Reliable Neural-Interface Technology

Jack W. Judy, Ph.D.

DARPA MTO

DoD Amputee Challenge

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- Limb loss: big DoD problem
- OIF/OEF limb loss:
  - ~80% lower limb(s)
  - ~20% upper limb(s)
  - ~25% multiple limbs

Soldiers with Limb Loss		
Civil War	~50,000	12.0%
WW1	2610	1.7%
WW2	7489	1.2%
Korea	1477	1.4%
Vietnam	5283	3.4%
OIF/OEF	~1000	2.3%

- Goal of the patient population
  - regain function needed to return to duty
  - maintain quality of life (rotation / post service)
- Requirements of prosthetic technology
  - high performance, robustness, and reliability

Cpl. Garrett S. Jones

- **Lost leg in Iraq due to an IED (7/23/2007) while with the 2nd Battalion, 7th Marine Regiment, 1st Marine Division**
- **Redeployed with his unit to Afghanistan in early 2008**

Sgt. James Wright

- **Lost both hands and suffered a severe wound to his leg when his vehicle was struck by a RPG in Iraq's Al Anbar Province (4/7/2004)**
- **Received the Bronze Star with Combat V**
- **Refused to use the best commercially available prosthetic arms:**

  "I remember when I first came back for rehabilitation, they were touting the myoelectric (battery-powered) hands as the greatest innovation. I was so disappointed."
- **Began serving as a Martial Arts instructor later in 2004**

Amputee Medical Care:
Walter Reed Army Medical Center

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- **Largest Amputee Patient Population (~130)**
- **Sports-Medicine Model**
  - immediate adaptation, training, acceptance
- **Extensive Facilities**
  - physical/occupational therapy:
    - track with overhead support, handrails with ramp
    - motion capture, climbing wall, etc.
  - simulators:
    - shooting, driving, skiing/snowboarding, etc.
  - prosthetics (best available):
    - proving grounds, beta testing, stress testing

WRAMC: Focus on the Goal

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- **Return to Active Duty**
  - **Physical:**
    - running, climbing, throwing
  - **Mission:**
    - carrying, shooting, driving, …
  - **Timeline:**
    - ~1 year (best ~4 months)

- **Civilian Life (VA)**
  - **Personal:**
    - eating, hygiene, dressing, social, …
  - **Physical and Professional:**
    - strength, dexterity, sensitivity, sports, hobbies, …

Go/No-Go: Breaking Down and Reassembling a Weapon

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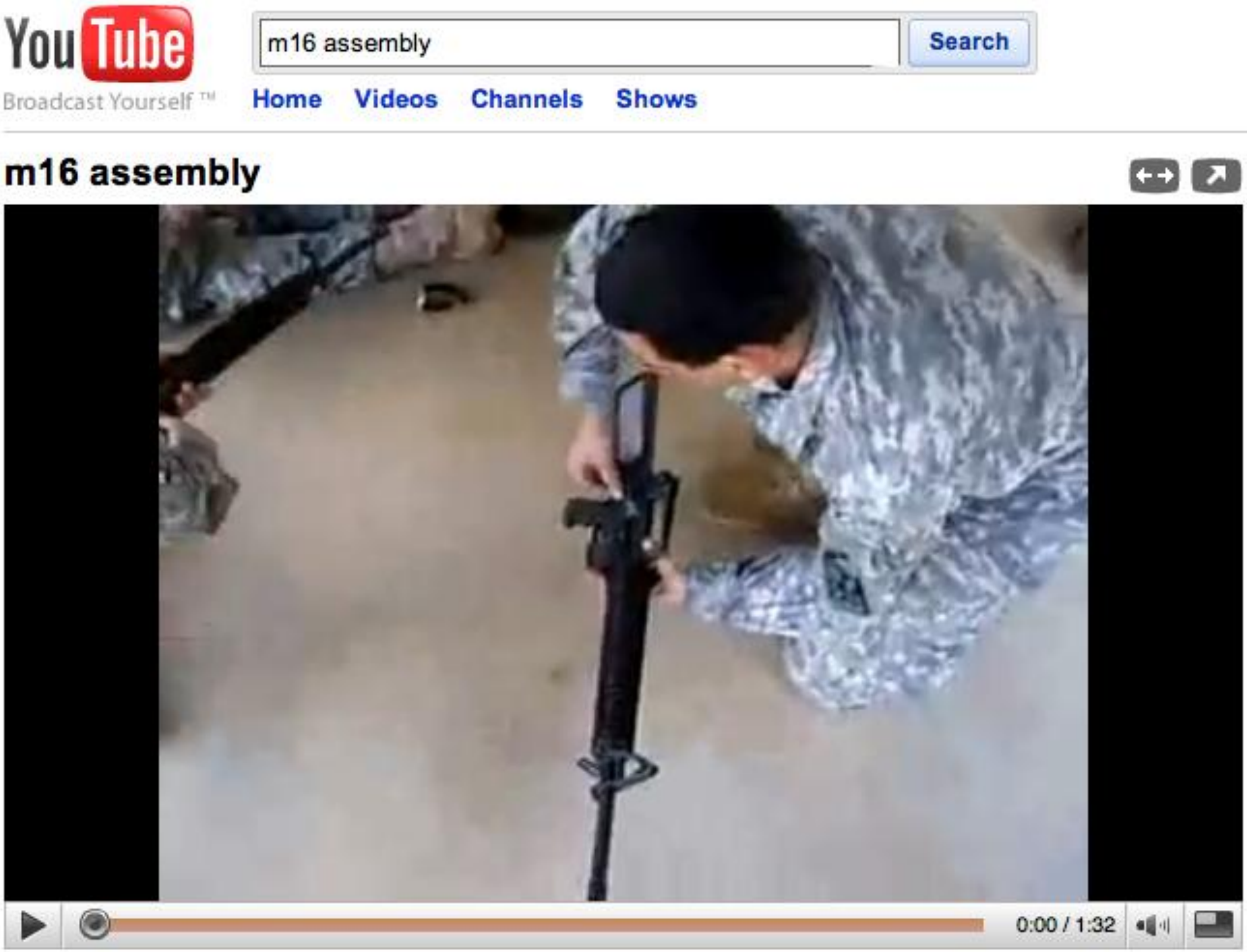

Cpl. Jones

Sgt. Wright

Brain-Machine Interfaces

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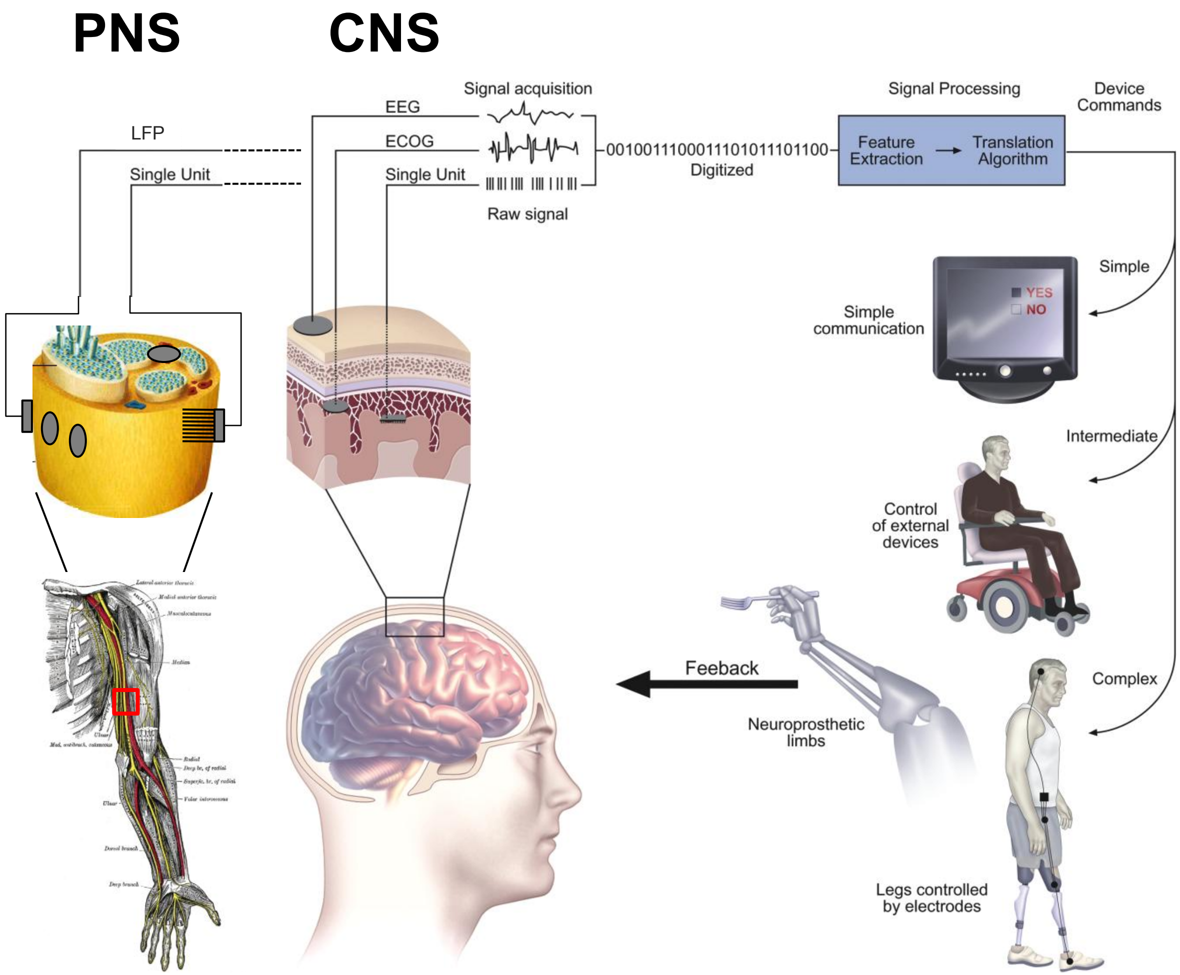

- **Current Strategy**
  - record signals of many channels
  - use adaptive algorithms to decode brain activity
  - map activity to control signals for prosthetic machine
  - rely on visual feedback

Grand Challenge: *Reliable* Neural-Electronic Interface

- **The Unfortunate Truth of BMI:**
  - There does not exist a long-term (years) reliable neural-electronic interface or BMI
    - Even a one-bit switch has yet to be controlled reliably
    - Applications that call for high-precision/speed control of many-degree-of-freedom systems are presently out of reach
- **Reliability Challenge 1:**
  - Physical neural-electronic interface
    - Signal-to-noise ratio of single-unit potentials typically decays to zero in < 1 to 2 years (often much sooner)
- **Reliability Challenge 2:**
  - Fast and correct operation (>>99%) required
    - Friend, Friend, Friend, Foe, Friend, Foe, ~~Friend~~ (oops), Friend, …
    - Patient acceptance of prostheses

DARPA's Investment

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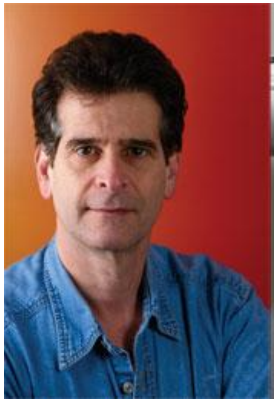
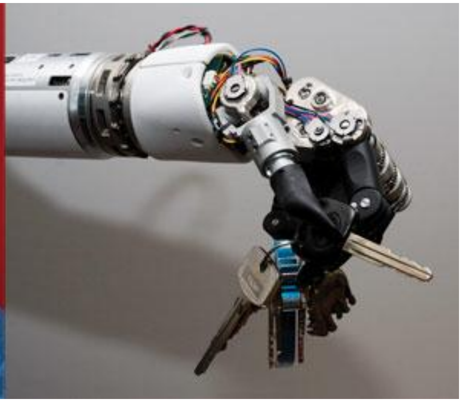
- **COL Geoffrey Ling, M.D., Ph.D.**
  - **Helping the Wounded Warrior**
    - **Human Assisted Neural Devices**
    - **Revolutionizing Prosthetics**





State of Investment and Research in Neuroscience

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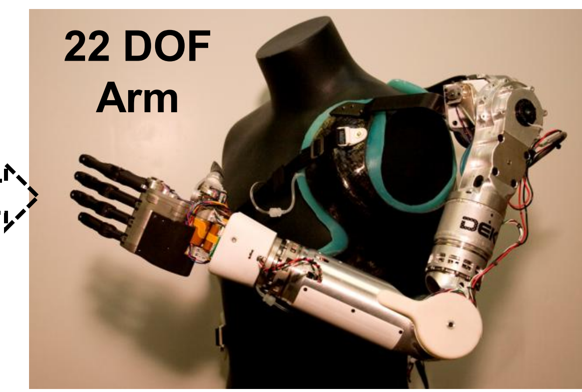
Over the last 15 years, DARPA has heavily invested in technologies to develop prosthetics for wounded warriors. Less than 2% of this investment has gone to the neural interface.

Cognition	Neural Pathways & Neuro-Chemistry		Communication & Algorithms	Mechanical Prosthetics

Investments by NIH and NSF in basic neural-interface science…

Neural Interfaces

… have not led to clinically viable engineered systems.



Advances in prosthesis technology have far exceeded all neural interface technologies.

Observing Neural Activity

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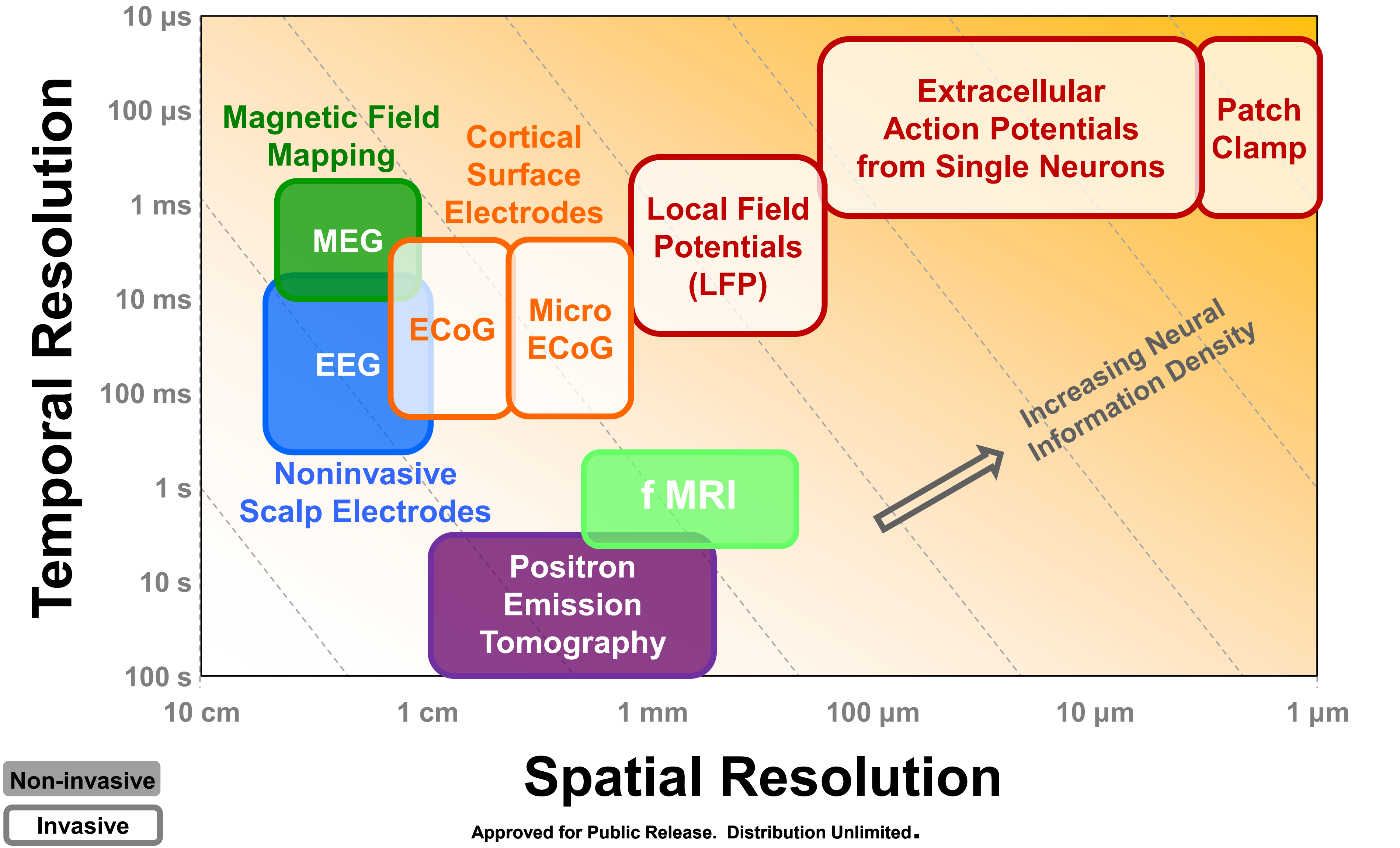

Mobile High-Performance Neural Monitoring

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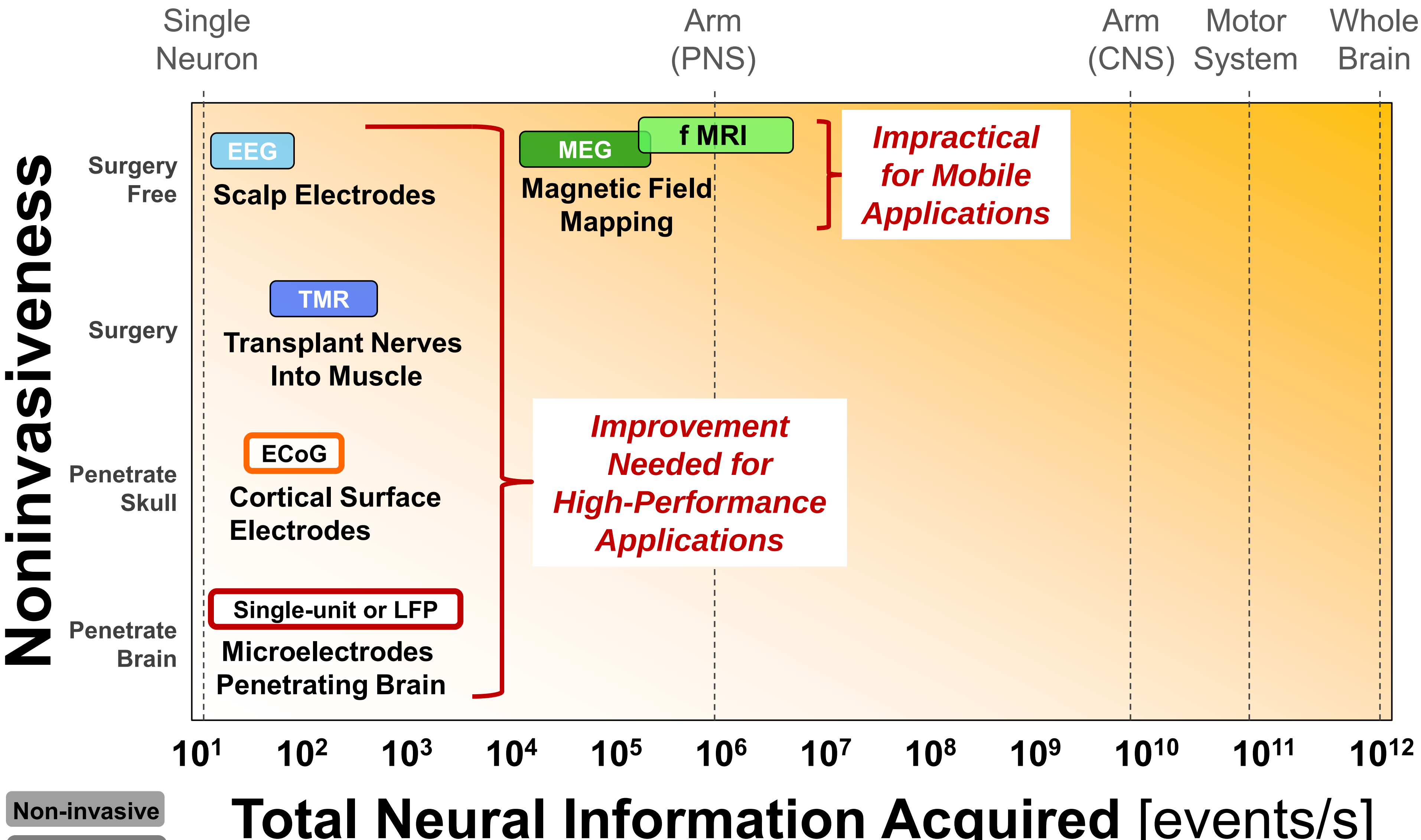

Reliability of SOA Cortical Probe Arrays

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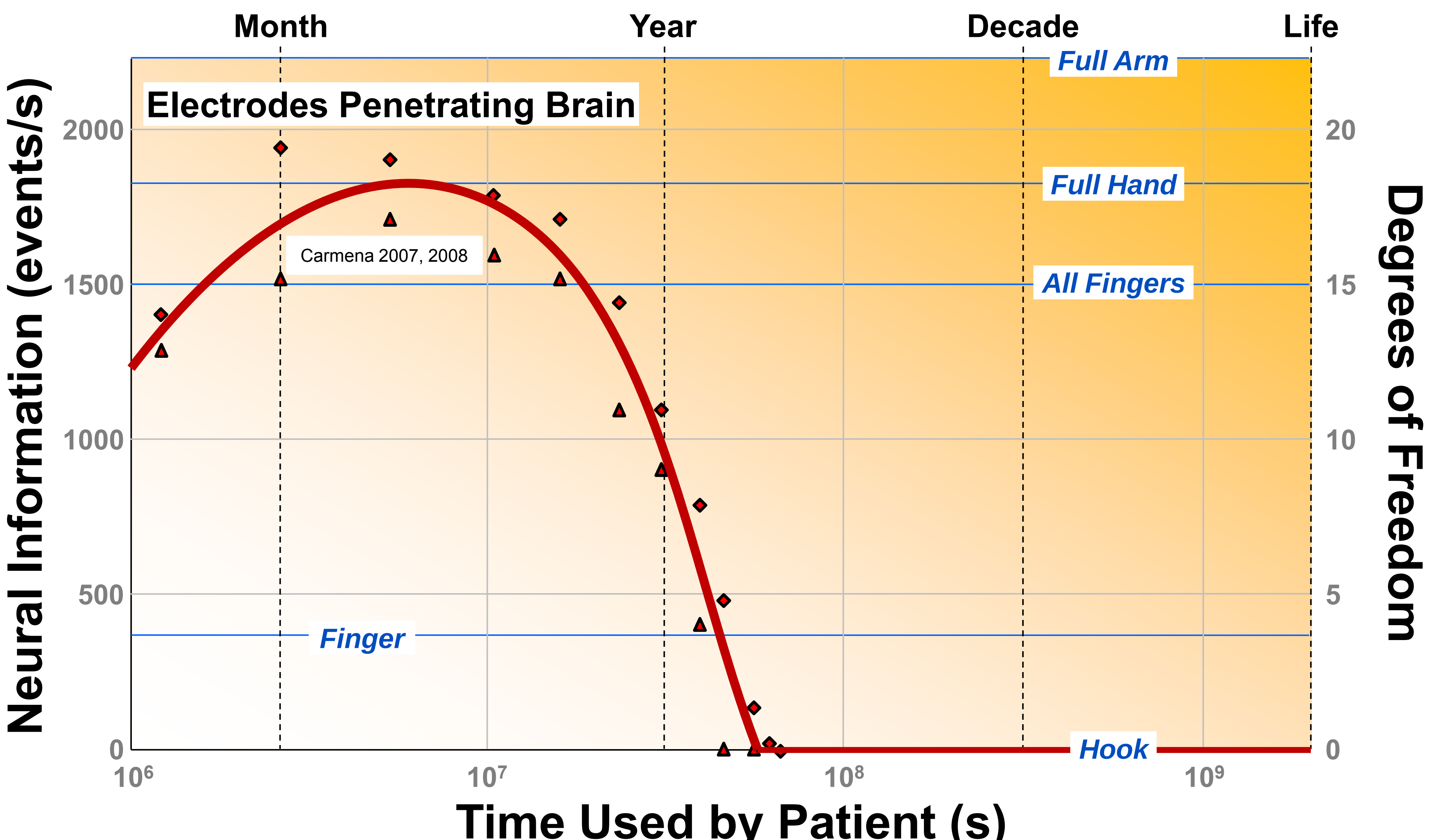

Tissue Response

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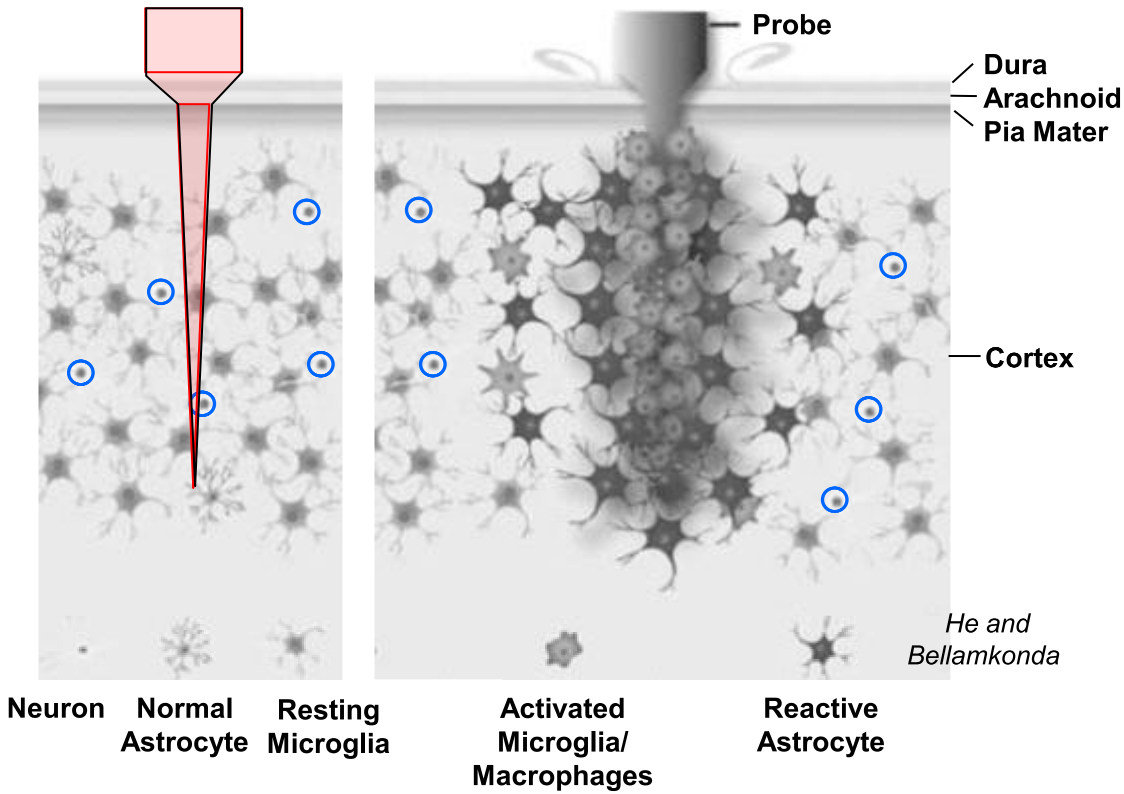

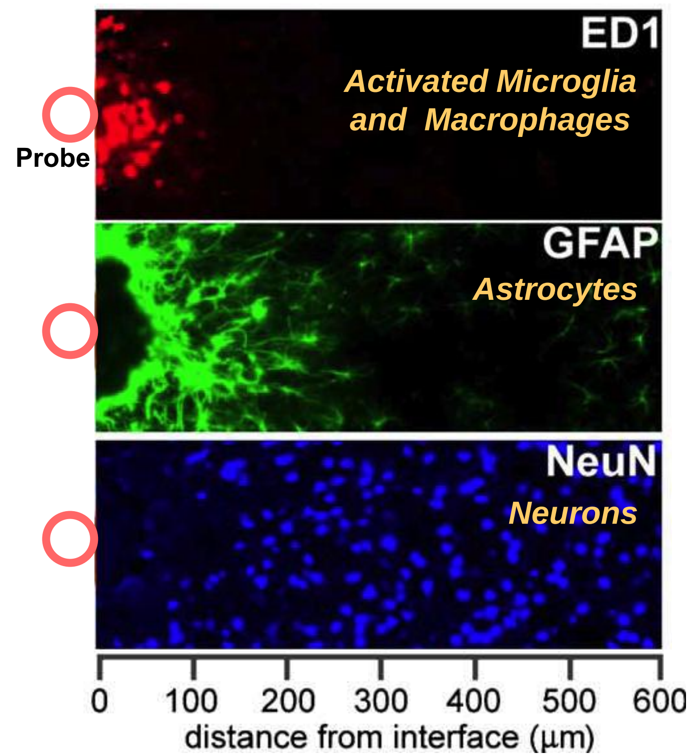

- **Penetrating Microprobe Arrays: Foreign-Body Response**
  - protein absorption, inflammatory reaction
  - increased impedance, decreased neuronal density: SNR ↓
- **Mechanical Stiffness Mismatch**

CNS Tissue Response: *Mechanical Challenges*

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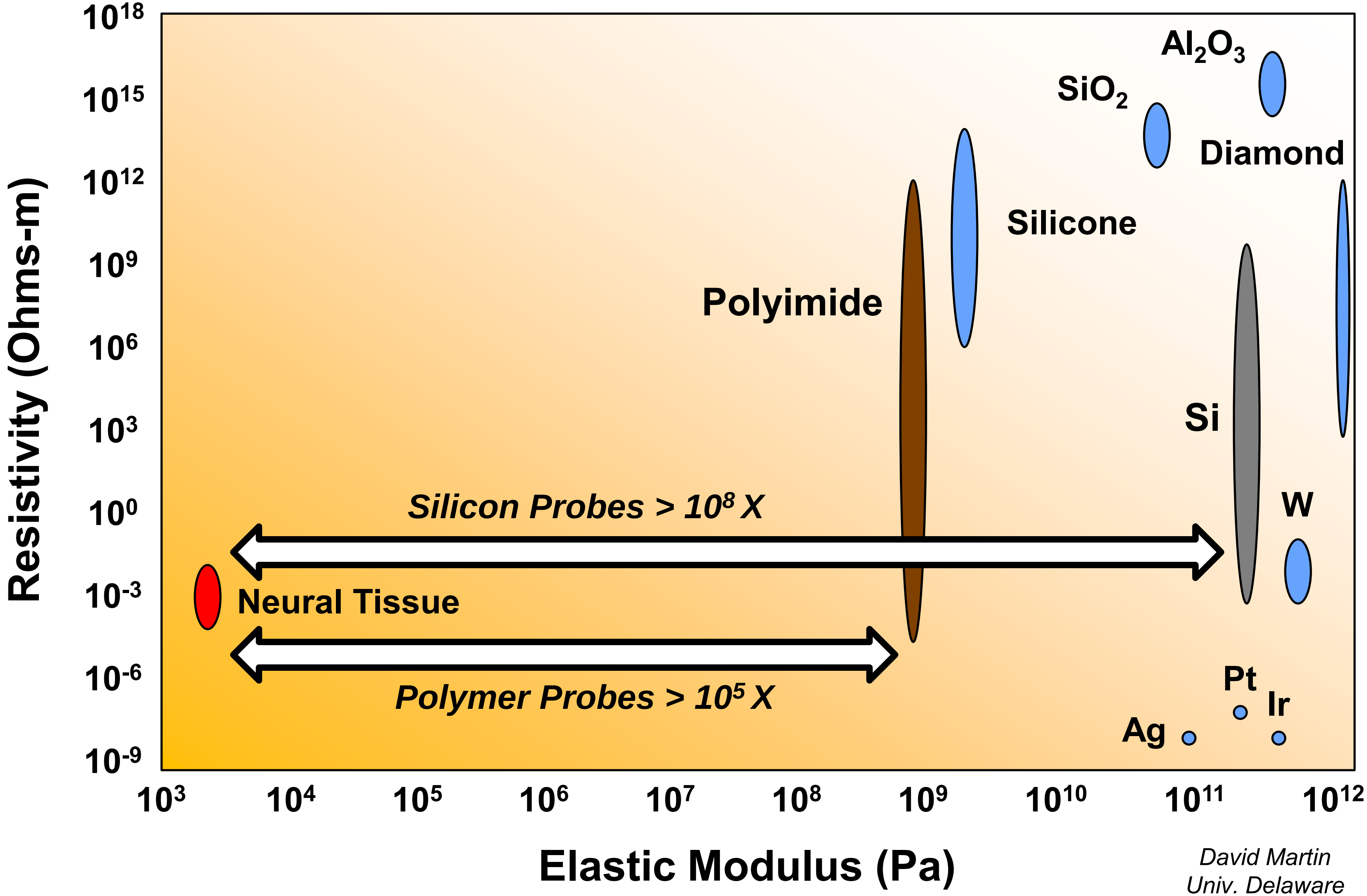

David Martin
Univ. Delaware

Approaches for Challenge 1:
Unreliable Physical Interface

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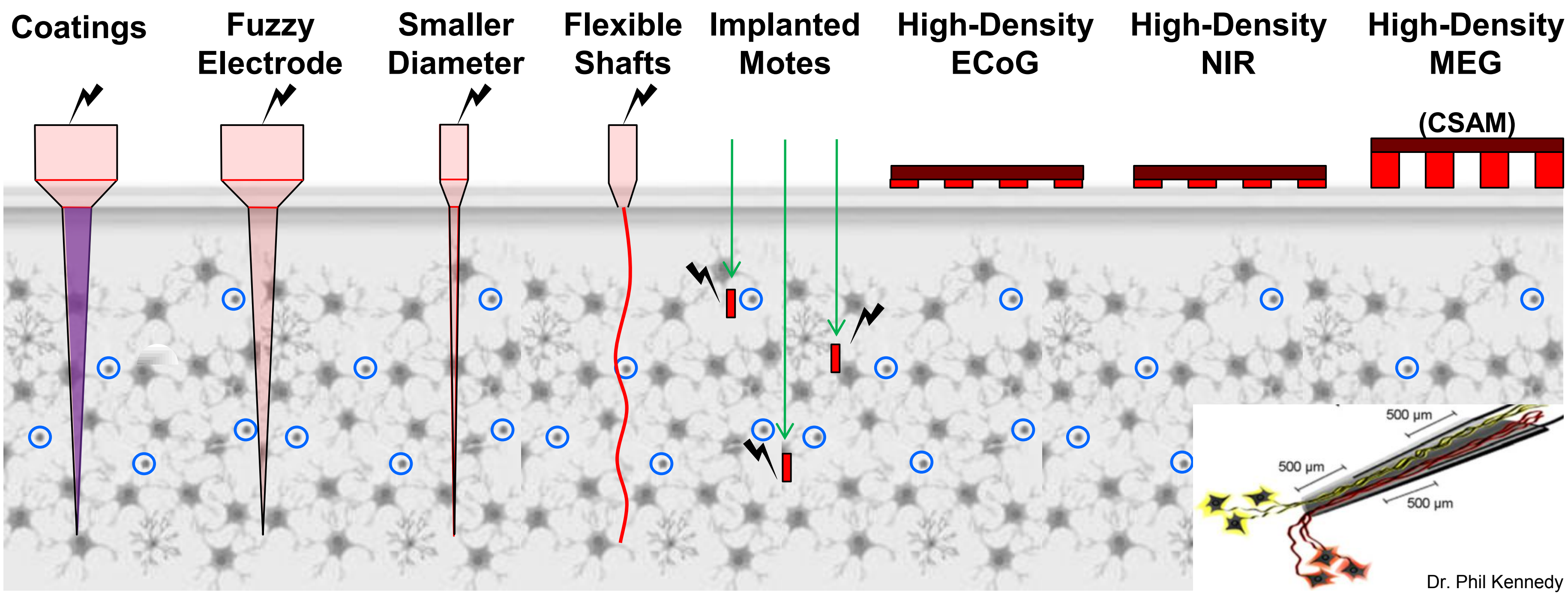

- **Reduce Tissue Response:** coatings, shrink size, flexible
- **Avoid Tissue Response:** high-resolution epidural sensing
- **Overcome Tissue Response:** reach across glial scar

Reliability of Neurotrophic Probes

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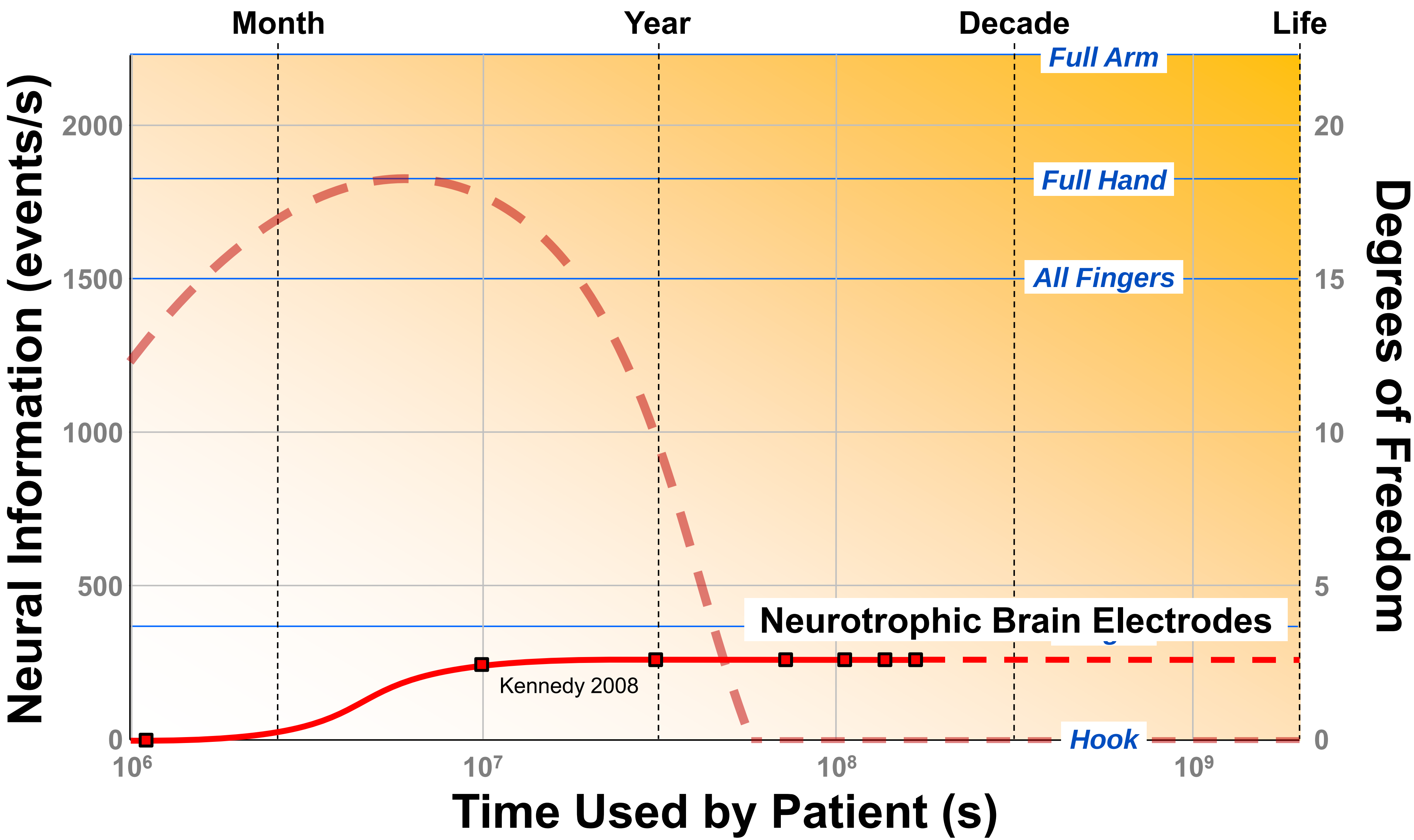
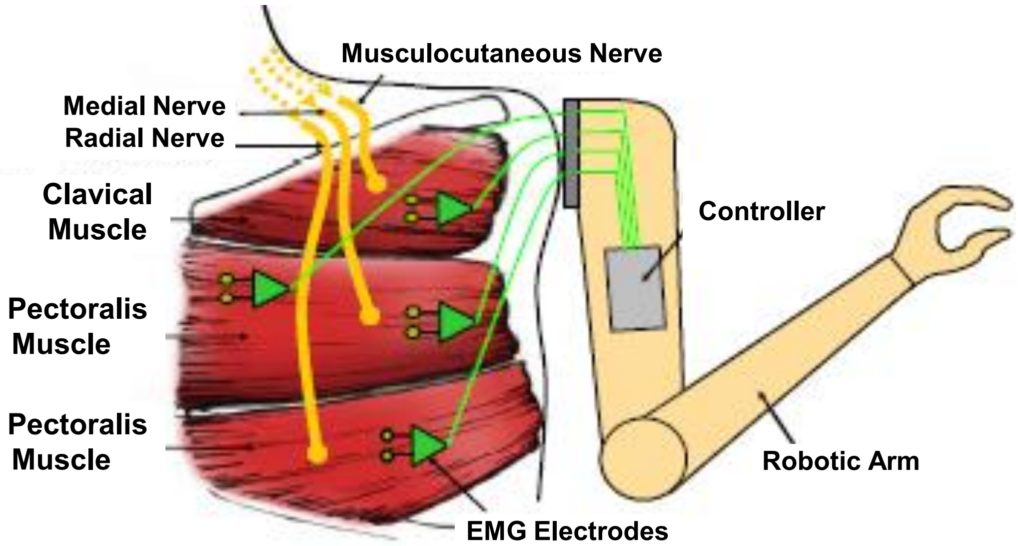
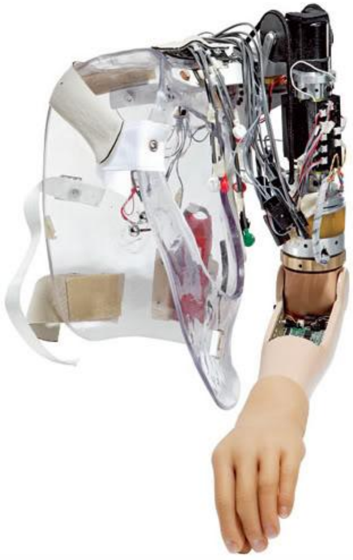


Targeted Muscle Reinnervation





Dr. Kuiken (Rehabilitation Institute of Chicago)

- **Transplant nerves from stump into other muscles**
- **Myoelectric read out allows more direct and natural "thought" control (enables only 4 control signals)**
  - **elbow up, elbow down, hand open, hand closed**

Targeted Muscle Reinnervation Reliability

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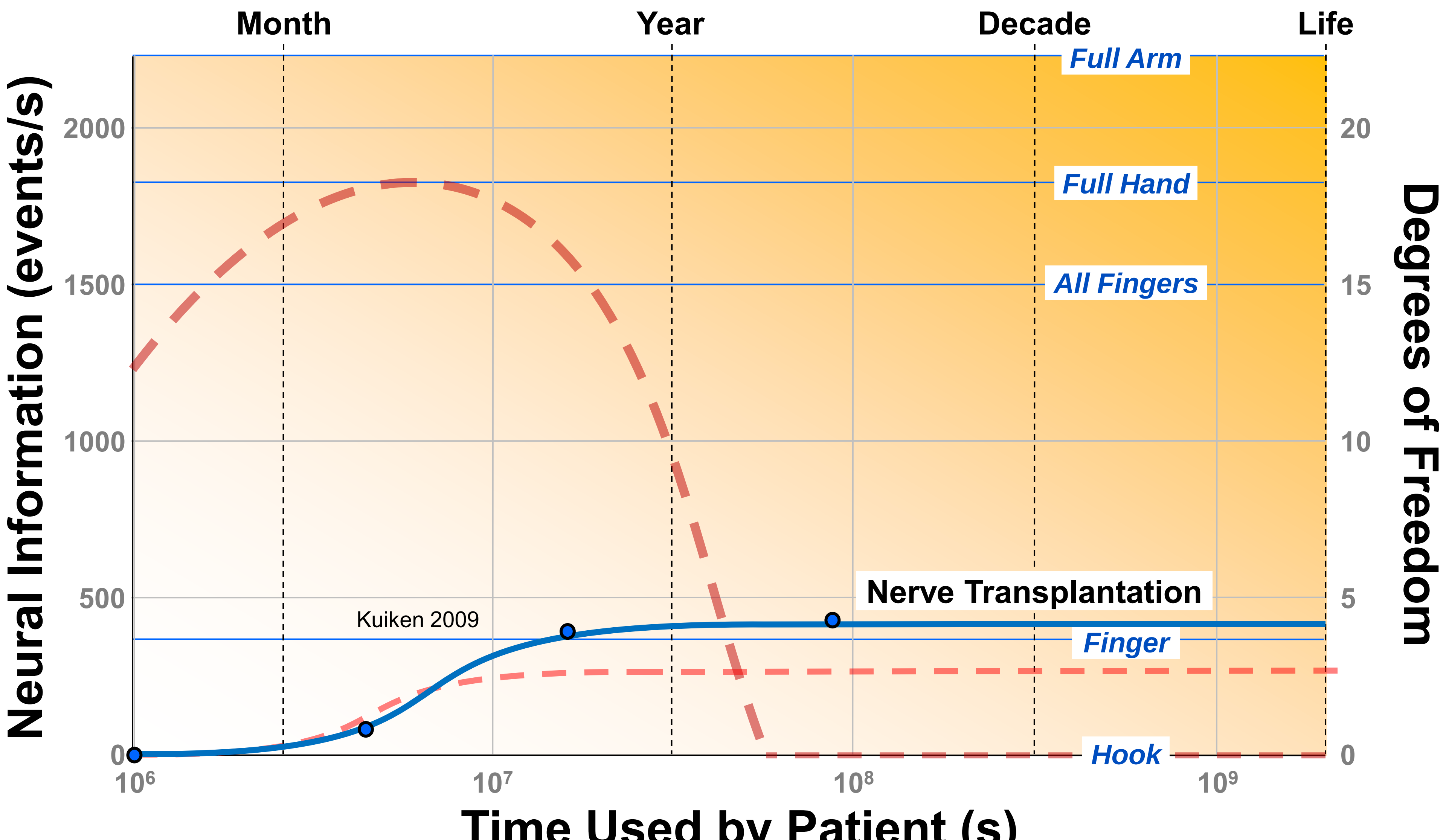

Reliability Challenge: *Unreliable Brain-Control Algorithm*

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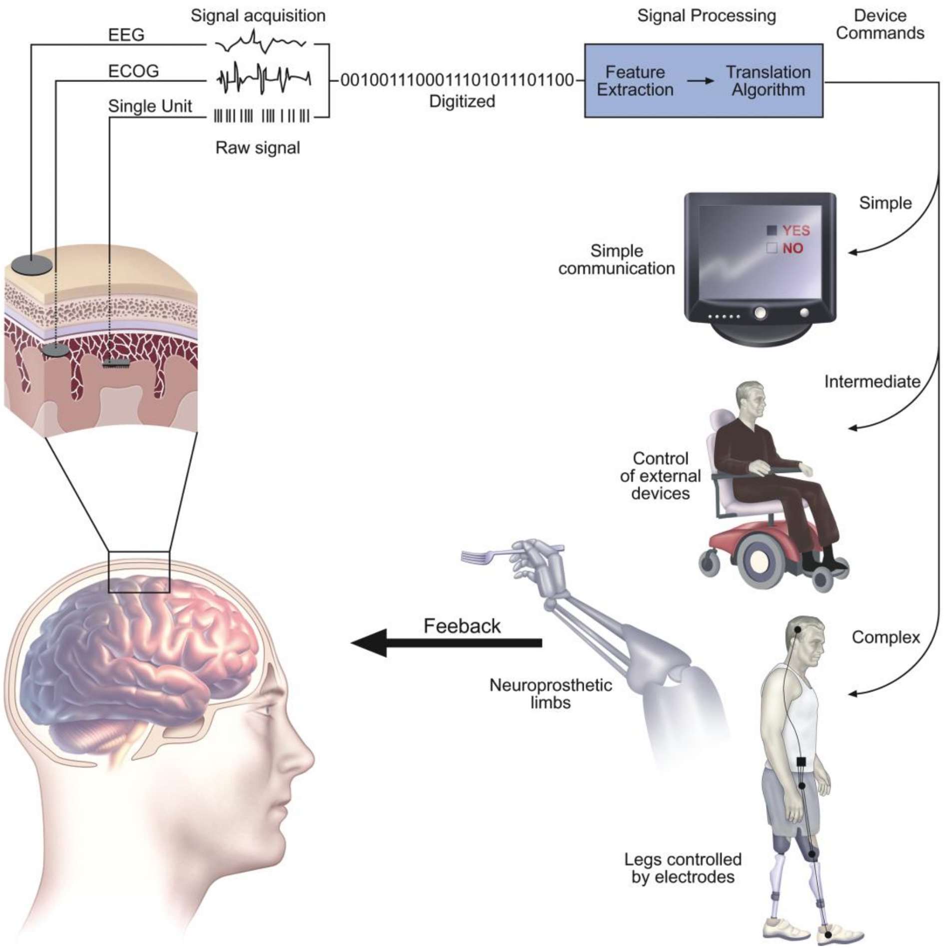
- **Dominant Approach**
  - use large electrode array
  - correlate neural activity with intended activity or behavior
  - develop adaptive algorithms
  - use output to control machine
- **Problem**
  - algorithms cannot adapt to the ultimate adapter (the brain)
  - approach fights built-in neural plasticity (dominant)
  - no examples of this approach ever being clinical successful
- **Result**
  - machine control is not reliable



Approach for Challenge: *Unreliable Brain-Control Algorithm*

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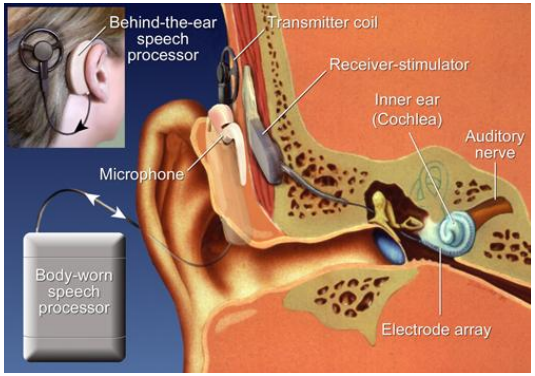
- New Approach
  - use electrode array
  - no correlation required
  - use "fixed" algorithms
  - use output to control machine
  - do so in field-relevant setting
- Advantage
  - exploits instead of fights neural plasticity
  - brain adapts to new "limb" through trial-and-error process
  - many examples of this approach being successful
- Result
  - reliable machine control
  - requires stable interface



Higher-Performance and Reliable Brain-Controlled Neural Prosthetics

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- Need <u>reliability</u> and <u>performance</u> metrics
  - Accelerated in-vivo testing
  - Pre-clinical testing at scale >> University labs
- Need new micromachined interfaces
  - High spatial and temporal resolution
  - Highly biocompatible
- Convenient, low-power, high-data-rate signal processing and wireless telemetry
- Need new system-level approaches with plasticity-enhanced reliable control

Impact of Reliable Control of More Prosthesis Degrees of Freedom

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0 DOF: *Passive Hook*

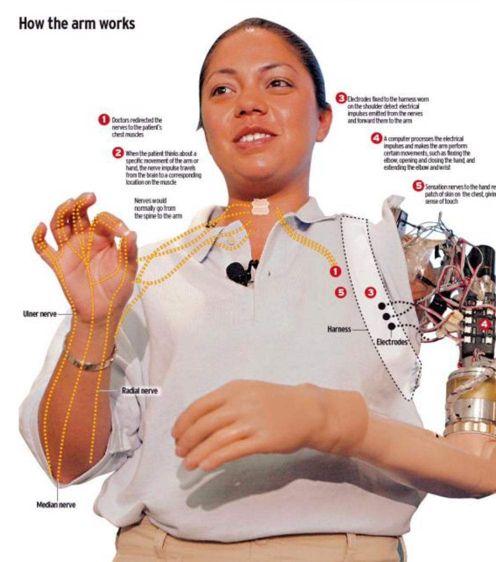
1 DOF: *Active Hook*

2 DOF: *Claw + Elbow*

SOA

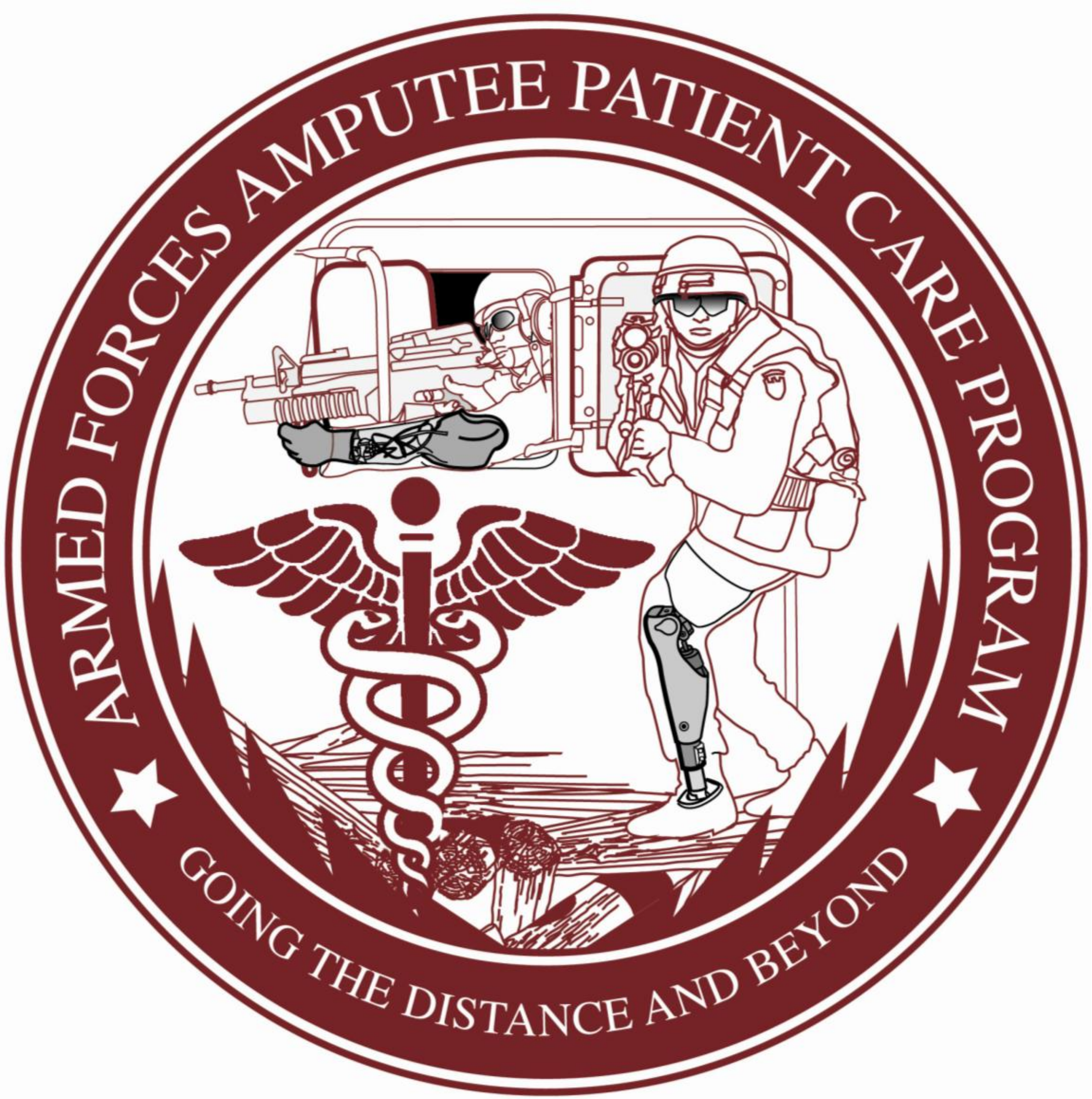
6 DOF: *Two Fingers*

18 DOF: *Forearm*



22 DOF: *Full Arm*

Questions?


ARMED FORCES AMPUTEE PATIENT CARE PROGRAM
GOING THE DISTANCE AND BEYOND

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As the DoD's innovation engine, we are committed to the boldest, creative leaps…

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Creative leaps require…

finding the…

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the ability to…

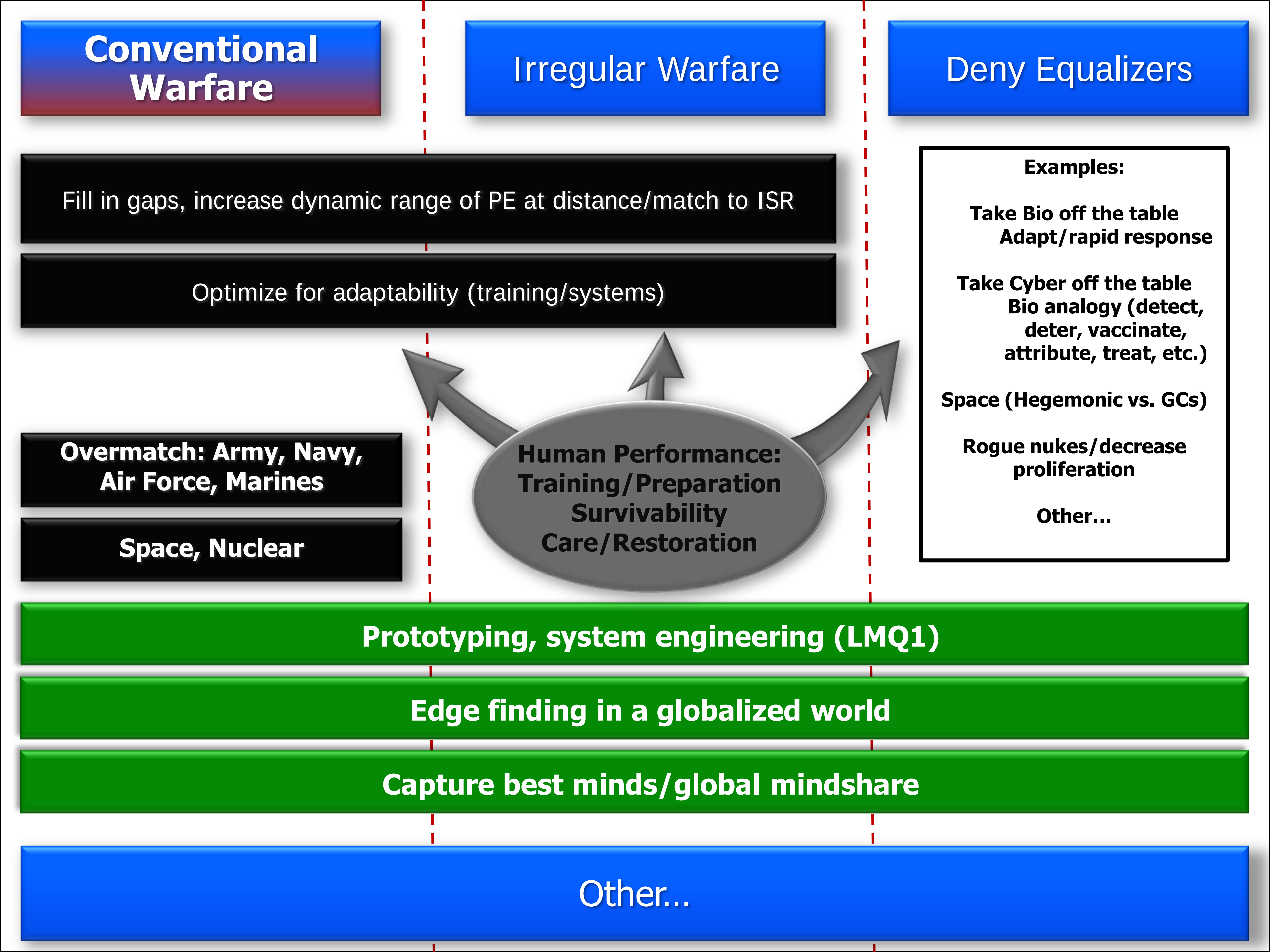
Protect the Fragile/Fleeting

…who recognize opportunities and are empowered to act rapidly…

the willingness to…

Challenge One's World View

…and are unafraid to challenge conventional viewpoints or methods.


Conventional Warfare
Irregular Warfare
Deny Equalizers
Fill in gaps, increase dynamic range of PE at distance/match to ISR
Optimize for adaptability (training/systems)
Examples:
Take Bio off the table
Adapt/rapid response
Take Cyber off the table
Bio analogy (detect, deter, vaccinate, attribute, treat, etc.)
Space (Hegemonic vs. GCs)
Rogue nukes/decrease proliferation
Other…
Overmatch: Army, Navy, Air Force, Marines
Space, Nuclear
Human Performance: Training/Preparation Survivability Care/Restoration
Prototyping, system engineering (LMQ1)
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- Application

IPTO
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- High Priority Computing
- Language Processing
- Sensors & Processing
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TTO
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- Advanced Platforms
- Advanced Space Systems

STO
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- Global Tactical ISR
- Energy
- Hybrid Warfare
- Extreme Environments

TCTO
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