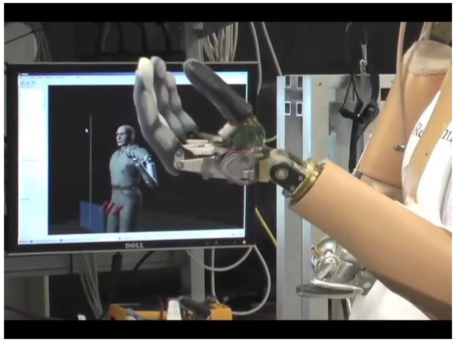
# Prototype 2 Intrinsic Hand Dexterity



# Virtual Integration Environment

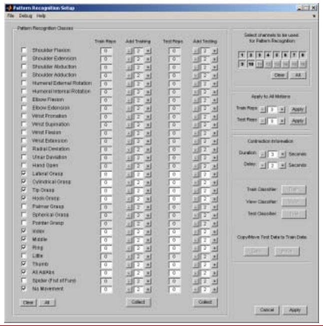

- **Complete limb system simulation environment**
  - **Supports engineering development,**
  - **Neural signal acquisition**
  - **Algorithm development**
  - **Mechanical approach evaluation**
  - **Patient training / therapeutic applications**
  - **System performance validation and design compliance**

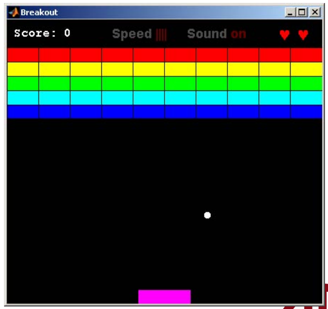




- **End-to-end interactive simulation**
  - **Acquires control signals (myoelectric, mechanical, neural, other)**
  - **Signal Analysis: Interprets the intention**
  - **Controls: Translates intention into movement of a virtual limb**
  - **Allows the user to interact with objects with feedback (haptics or other)**

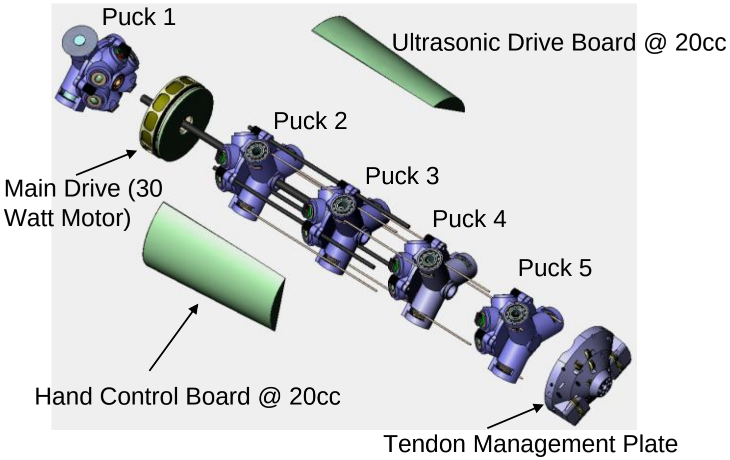

- **Modular and configurable**
  - **Support various limb models and control algorithms**
  - **Engineering test bed for improvement of these designs**
  - **Evaluate patient interfaces for control signal extraction and sensory feedback**



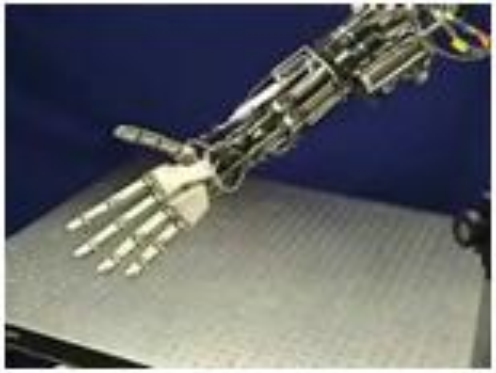


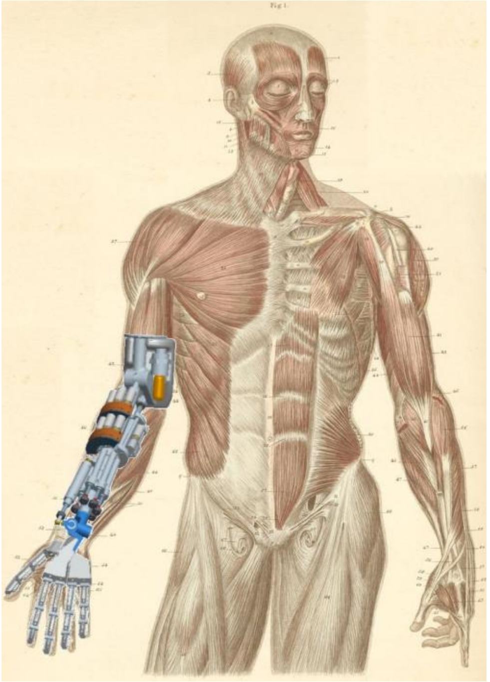
# Advanced Actuation

## Cobotics

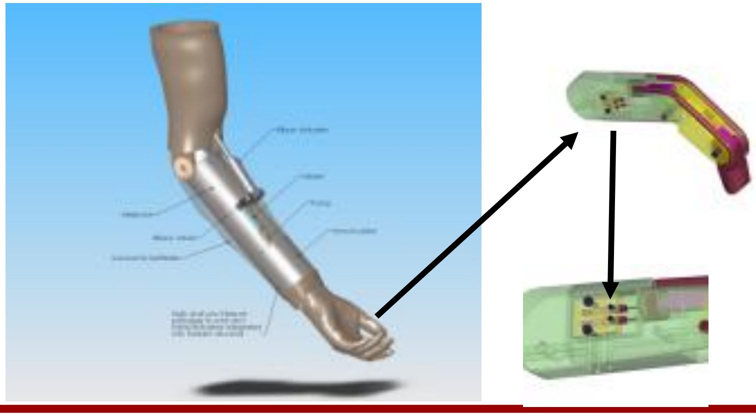



## Monopropellant Pneumatics





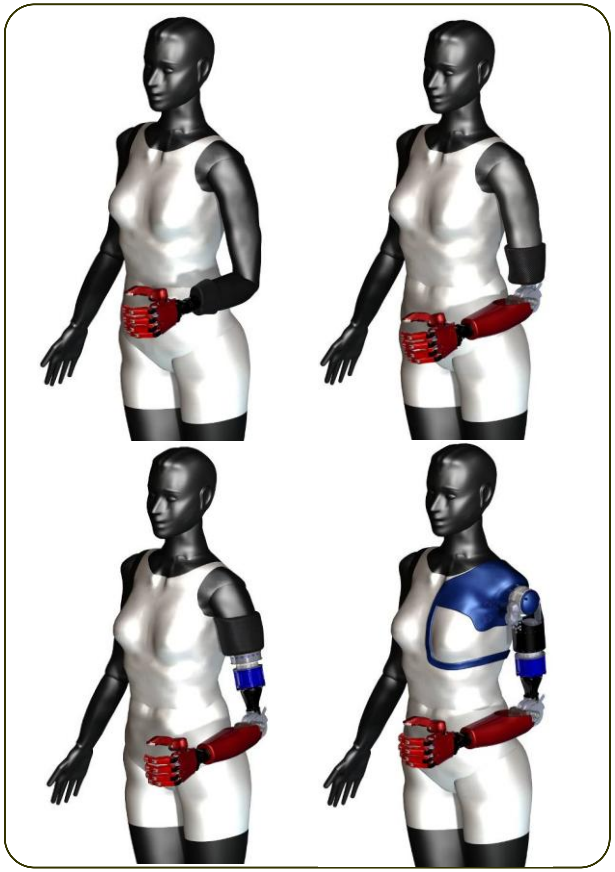
## Mesofluidics



## Broader Power Alternatives

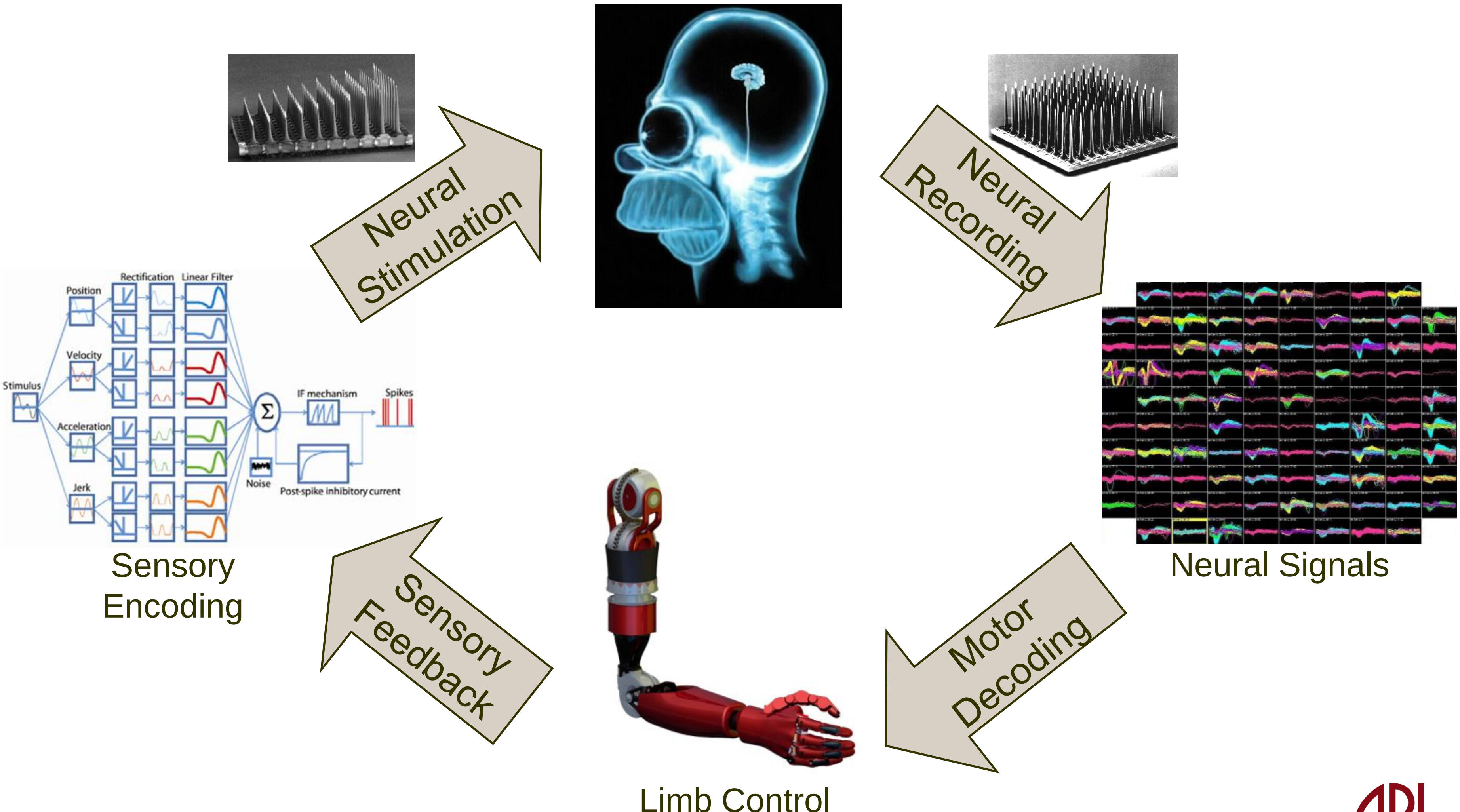
# Modular Prosthetic Limb Toolkit

## Modular Prosthetic Limb (MPL) modules can be assembled in any combination for use with different amputation levels



- Up to 21 motors
- Intrinsically actuated hand
- Lithium batteries
- Less than 8 lb
- Approaches human strength
- 120 deg/s arm motion
- 360 deg/s hand motion

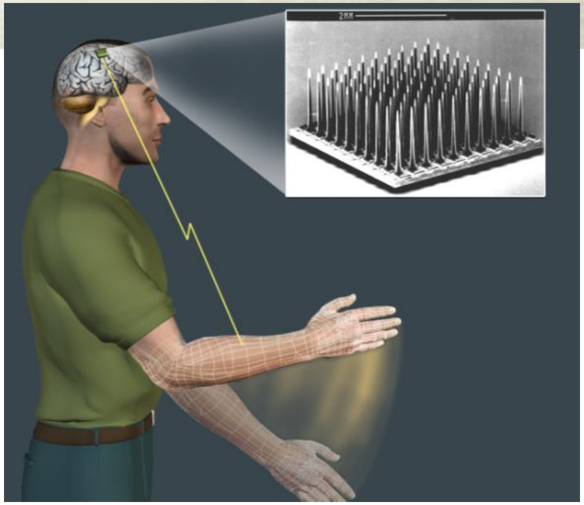
# Neural Interface System Block Diagram

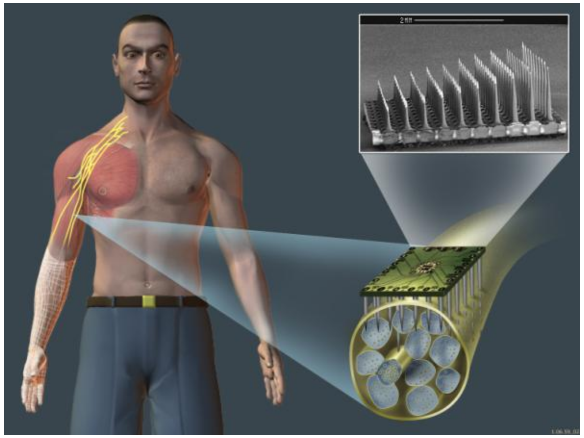


# Neural Integration

## Research Components

| | |
|---|---|
| Cal Tech | High Level Cortical, Reach Decoding and Prediction |
| U of Utah | Peripheral Nerve, Efferent and Afferent |
| ASU | Cortical, Reach and Hand Positioning |
| USC | Simulation Environment and Biomimetic Control |
| URMC | Cortical, Dexterous Digit Manipulation |
| NUPRL/ Sigenics | Wireless Injectable EMG Recording Methods |
| Zyvex* | Wireless, Direct Peripheral Nerve Interface Methods |
| RIRC*/UBN | Targeted Motor Reinnervation and Signal Analysis |
| JHU | Signal Classification, Synthesis, Simulation, and Hybrid Integration |





# Neural Interface Toolkit

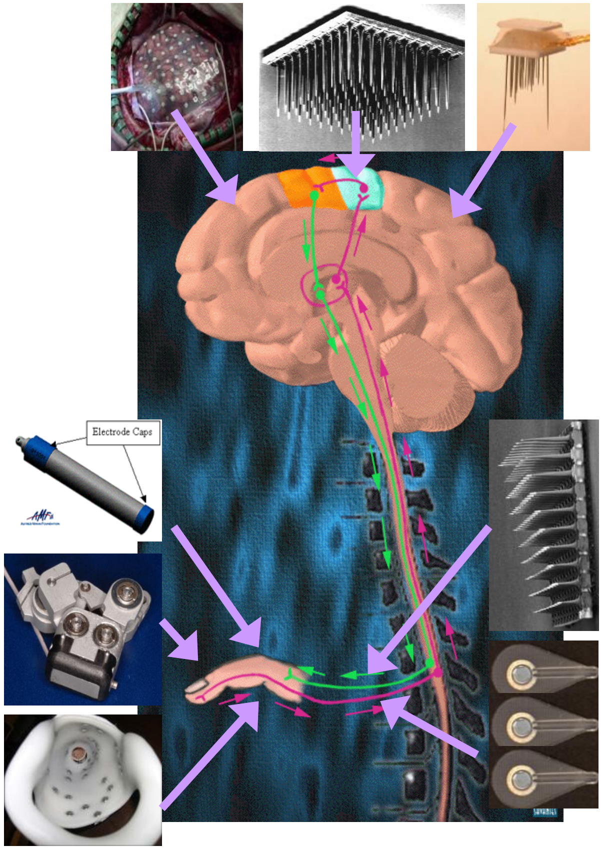
**Conventional Prosthetic Control & Non-invasive devices**
- Surface EMG (sEMG)
- Tactile sensory stimulator (Tactor)

**Minimally-invasive devices**
- Implantable MyoElectric Sensor (IMES)

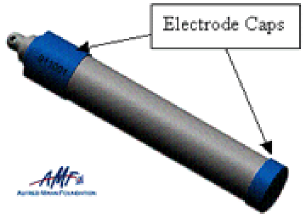
**Implantable Peripheral devices**
- Utah Slanted Electrode Array for Recording (USEA-R)
- Utah Slanted Electrode Array for Stimulating Feedback (USEA-S)
- Next Generation Peripheral Interface Arrays using Biodegradable Structures

**Implantable Cortical devices**
- Epidural electrocorticography grid (ECoG)
- Floating Microelectrode Array (FMA)
- Utah Electrode Array (UEA)

**Multimodal System Components (Multi-BID/Multi-PID)**
- Multi-Mode Control Unit (MCU)
- Headcap
- Armband



# Hybrid Neural Integration Example

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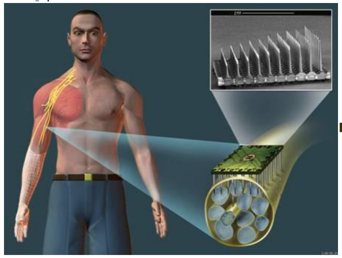
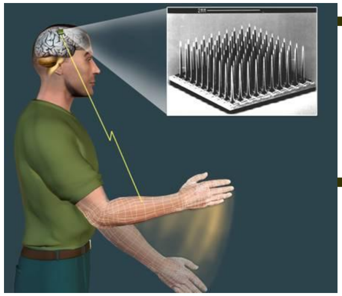
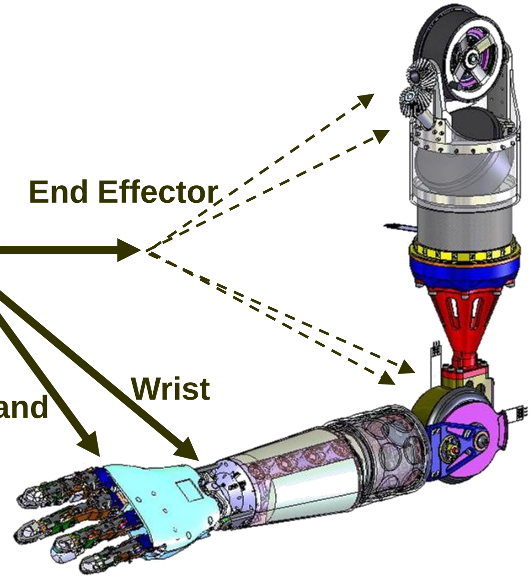




**Full control**
**Hand, Wrist, End Effector**

- Simultaneous Joint Actuation
- Wrist Orientation
- End Effector Velocity
- Simultaneous Finger Movements

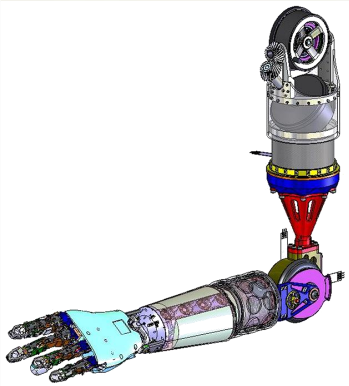
→ **Command Conflict Resolver** → End Effector / Wrist / Hand



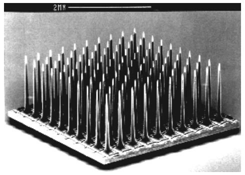
# Neural Integration Strategy with Sensory Feedback

## Perception and User Modified Intent

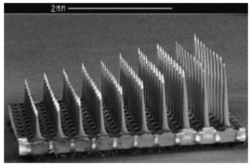
## Sensory Feedback



Sensors



http Direct Somatosensory Stimulation

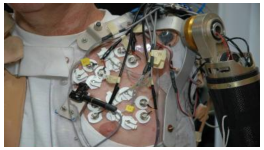



Sensors

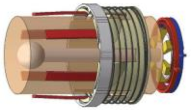
**Proprioception**
(position)

**Tactile**
(contact, pressure, temp)

Peripheral Afferent &
Muscle/Tendon Stimulation



Multi-mode Haptic Displays



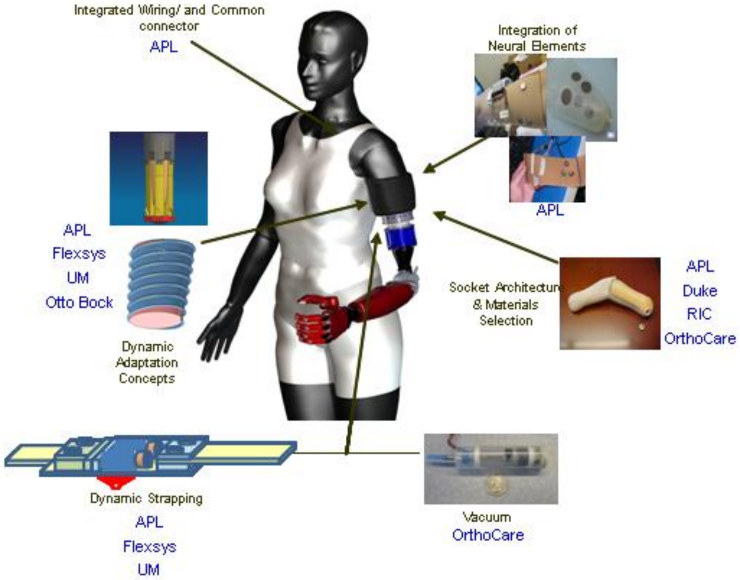
Dynamic Socket Accommodation

## Embedded Intelligent Control Algorithms

# Comfort & Appearance

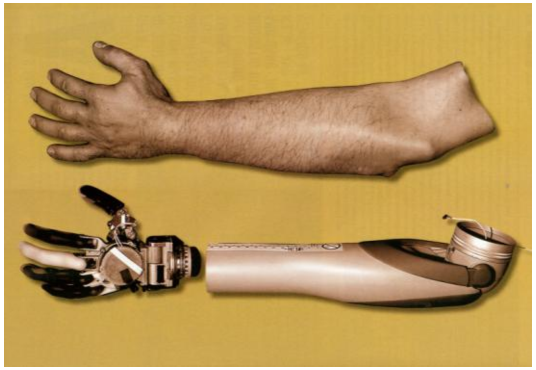
## Body Attachment

- Investigating multiple volume accommodating and dynamic shape changing socket methods
    1. Pneumatic or air filled bladders
    2. Hydraulic or fluid filled bladders
    3. Vacuum attachment methods
    4. Electro-active Polymers
    5. Shape changing material structures



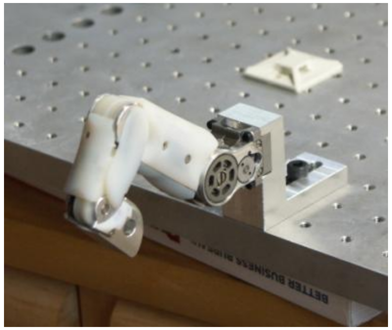

## Cosmesis

- Exploring alternative materials and designs for reducing stress on joints
- Establishing metamerism insensitive color formula
- Testing for sensor performance (force, vibration, slip, thermal)
- Testing alternative mold designs to improve fabrication

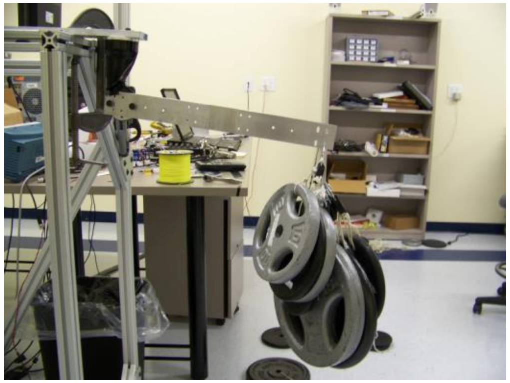


# Phase II System Build & Integration

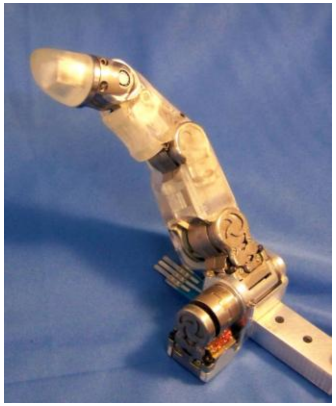
One Motor Finger Subassemblies



One Motor Finger



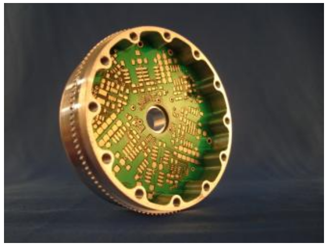
Elbow / Humeral Rotator Load Testing (150 lbs)



Thumb

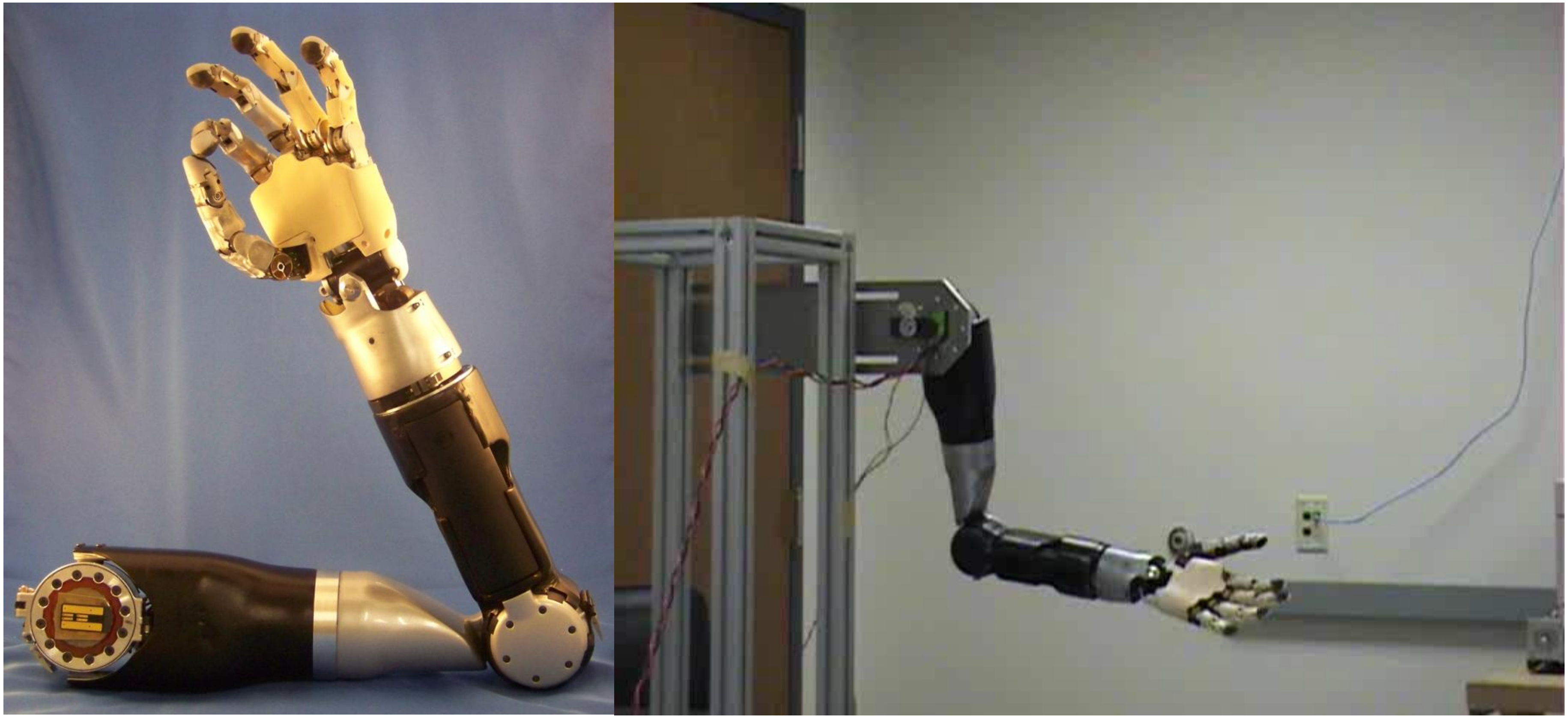
Thumb with Cosmesis

MPL Common Connector



Large Motor Controller

# Phase II Modular Limb System

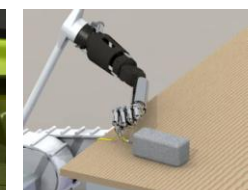


# Technology Transition

***The Upper Extremity Prosthetics market  alone may not not have the base to sustain the advanced limb system…***

- **"Opportunities to scale" – leverage subcomponents of limb/neural systems into additional applications**
  - **Extend to lower extremity & related rehabilitation applications**
  - **Military ➔IED defeat, battlefield trauma care/extraction robotics**
  - **Homeland Defense ➔ chem/bio response, rad mitigation**
  - **Medical ➔ peripheral nerve repair, spinal injury mitigation rehabilitation, remote tele-care**
  - **Space ➔ microgravity mitigation, robotic exploration**
  - **Commercial ➔ assistive robotics, home care, etc.**
  - **Other…**

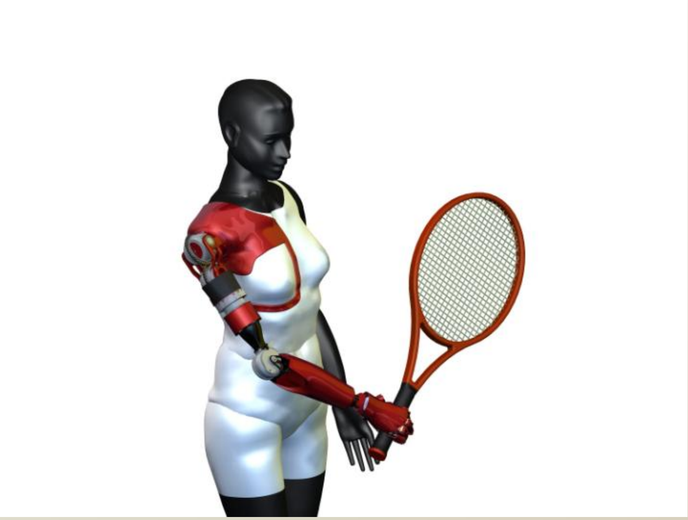







# IED Robotics

# Thank You!



# Questions?

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