A Common Architecture Recipe for BCI Systems

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Standardized and Modular Open Systems Approach to BCI

- **Common advantages**
  - **Ensures interoperable and complimentary components**
  - **Enhances commonality and reuse of components**
  - **Accelerates development and integration by eliminating redundant efforts (DT&E); assured performance**
  - **Reduces cost through increased commercial competition**
  - **Adapts quickly to evolving technology and capabilities (Tech Refresh)**
  - **Accelerates scientific discovery (vice engineering)**

- **Establishes development and integration aids**
  - **Common test beds and development environments**
  - **Affords system and component simulators**
  - **Provides specifications for procuring components and capabilities**

The Challenge

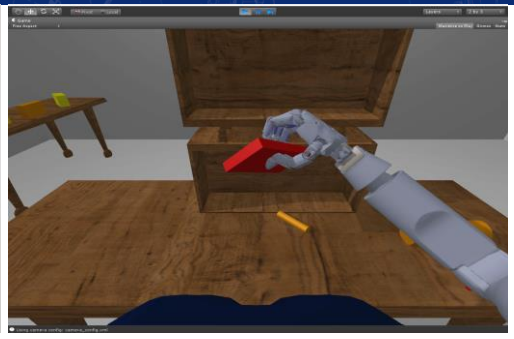
- **Sources**
  - EEG
  - ECOG
  - Cortical Arrays / Areas
  - Peripheral Nerve Arrays (Efferent / Afferent)
  - Non-Invasive?
  - EMG / Intramuscular
  - Targeted ReInnervation
  - Augmented Controls

- **Signal Characteristics**
  - Quantity / Channels / Bandwidth
  - Type, Duration,
  - Frequency, Amplitude
  - Fidelity
  - Spatial Resolution
  - Temporal Resolution
  - Purpose / Intent

Other Considerations: Regulatory framework for modular designs…

Relevant Work in BCI System Architectures: Revolutionizing Prosthetics

- **DARPA's Revolutionizing Prosthetics (RP)**
  - APL is one of two prime performing institutions
  - Generate a revolutionary system to restore functionality to amputees and SCI patients
- **We adopted concepts of a modular open system approach**
  - Modular Prosthetic Limb (MPL)
    - State of the art prosthetic device
  - Virtual Integration Environment
    - Surrogate to the MPL for development and testing
  - Architecture definition and capture
    - Neural Interfaces ICD
      - Provides for a common neural data format and interface definition
    - MPL UDP ICD
- **Our architecture definition has allowed us to rapidly integrate technologies for patient care**
  - EMG
    - Conventional myoelectric control, pattern recognition, and IMES
    - Targeted Muscle/Sensory Reinnervation
    - Tactile feedback
  - Cortical BCIs
    - Utah arrays, ECoG arrays, IMES
    - Tactile/proprioceptive feedback
  - Assistive technologies
    - Eye tracking, heads up displays, voice recognition
  - Upper limb implant osseointegration



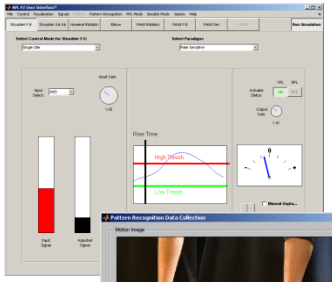
Virtual Integration Environment

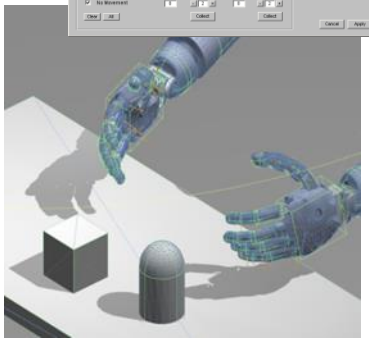
Input → Signal Analysis → Controls → Plant → Presentation

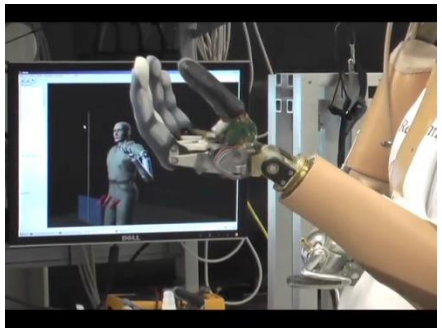
- **Complete limb system simulation environment**
  - Supports engineering development
  - Neural signal acquisition / analysis
  - Algorithm development
  - Mechanical approach evaluation
  - Patient training / therapeutic applications
  - System performance validation and design compliance

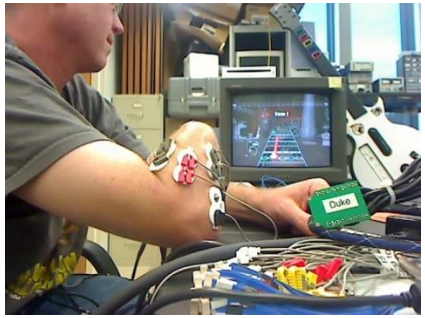
- **End-to-end interactive simulation**
  - Acquires control signals (myoelectric, mechanical, neural, other)
  - Signal Analysis: Interprets the intention
  - Controls: Translates intention into movement of a virtual limb
  - Allows the user to interact with objects with feedback (haptics or other)
  - 2D and 3D visual perspective of virtual world
  - Real-Time physics engine support
    - Grasping, orienting, placing of objects
    - Contact, force, torque and slip perception

- **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
  - Build scenarios from custom and commercial objects



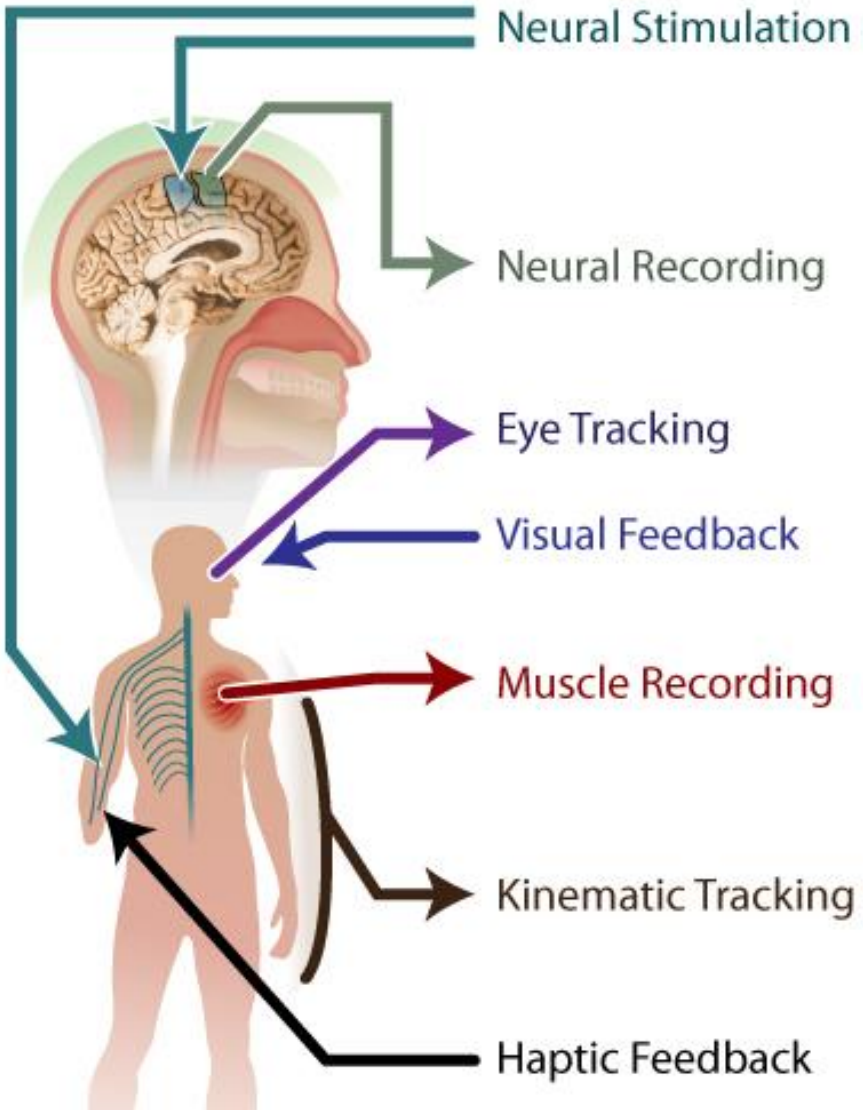






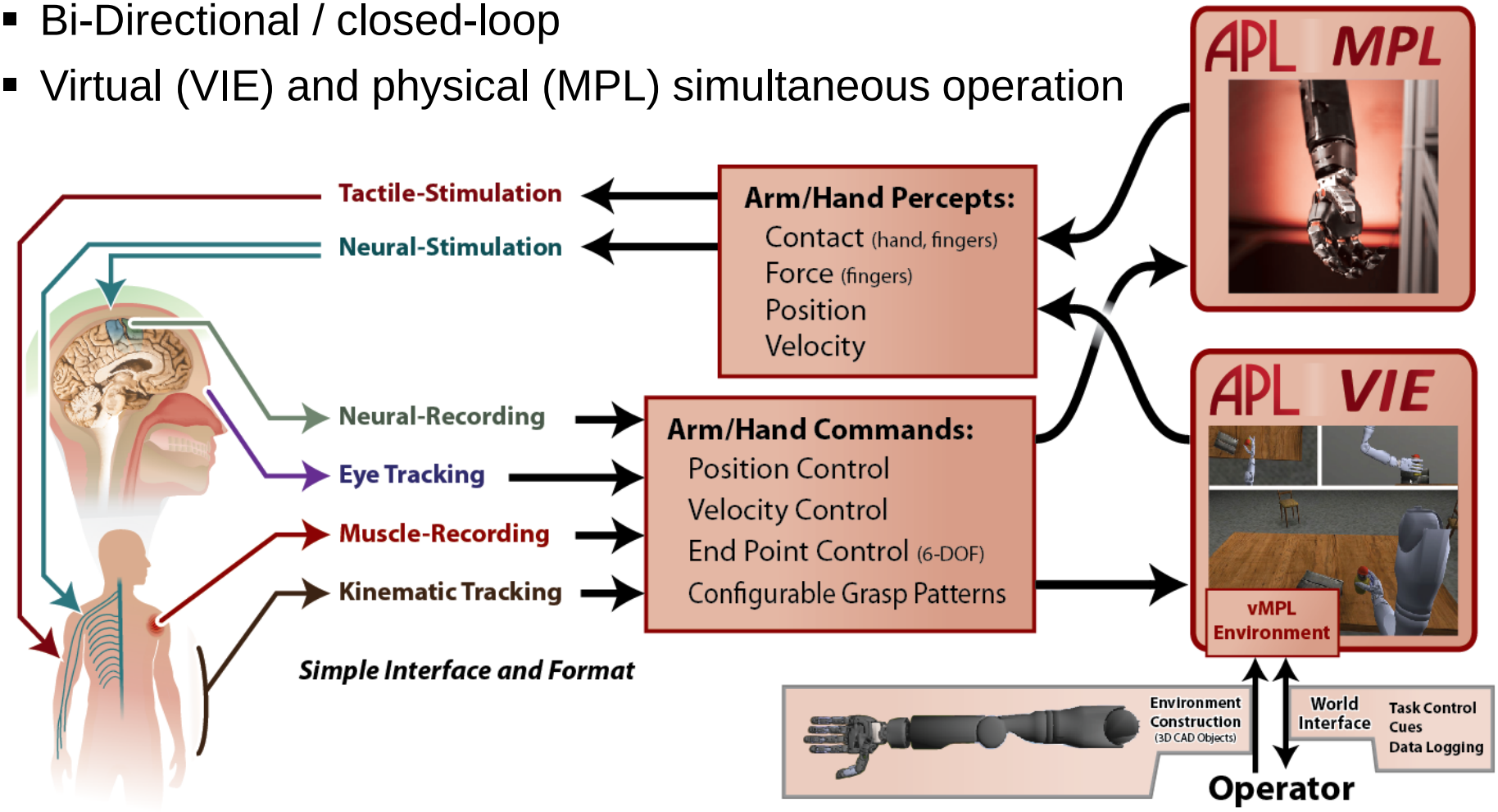
Revolutionizing Prosthetics – Control Approaches

- **Quadriplegia, Spinal Cord Injury**
  - **BCI, Hybrid Control**
  - **Sensory Stimulation**
- **ALS, Muscular Dystrophy**
  - **Hybrid Controls**
- **Trans-Radial/Humeral Amputation**
  - **sEMG Control**
  - **Haptic Feedback (TMR)**
- **Bilateral Amputation**
  - **Bimanual sEMG Control**
  - **Haptic Feedback (TMR)**

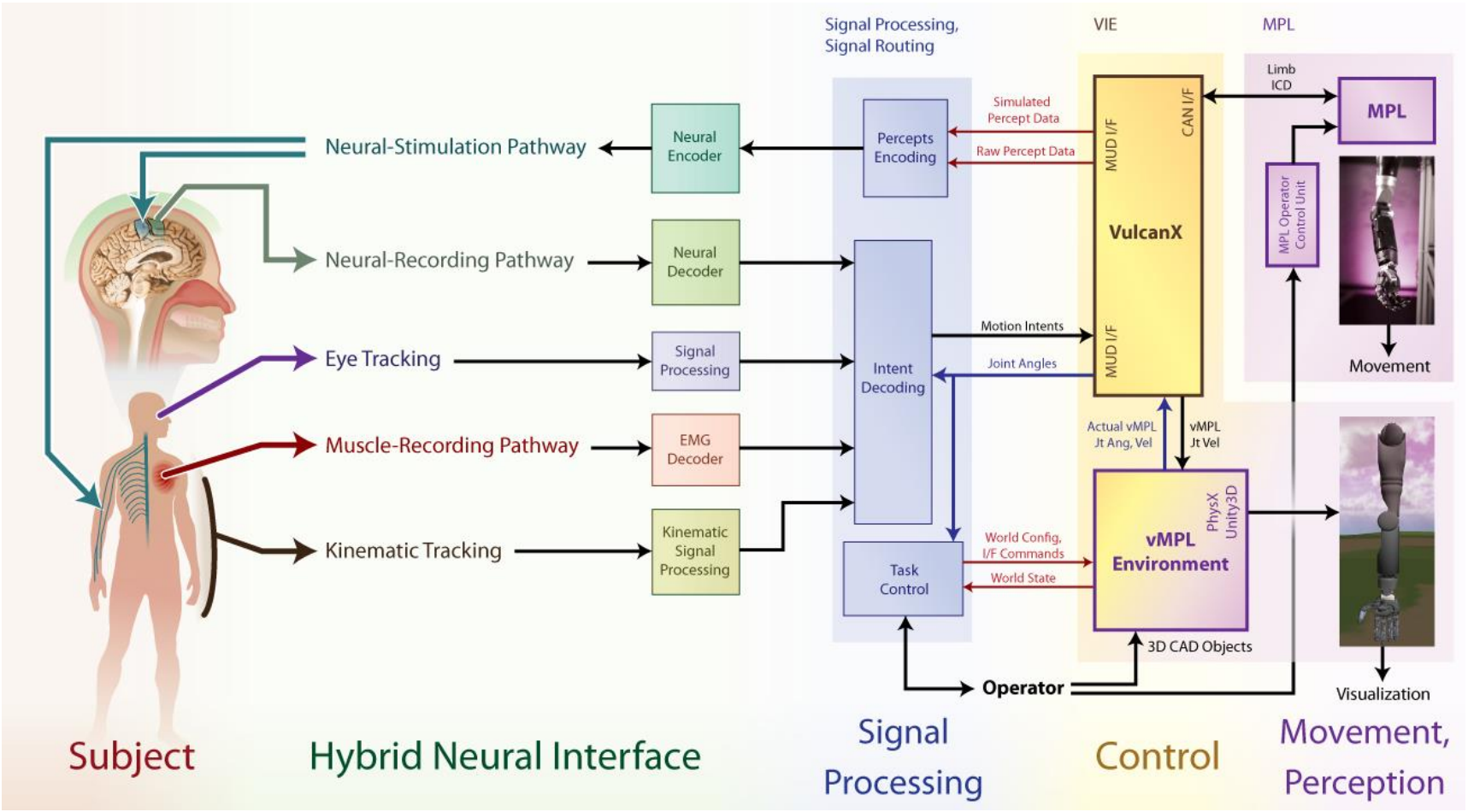


Closed Loop Experimental Interfaces

- Multiple inputs possible
- Bi-Directional / closed-loop
- Virtual (VIE) and physical (MPL) simultaneous operation

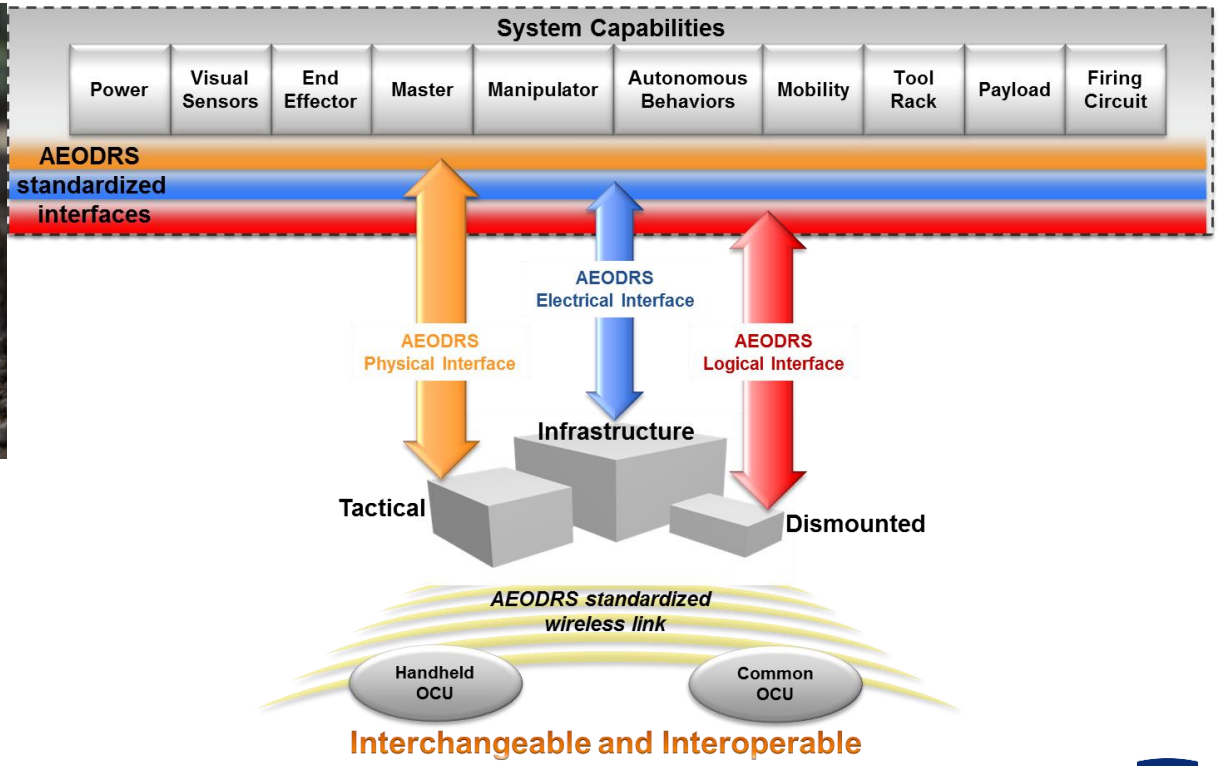


Modular Control Interfaces



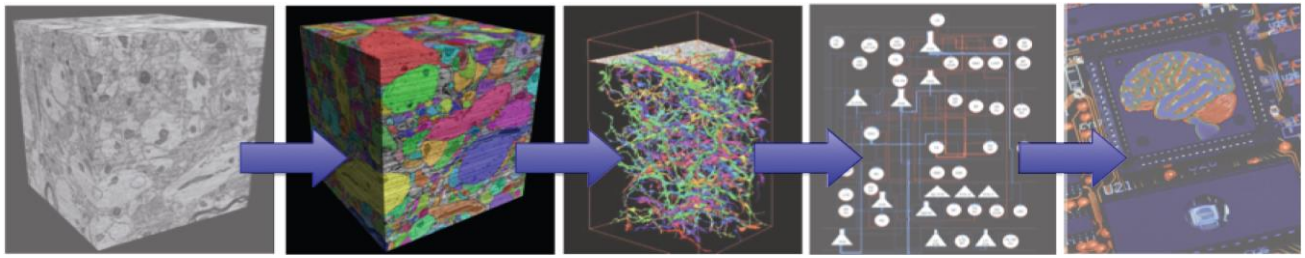
Systems Engineering Approach to Open Architectures: AEODRS Case Study

- **The Advanced Explosive Ordnance Disposal Robotic System (AEODRS)**
  - **Navy program of record - *govt owned and mandated* modular open systems architecture for a family of Robotic Systems**
  - **APL is lead systems integrator**
- **An open architecture approach enables interoperability and facilitates rapid technology integration, development, and collaboration**

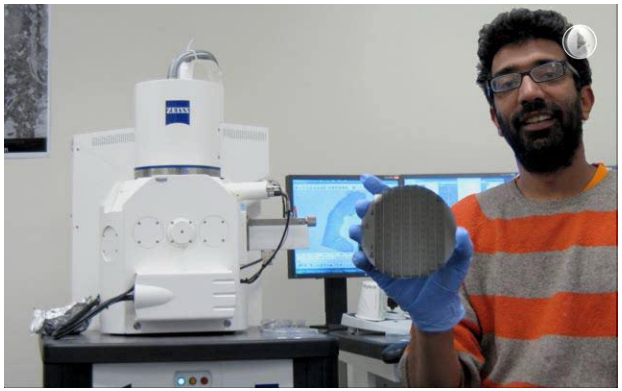


MICrONS – Neural Connectomics Investigation

- **Machine Intelligence from Cortical Networks (MICrONS)**
- **Revolutionize machine learning by reverse-engineering the algorithms of the brain used for processing data**
  - **Neural anatomy & physiology + Connectivity -> Neural Circuit**
  - **Neural Circuit understand will lead to new methods for processing data (e.g. visual, auditory, semantic) and machine learning algorithms**

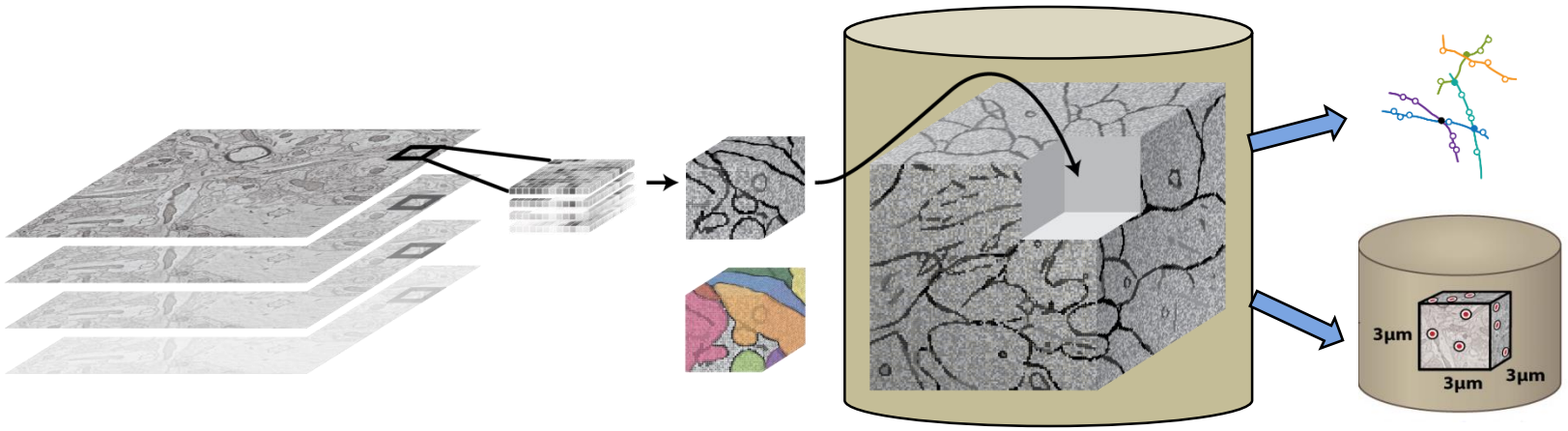


- **Program will generate multiple data types**
  - **Neural Anatomy (images, structural data)**
  - **Neural Physiology (electrophys., time series data)**
  - **Neural Graph Reconstructions**
  - **Neural Cell & Tissue Morphologies, Annotations**



MICrONS – Data Storage Systems Engineering

- **Challenge**
  - Massive multi-dimensional neuroimaging datasets are challenging to store, access, and process
  - Image data is too big to analyze and extract neuronal network structure by hand
- **Approach**
  - Leverage Amazon Web Services to develop a cloud database service that can scale to petabytes while minimizing cost and maximizing performance
  - Develop RESTful interfaces to accommodate data access, and leverage cloud services to utilize computer vision and machine learning to automatically estimate neuronal network structure in the image data



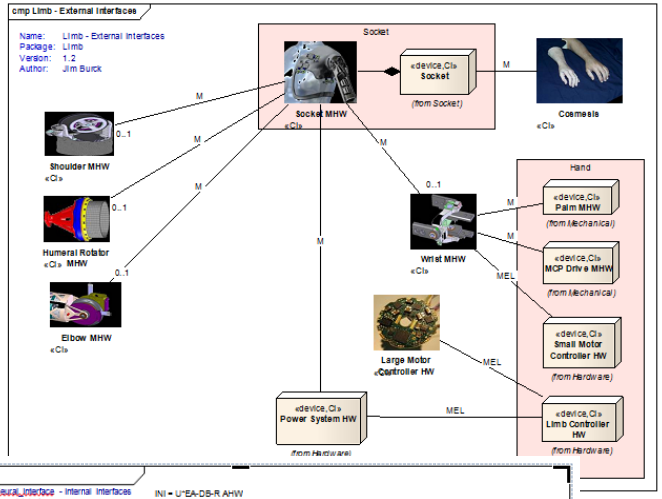
The Recipe

- **Modular architecture recipe**
  - Define capability or development modules
    - Functional decomposition into definable units
    - Establishes physical implementation
      - Current technology and forward looking
  - Define and document the interfaces
    - Leverage existing standards/conventions
    - Defined at three primary levels
      - Logical (data structures, message definitions, and formatting)
      - Physical (interconnects, mounting footprints, size, weight, volumetric space claims)
      - Electrical (voltage, current, connector pinout designations, signal type/protocol and characteristics)

- **This recipe has transcended problem domains**
  - MDA's Kill Vehicle Modular Open Arch – defensive technology
  - SOCOM TALOS Exoskeleton System
  - Joint Military Communication Systems (JCAUS)
  - DARPA Squad X Infrastructure Study
  - JHMI ICU - EMERGE
  - MICRONS - focuses on standardization/sharing of neural data and "circuits"

How do we get there?

- Define the “types” of BCI
- Define the characteristics
- Instantiate known examples
- Incorporate / accommodate future growth
- Define standards (interfaces, functional performance, etc)



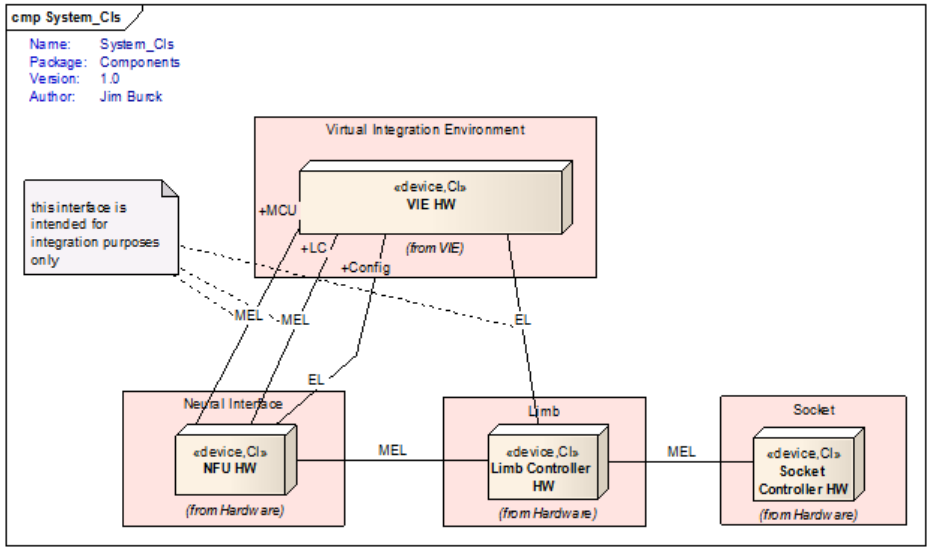


Figure 1 - Top-level Interfaces

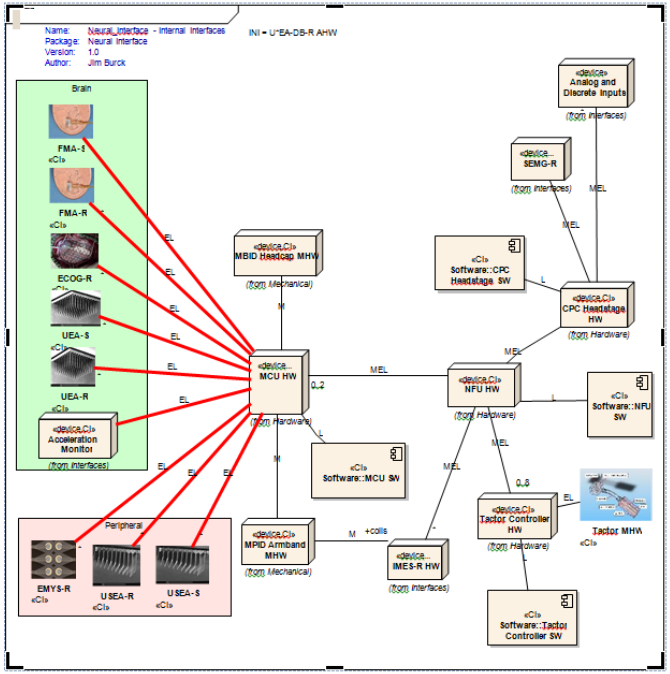
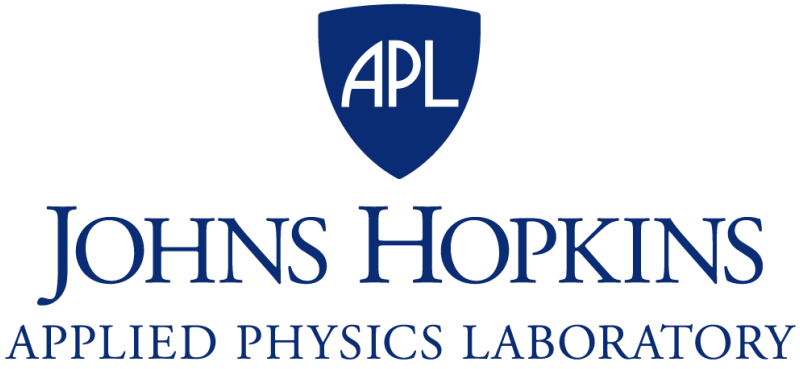


Figure 1 System context of interfaces described in this document (drawn as bold red lines).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