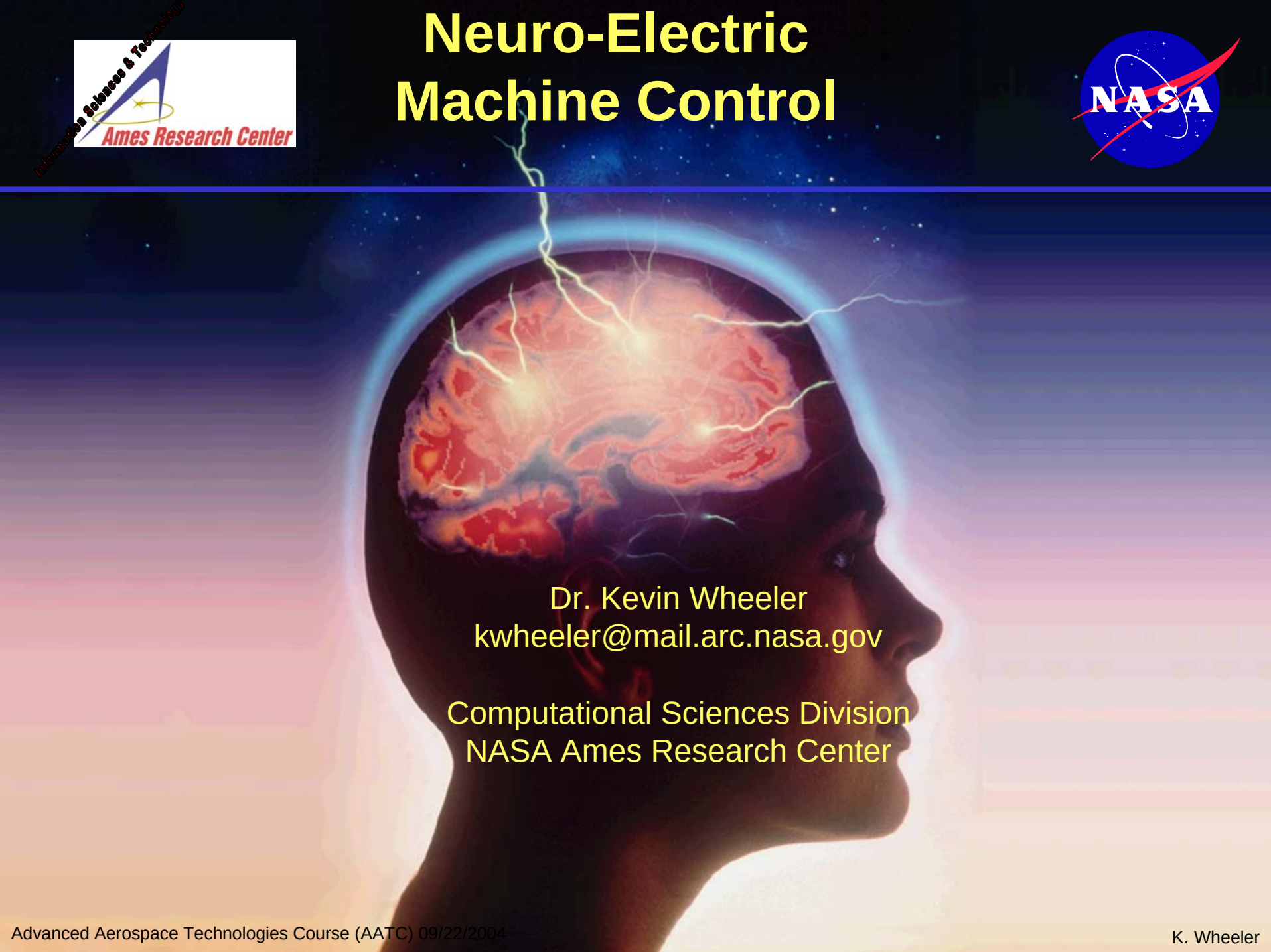
Neuro-Electric Machine Control



Dr. Kevin Wheeler
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NASA Ames Research Center

Neuro-Electric Machine Control

OVERVIEW

- Definition – What is Neuro-electric machine control?
- Why do this? - NASA capabilities - Partnerships
- Approach – Method & Experiments
- Accomplishments - Movies
- Educational requirements - What do we need to know?
- What's next?

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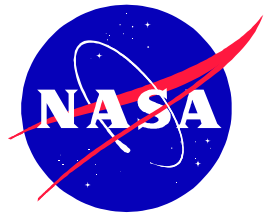
Neuro-Electric Machine Control
DEFINITIONS



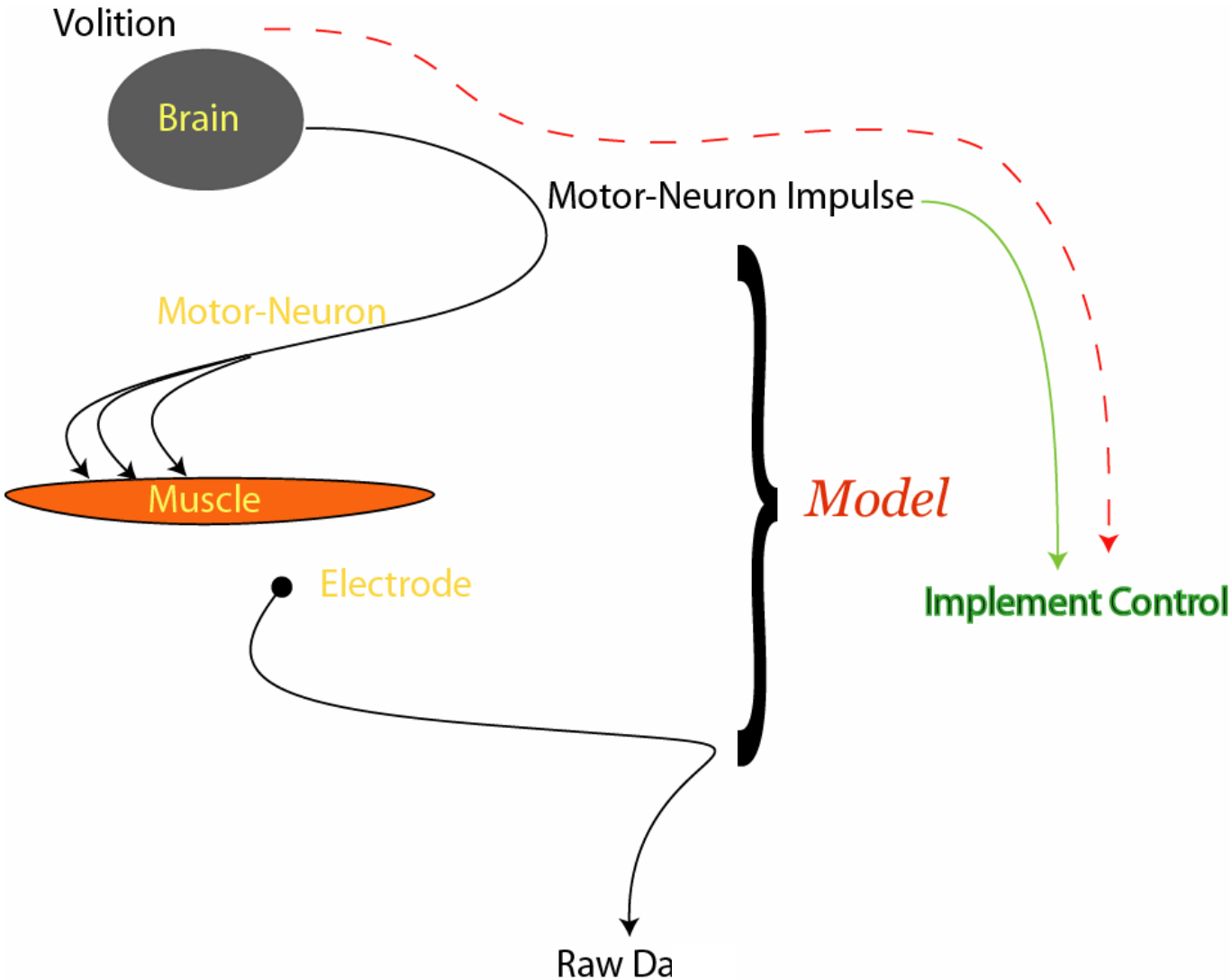
DEFINITIONS:

Neuro-electric machine control - the capability to interface computers & machines with people by using Electromyograms (EMGs) (electrical activity in muscles) and Electroencephalograms (EEG) (brain waves) to generate control commands.

EMG – Electromyogram - Represents the electrical activity in the muscles during contractions.

EEG – Electroencephalogram - Represents the electrical activity in the brain associated with cognition.

EMG for Control



Picture courtesy of M. Millonas

Neuro-Electric Machine Control
Why Do This?

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Trends in Personal Computing

Laptops, cell phones and PDAs have been evolving as follows:

Larger screens - size limited by carrying convenience, can be replaced by active display glasses.

Smaller & faster motherboards - wearable cases

Spoken command input - speech recognition works for common words but not good for programming and science tasks

Full size keyboards - Design has NOT evolved. The physical size of input keys limits the evolution of cell phones, laptops, command panels, aircraft instrumentation …

Neuro-electric Machine Control Applications

Wearable Cockpit - virtual instrumentation, moves with pilot, works for AUVs and manned missions. Provides for faster and cheaper reconfiguration, and safety monitoring of pilots.

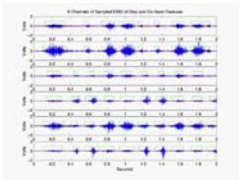
Spacesuit restricted typing - allows for typed data entry while wearing spacesuit or within confined environments.

Natural robotic arm interface - joystick can be replaced with a more natural interface.

Exoskeleton EMG interface - provides capability of working in extreme environments and manuvering heavy items. Provides for training exoskeleton to do tasks autonomously.

Applications

Nano Device Control

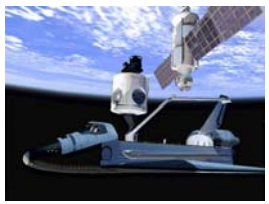


Exoskeleton Control

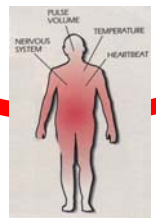
Planetary Discovery

Neuro-electric Interfaces

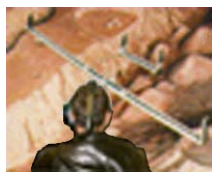
Silent Communication

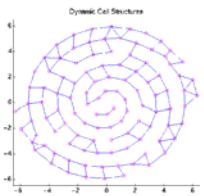


Manipulator Control



Wearable Cockpits

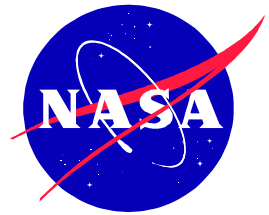




Data World Immersion

Human/Machine Communication

Partnerships & Funding



External Partnerships:

- Space Act Agreements with industries
- University affiliations
- Student internship opportunities
- Graduate student funding, faculty support

Program funding lines:

- CICT
  - o ITSR ICD NEMC - silent speech, EMG mouse, mu-rhythm control
  - o IS HCC - studying effects of multiple modalities
  - o IS IDU - development of data framework for Earth science
- DARPA - sensor developments

International Efforts

National & International Efforts

- Wadsworth Institute
- Brown University
- SALK Institute
- Wright Patterson Airforce Base
- Graz University of Technology, Austria (Pfurtscheller)
- RIKEN Brain Science Institute Japan
- Univ. La Sapienza & Univ. G. d'Annunzio Italy
- Joint Research Center of the European Commission
- Korean Research Institute in Taejon
- Britain's Defense Evaluation and Research Agency

Approach

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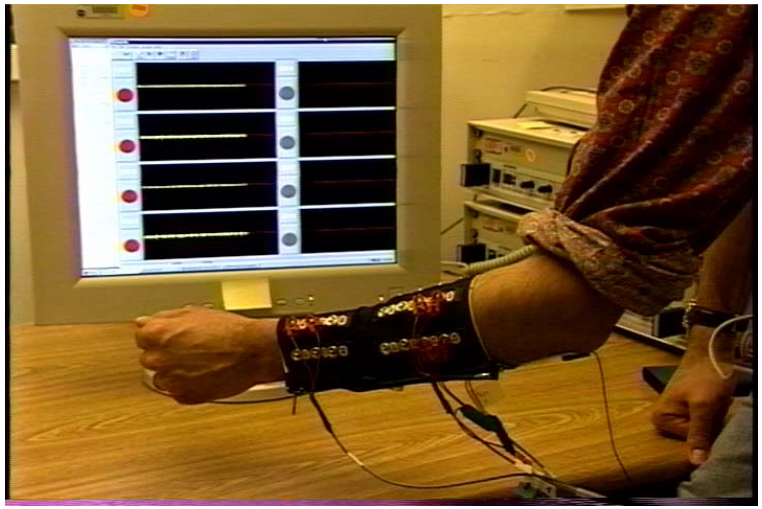
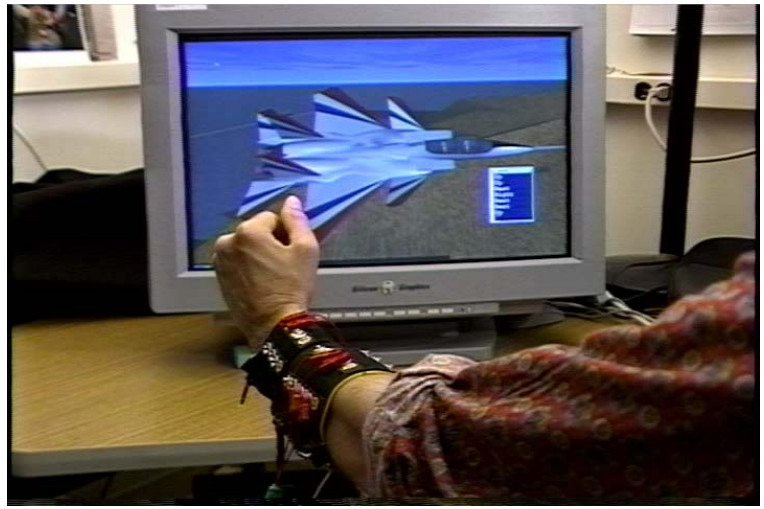
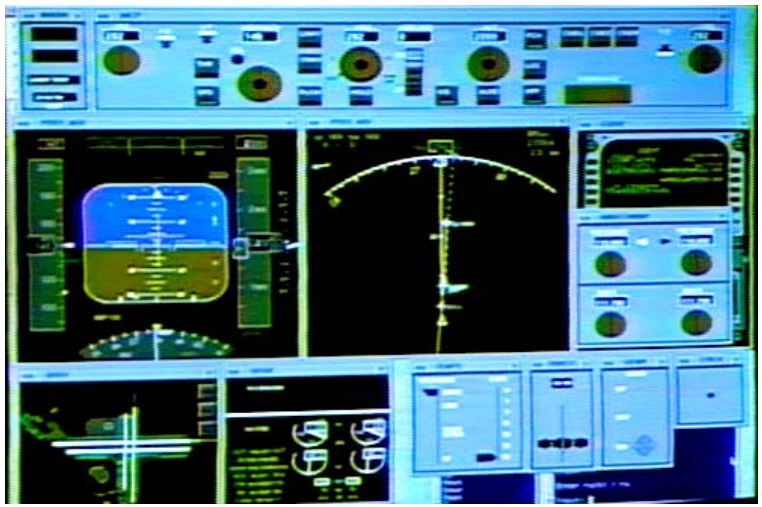
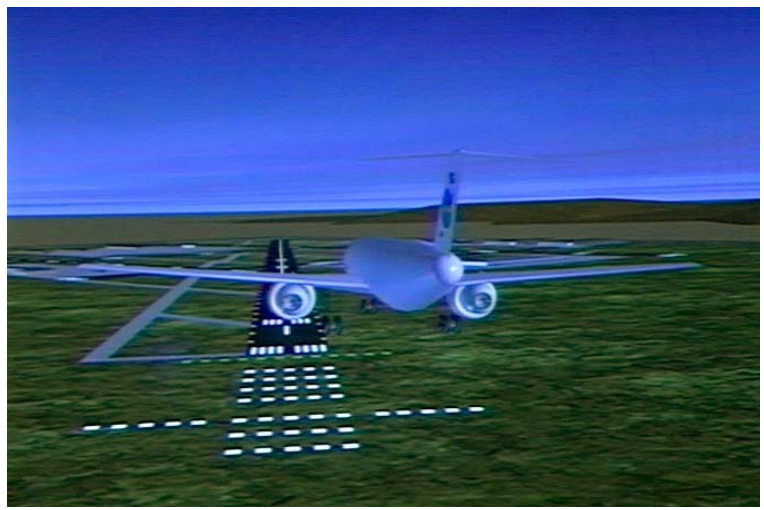
Output sensory mapping
Virtual joystick

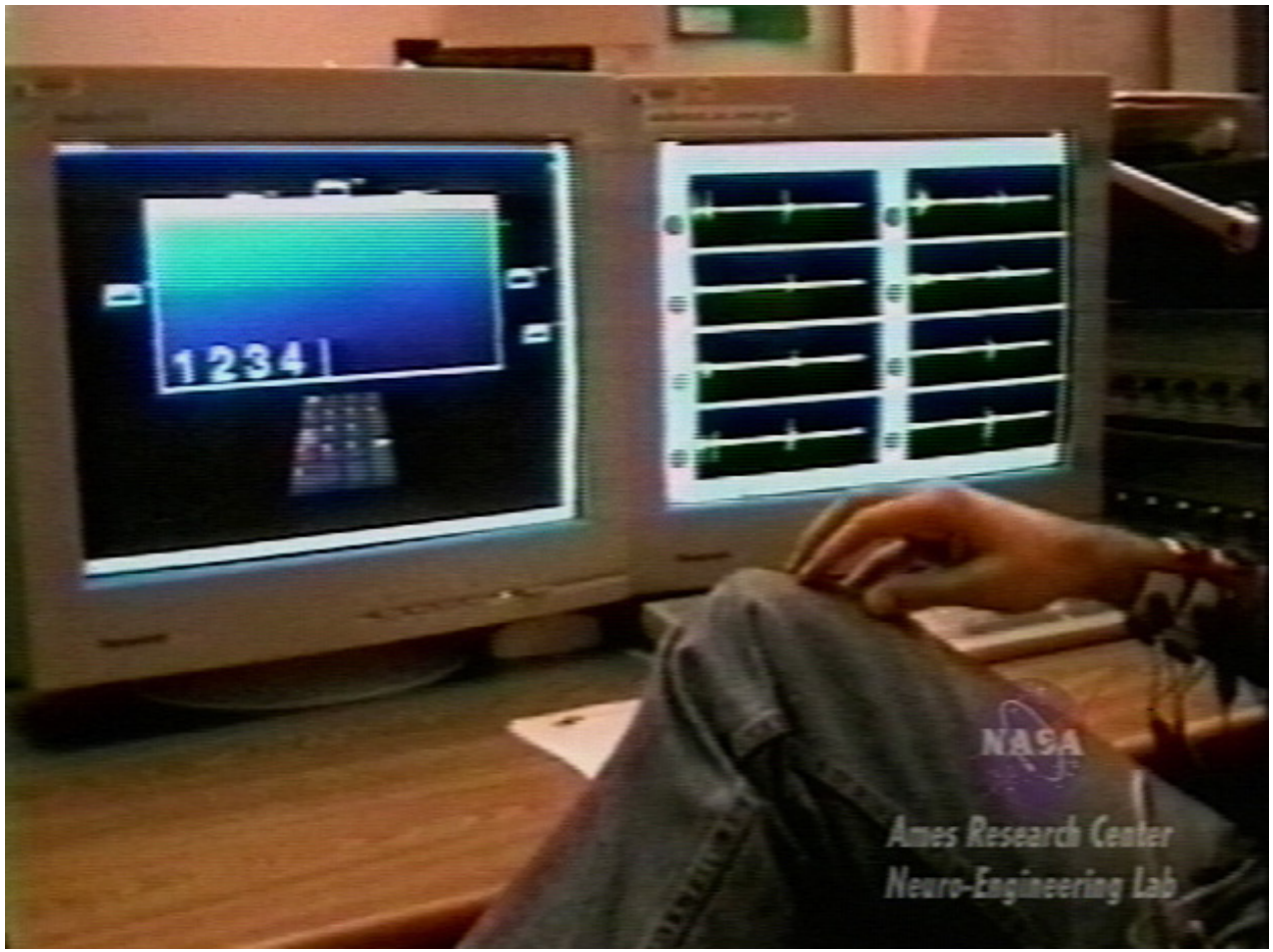








Output sensory mapping
Virtual typing



Steps in Creating a Neuro-electric Interface

1. Define the gesture set
2. Determine optimal electrode locations & types
3. Collect data
4. Training pattern recognition algorithms
5. Test interface in real-time & real-world

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Gesture Set Definition

- Finger Movements – only require electrodes on forearm
- Hand Movements – Forearm sensors, relative position
- Arm Movements – Front & back sensors, relative position
- Whole Body – Complete body suit.

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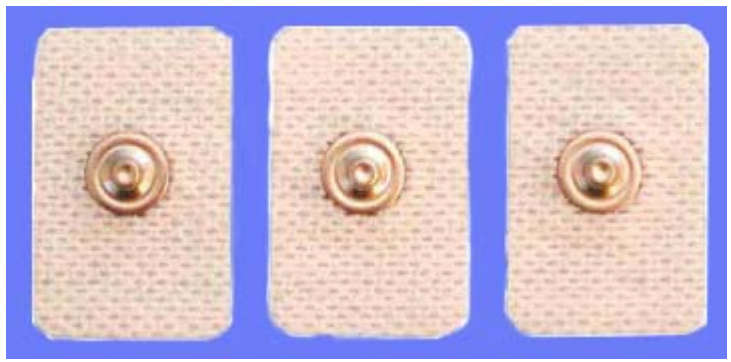
Determine Optimal Electrode Locations & Types

- Two types of electrodes – Wet & Dry
- Location determined from physiology & Statistical analysis

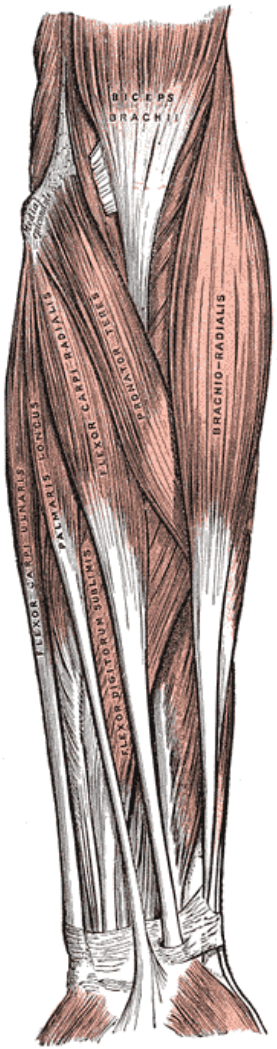
Needle EMG Electrodes

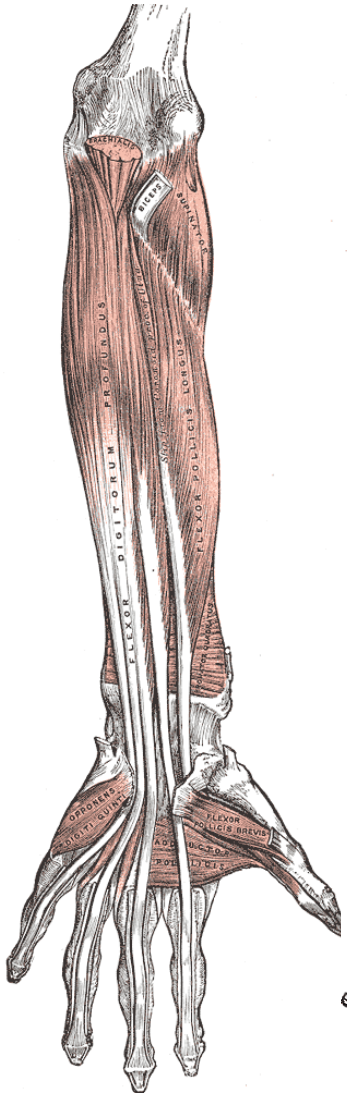


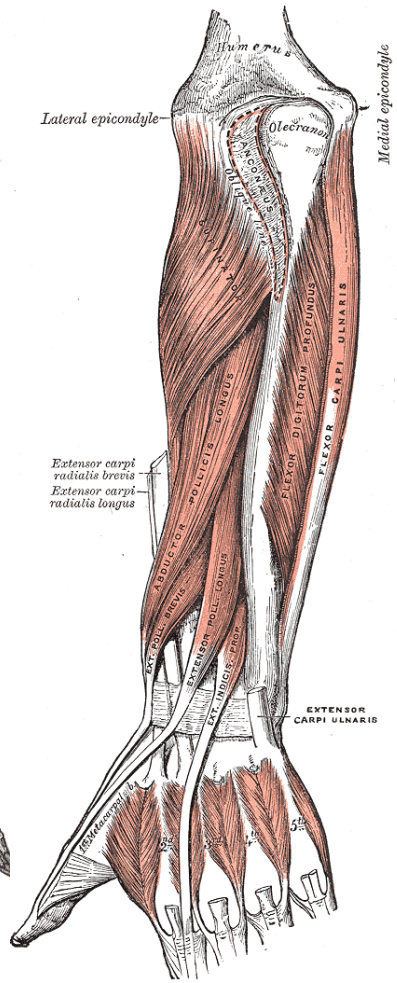
Wet EMG Electrodes

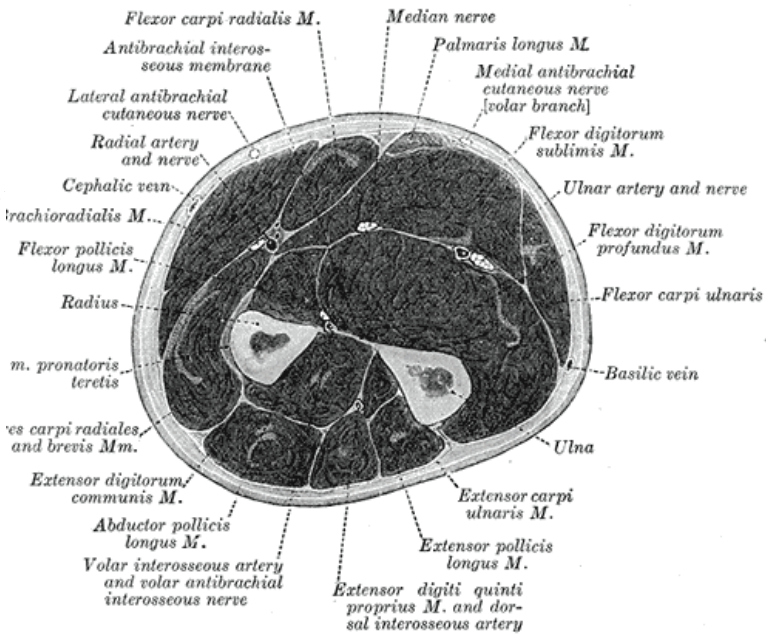
Dry EMG Electrodes

Physiology of the Forearm



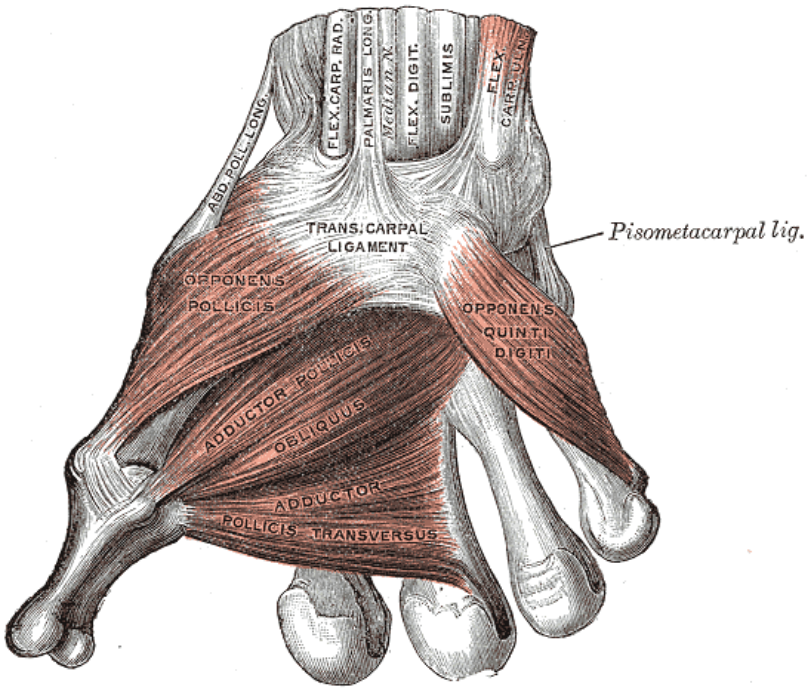


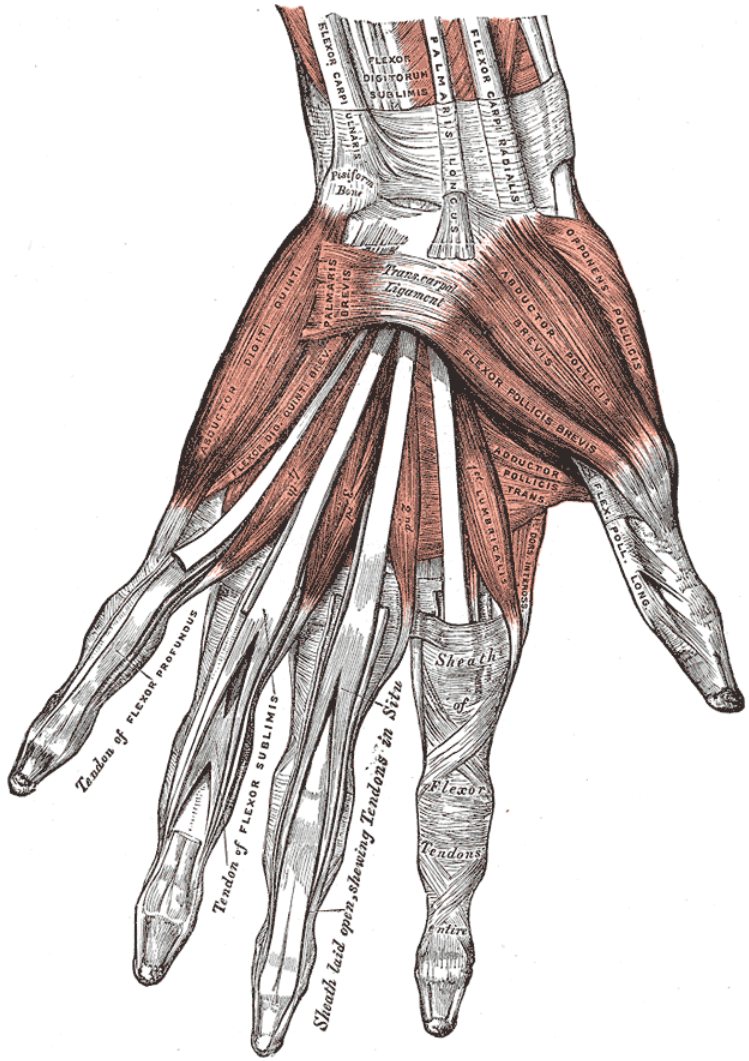




Pictures from http://education.yahoo.com/reference/gray/

Physiology of the Hand





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Steps in Creating Neuro-electric Interface

1. Define gesture set
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EMG Data Collection

- Collect data using a data acquisition card that converts analogue signal to digital numbers (similar to microphone input on a computer's sound card) (12 or 16 bit A/D)
- Medical practice uses 2000 Hz. sampling rate, research uses up to 50,000 Hz per channel.
- Experiment Design
  - Avoid complex movements
  - Avoid fatigue
  - Maximum voluntary contraction

Steps in Creating Neuro-electric Interface

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Train Pattern Classifier

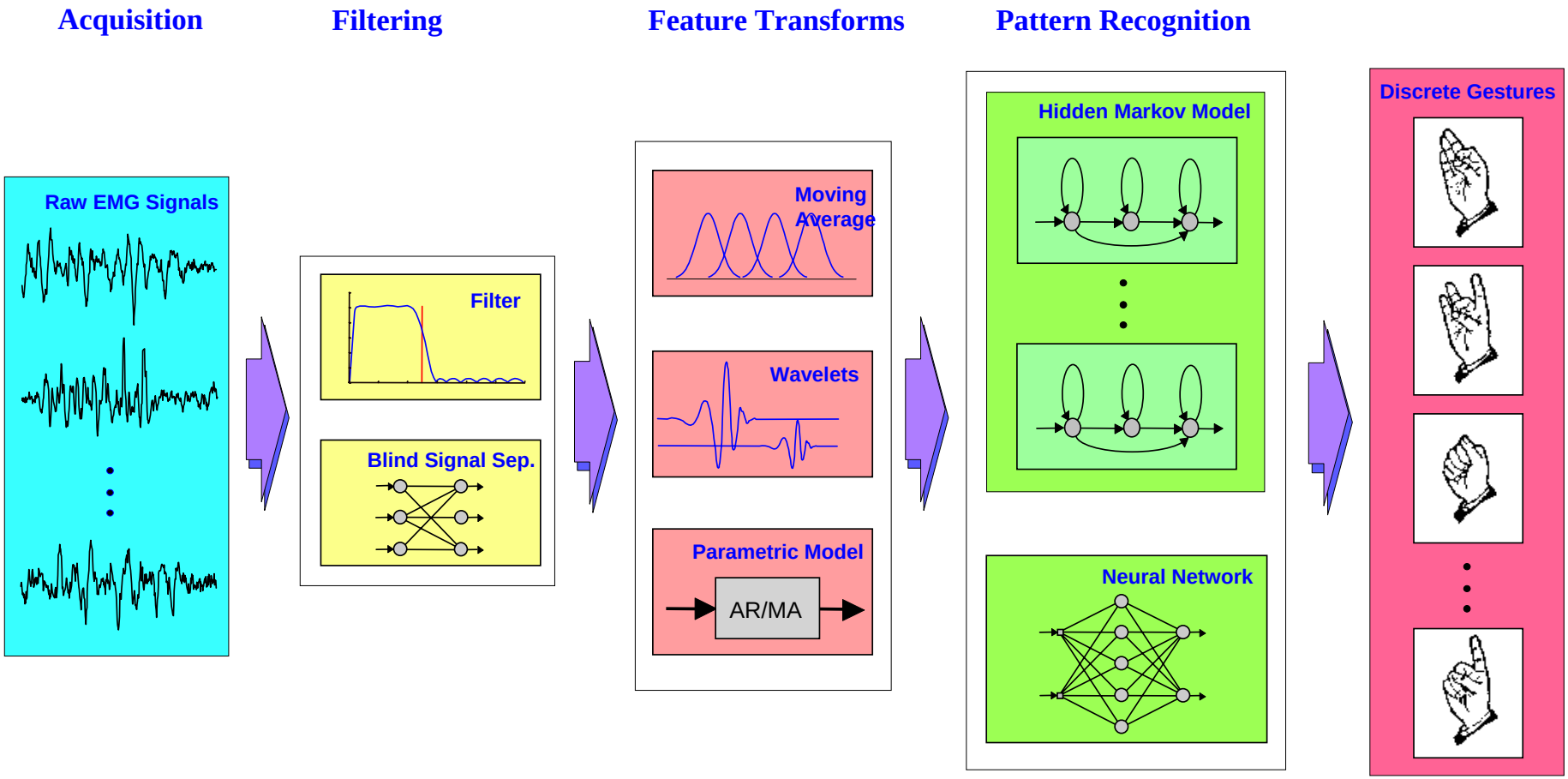
- Create and train pattern classifiers similar to those used in speech recognition: Hidden Markov Models (HMMs)
  - Isolated words single speaker
  - Isolated words multiple speakers
  - Continuous speech single speaker
  - Continuous speech multiple speakers

- Classifiers work on a representation or transformation of the data rather than on the raw EMG

Steps in Signal Processing & Recognition

1. Acquire and digitize data
2. Filter
3. Transform
4. Train & Test Pattern classification/recognition

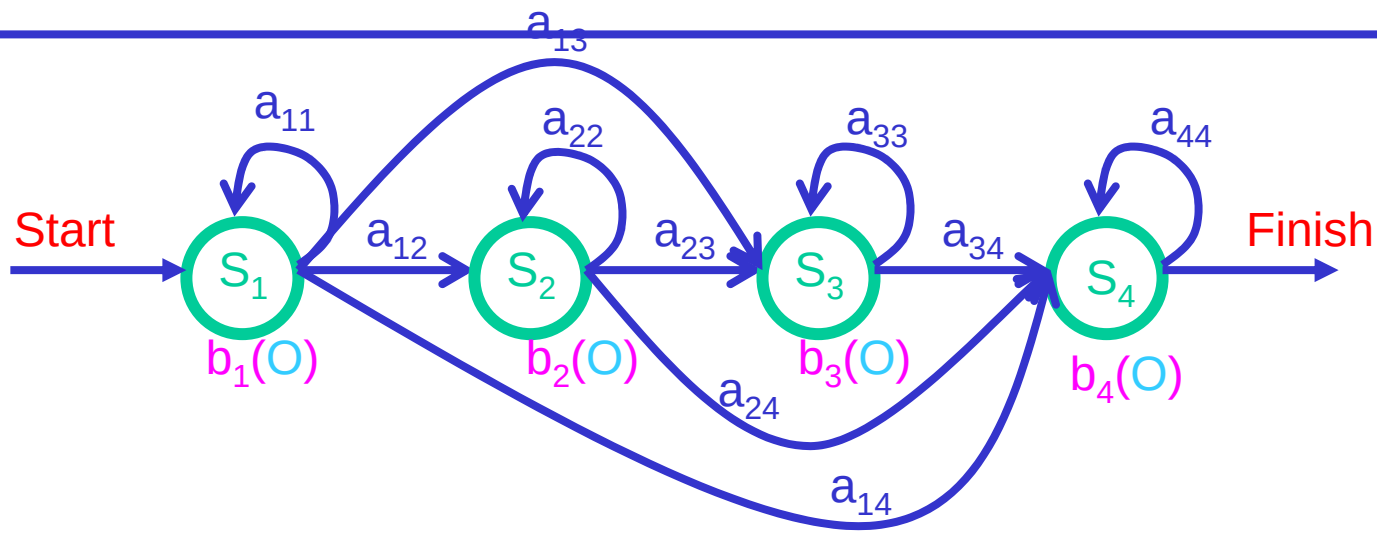
Algorithms & Processing



Algorithms & Processing Steps

- Sample data – convert to digital numbers, conversion works at 2000 up to 32,000 samples per second per channel.
- Filter – remove 60 Hz. noise
- Transform – for example calculate moving averages of absolute values
- Recognize Patterns – similar to speech recognition, we use Hidden Markov Models

Hidden Markov Models



a_{ij} $P(q_{t+1}=S_j|q_t=S_i)$ transition probability from state i to state j

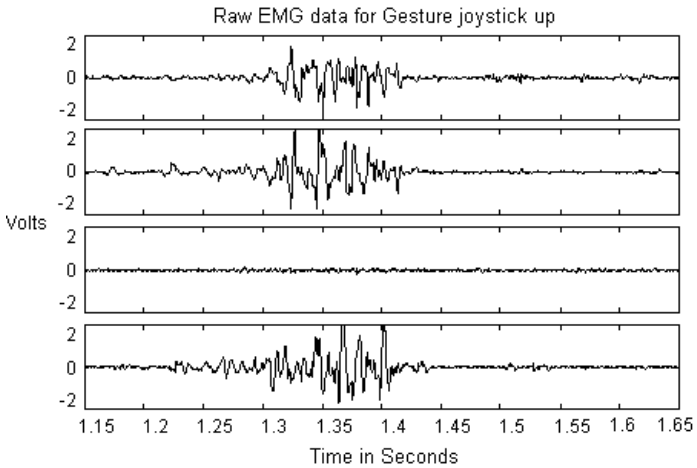
$b_j(O) = P(O|q_t=S_j)$ probability of observation when in state j at time t

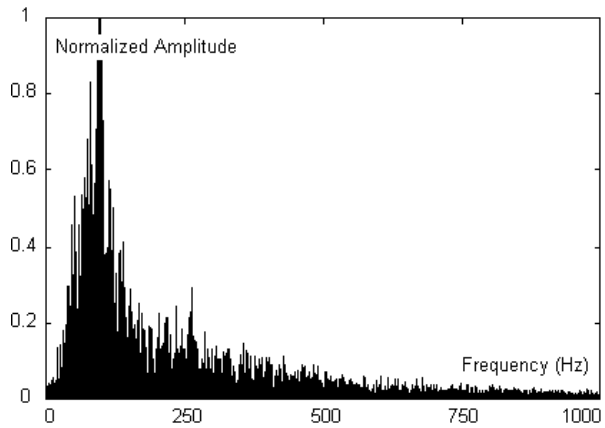
S_j State j,

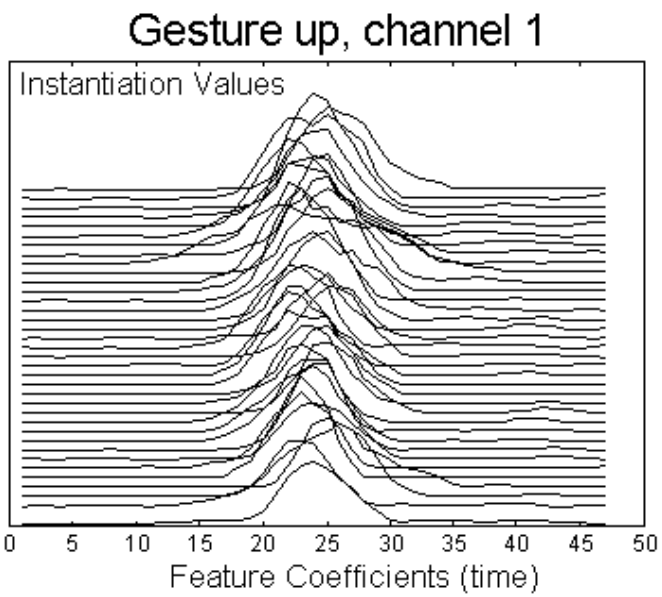
π_j probability of state j

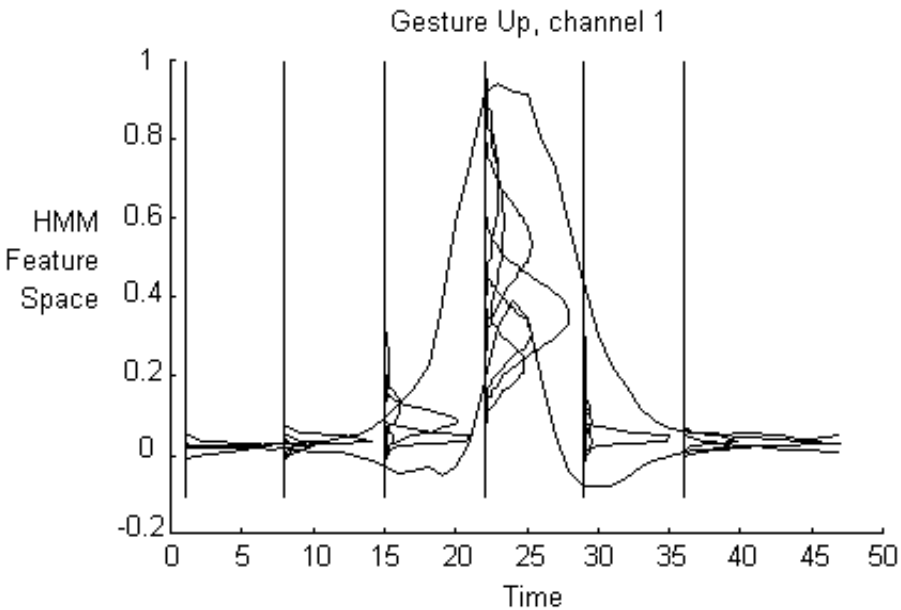
$$b_j(O) = \sum_{m=1}^{M} c_{jm} \mathcal{N}[O, \mu_{jm}, \Sigma_{jm}] , \quad \text{mixture model}$$

Feature Classification









Hidden Markov Model Overview

Initialization - The initial state probability densities are formed with variance based state partitioning with per state clustering.

Input - Overlapping moving averages of the absolute values of the signals are fed in.

Training - Standard Baum-Welch training of HMMs is employed.

Recall - Viterbi based recall is used with HMMs.

Real-time Recall - Uses multiple identical recognitions in a row.

Accomplishments

- Definition – What is Neuro-electric machine control?
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- Approach
- Accomplishments - Movie
- Educational requirements
- What's next?

Summer student Accomplishments

Summer 2004

Mindy Chang – *MIT* – Developed Bayesian model & decomposition software for separating EMG Motor unit action potentials.

Jack Culpepper – *U.C. Davis* – Developed EMG based finger tapping algorithms and real-time interface system.

Charles Curry – *U.C. Santa Cruz* – Developed transfer entropy analysis software for causality determination of Earth science ocean temperature oscillations identification.

Milovan Krnjajic – *U.C. Santa Cruz* – Developed non-parametric Bayesian mixture modeling techniques and software for satellite imagery variable selection.

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Educational Requirements

Depends upon your goals, we have all levels of engineers and scientists:

Title	Degree	Description
Computer programmer	B.S. or B.A.	Programs numerical & graphical applications in C, C++, FORTRAN, Matlab …
Scientific Staff	M.S.	Leads development efforts
Principal investigator	Ph.D.	Research, design, and develop innovative new capabilities & technologies.

Opportunities before & after graduation

Position	Requirements	Duties
High school internship	Currently in high school in good academic standing.	Usually in summer, work full-time supporting a research scientist.
College internship	Currently in a degree program at an accredited school in good academic standing.	Full-time summer, sometimes part-time during year. Work supporting a research scientist or group.
Post doctoral positions	Recent or expected Ph.D. and the advocacy of a NASA research scientist.	Usually involves independent investigation
Visiting Faculty	Current faculty position and the advocacy of a NASA research scientist.	Independent investigation

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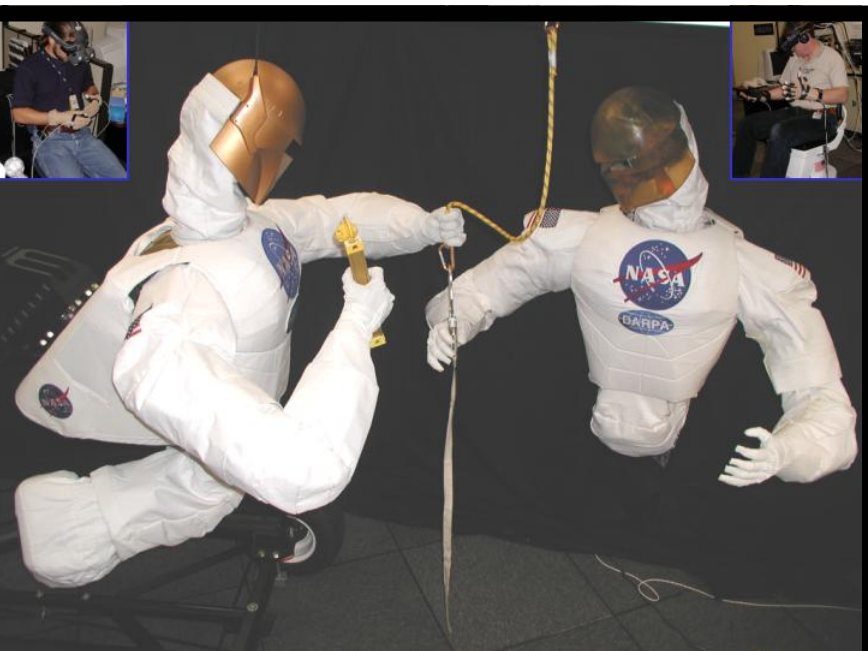
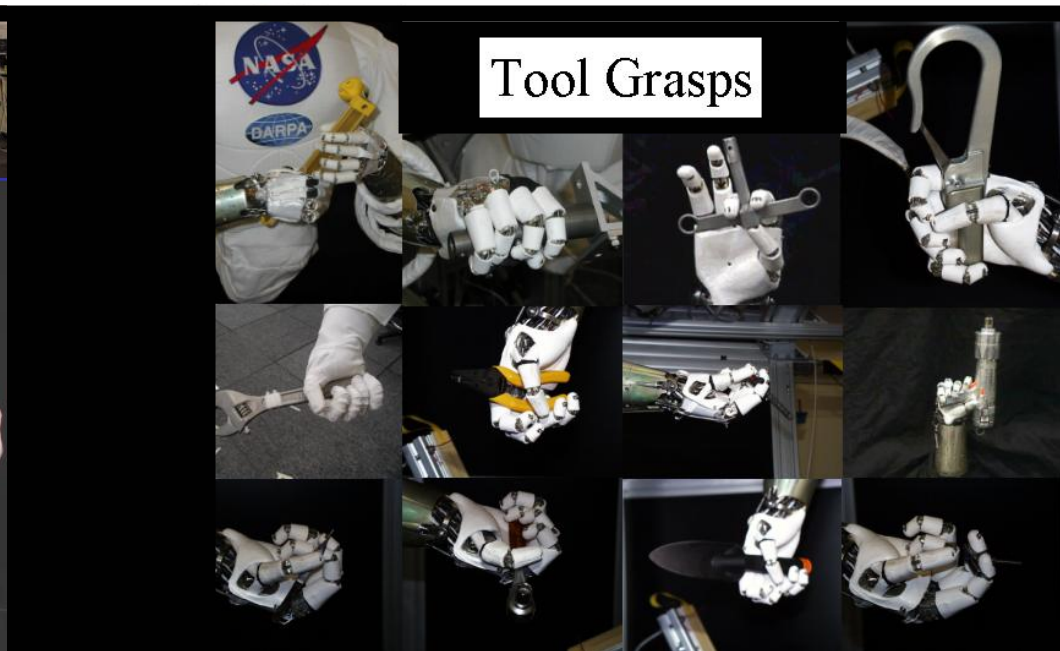
What's Next?

- Humanoid robot control – ROBONAUT (NASA JSC)
  autonomy & tele-operation
- Bayesian model formulation for decomposition



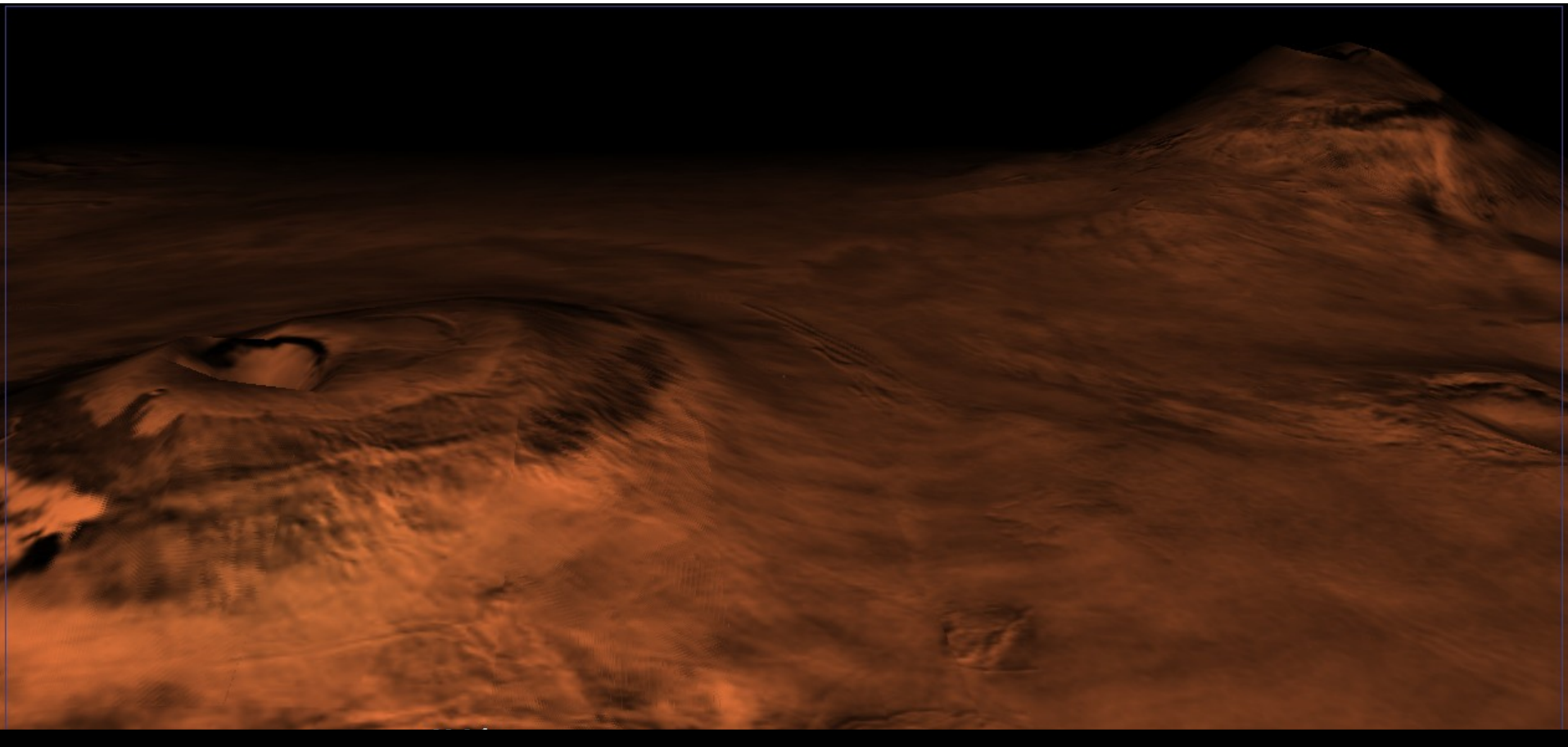


Information Sciences & Technology
Ames Research Center

What's Next?

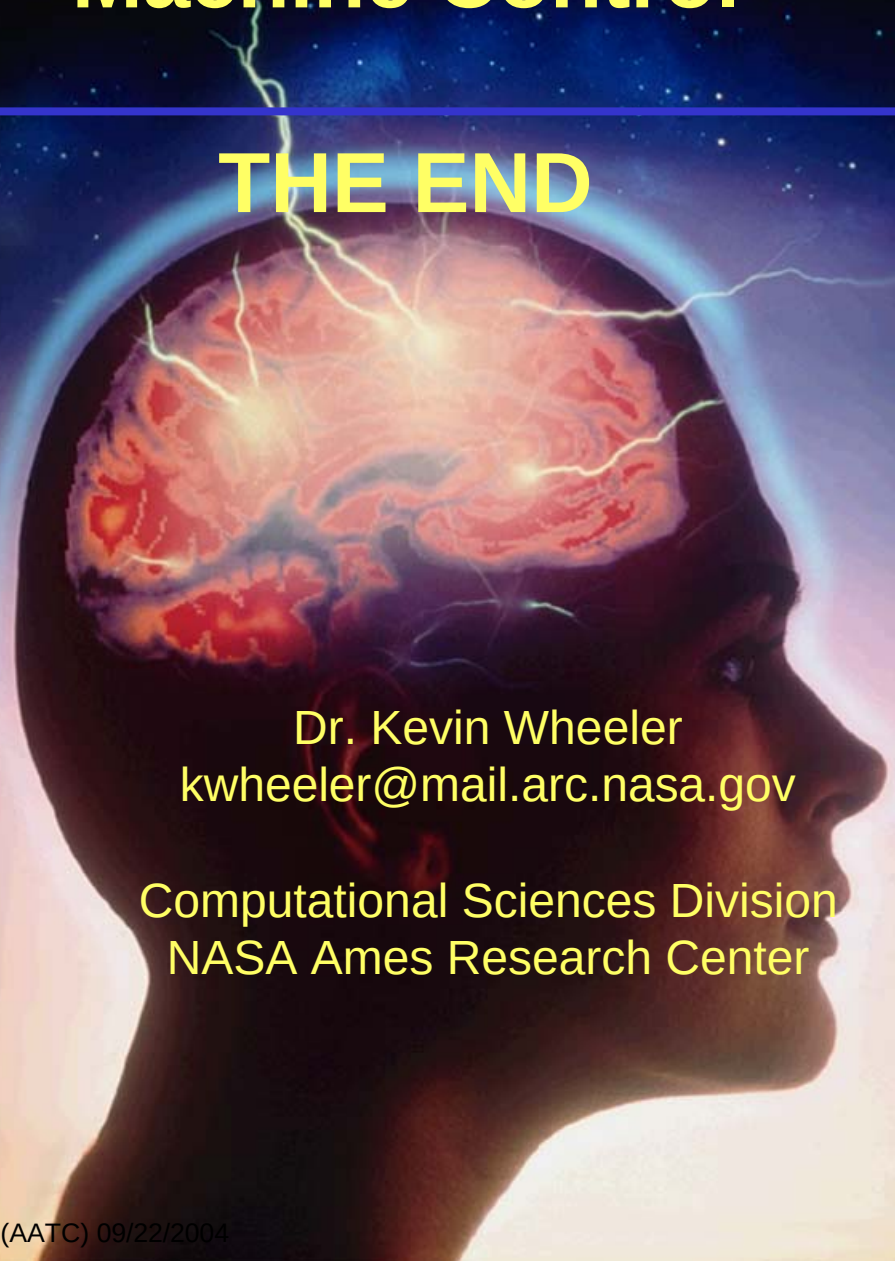
NASA

MARS & Beyond!



Neuro-Electric Machine Control

THE END



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