Brain-Computer Interfaces for 1-D and 2-D Cursor Control: Designs using Volitional Control of the EEG Spectrum or Steady-State Evoked Potentials

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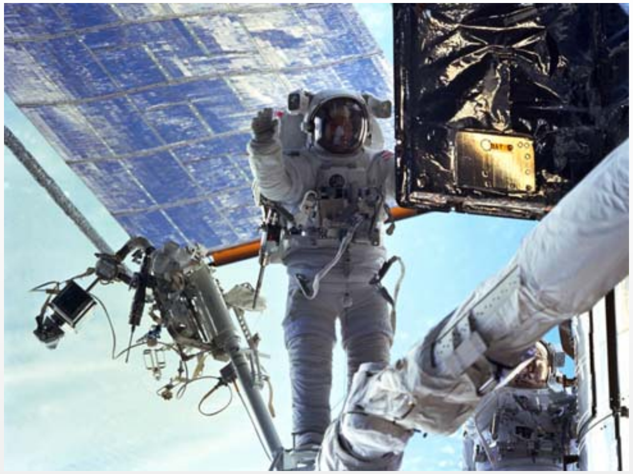
Context and Relevance to NASA Missions



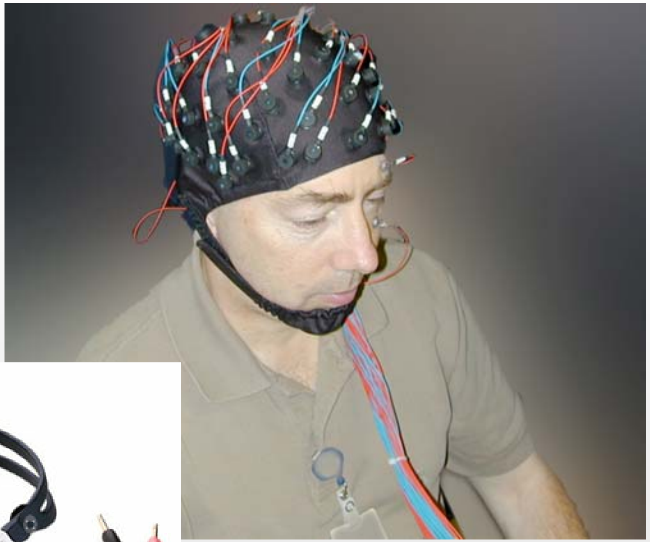
Problem

- Increasing mental and physical demands in long-duration human exploration
- Adverse and restricted environments, risk of fatigue, exhaustion, overload

Goals

- New interfaces for mobile or restricted environments
- Augmented interaction in normal environments
- Increased bandwidth / multi-tasking
- Quickening the interface
- Enhanced situational awareness
- Increased mission safety and reliability by early detection of adverse states and adaptive automation

Context and Relevance to NASA Missions

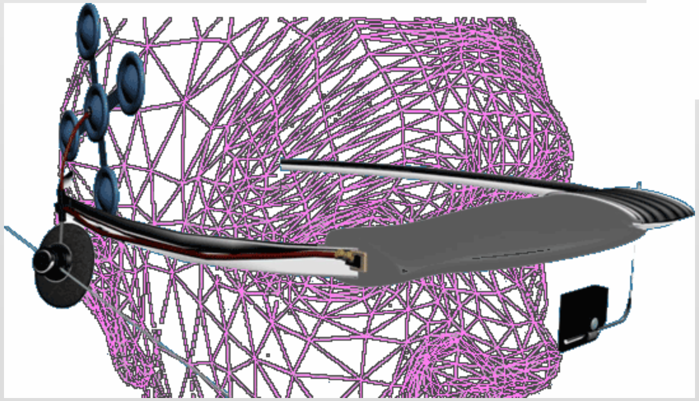


Projects

- Voluntary control of EEG (mu-rhythm) for cursor control
- SSVEP-based BCI for hands-free control of displays (moving maps)
- Mental state estimation

Recent Advances

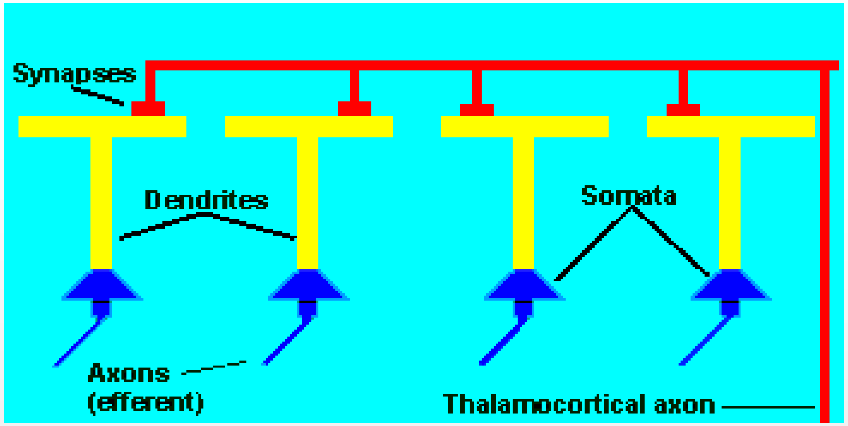
- Feature selection
- Classification algorithms
- On-line adaptation

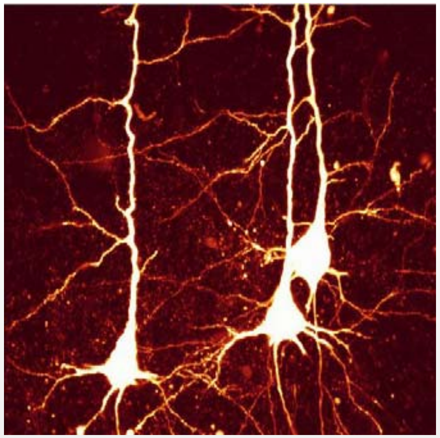


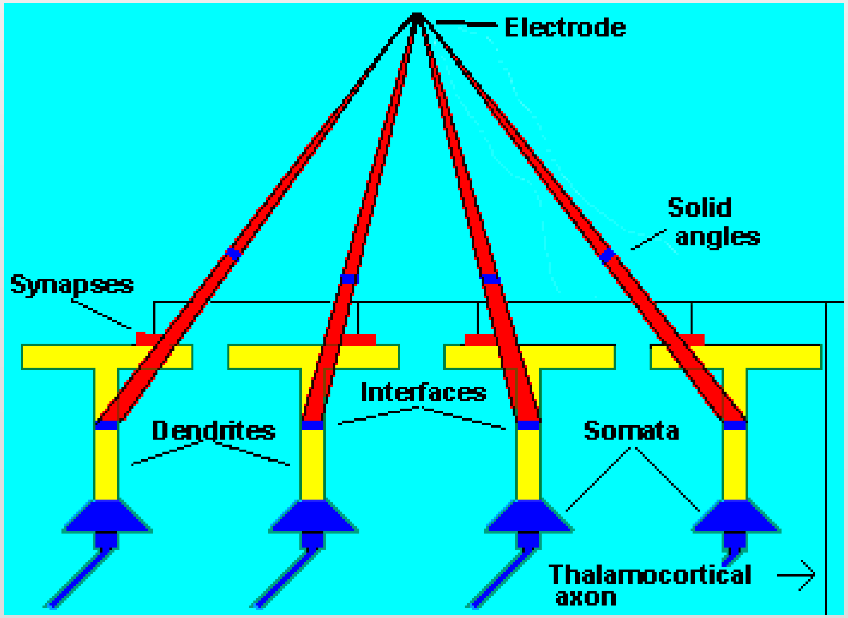
Challenges

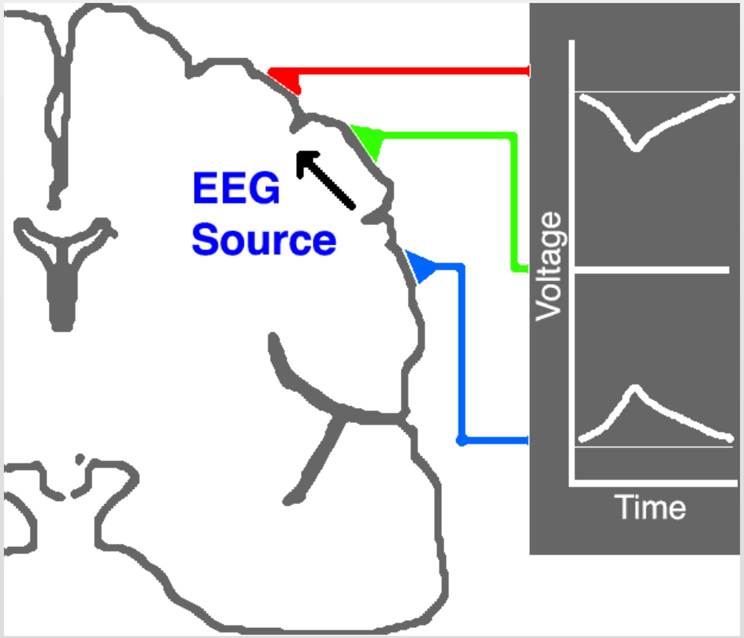
- Artifact removal
- Training methods
- Contactless sensors

Electroencephalography 101
Basis of EEG



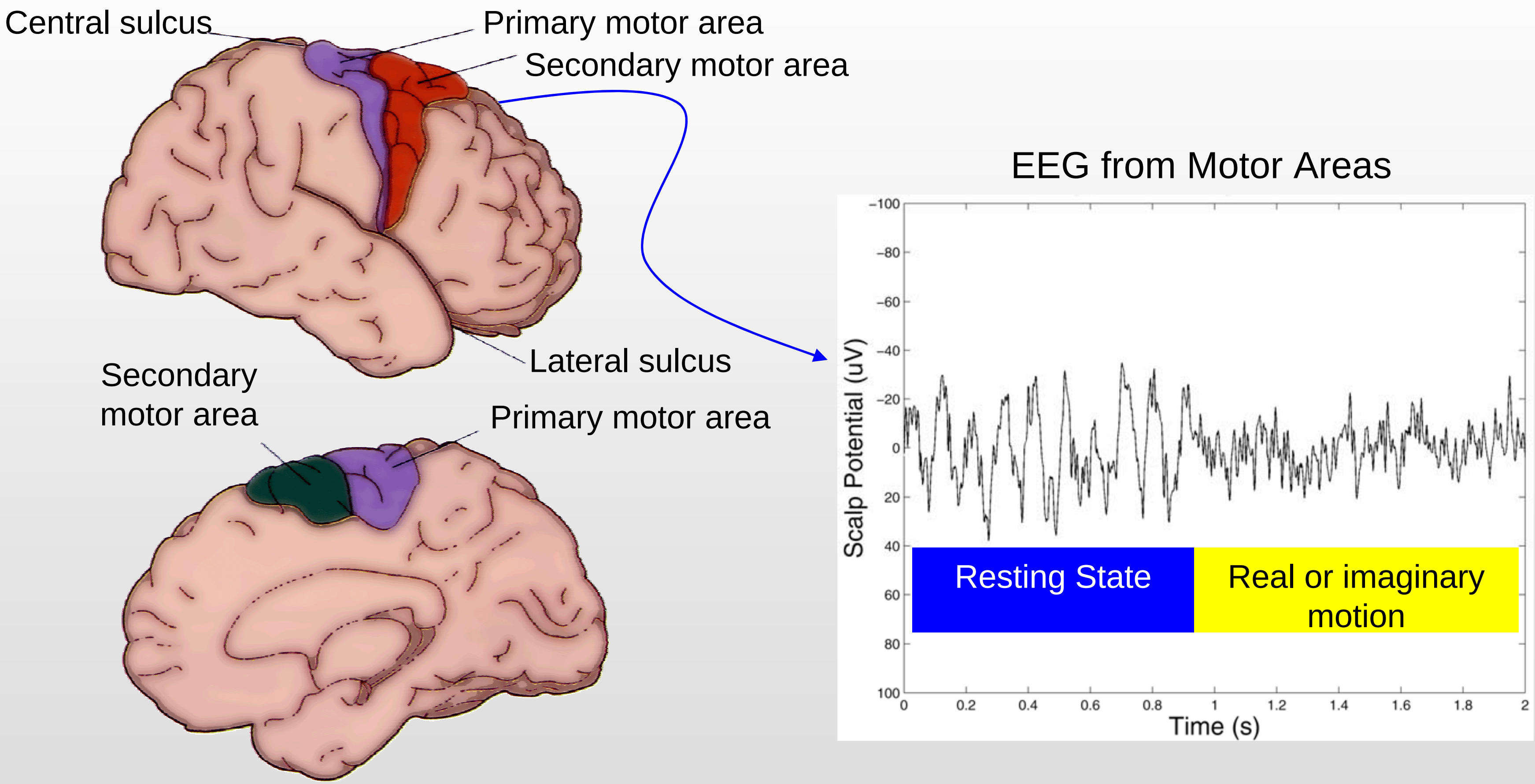






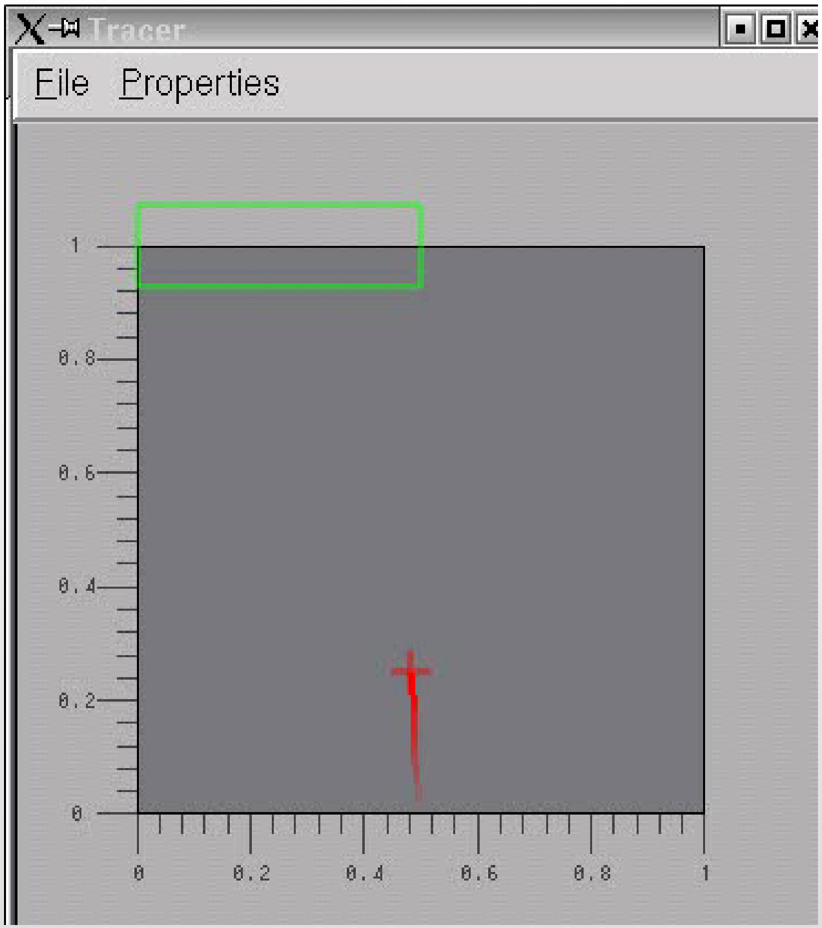
Biophysical Basis of Voluntary EEG Control

(Desynchronization of μ–rhythm)



(Adapted from Beatty, 1995)

Target Practice



PLS-based EEG Processing

- We regard the power spectral density of single EEG epochs of C channels and F spectral lines as a vector $\mathbf{x}$ (M), with M = C × F dimensions.
- Each $\mathbf{x_i}$ $(i = 1, 2, \ldots, n)$ is a row vector of a matrix of explanatory variables, $\mathbf{X}$ $(n \times M)$, with M variables and n observations.
- The n observations are the power spectral densities or PSDs of single EEG epochs from two classes, (e.g., experimental conditions, alert/fatigued, etc.).

PLS-based EEG Processing

- We regard the class membership of each EEG epoch as a matrix **Y** (n × 1) in which Class 1 is assigned the value 1 and Class 2 is assigned the value -1.
- PLS models the relationship between the explanatory variables and class membership by decomposing **X** and **Y** into the form

$$\mathbf{X} = \mathbf{T}\mathbf{P}^{T} + \mathbf{F}$$
$$\mathbf{Y} = \mathbf{U}\mathbf{Q}^{T} + \mathbf{G}$$

- **T** and **U** are matrices of p extracted score vectors (components),
- **P** and **Q** are matrices of loadings
- **F** and the $(n \times M)$ matrix **G** are matrices of residuals.

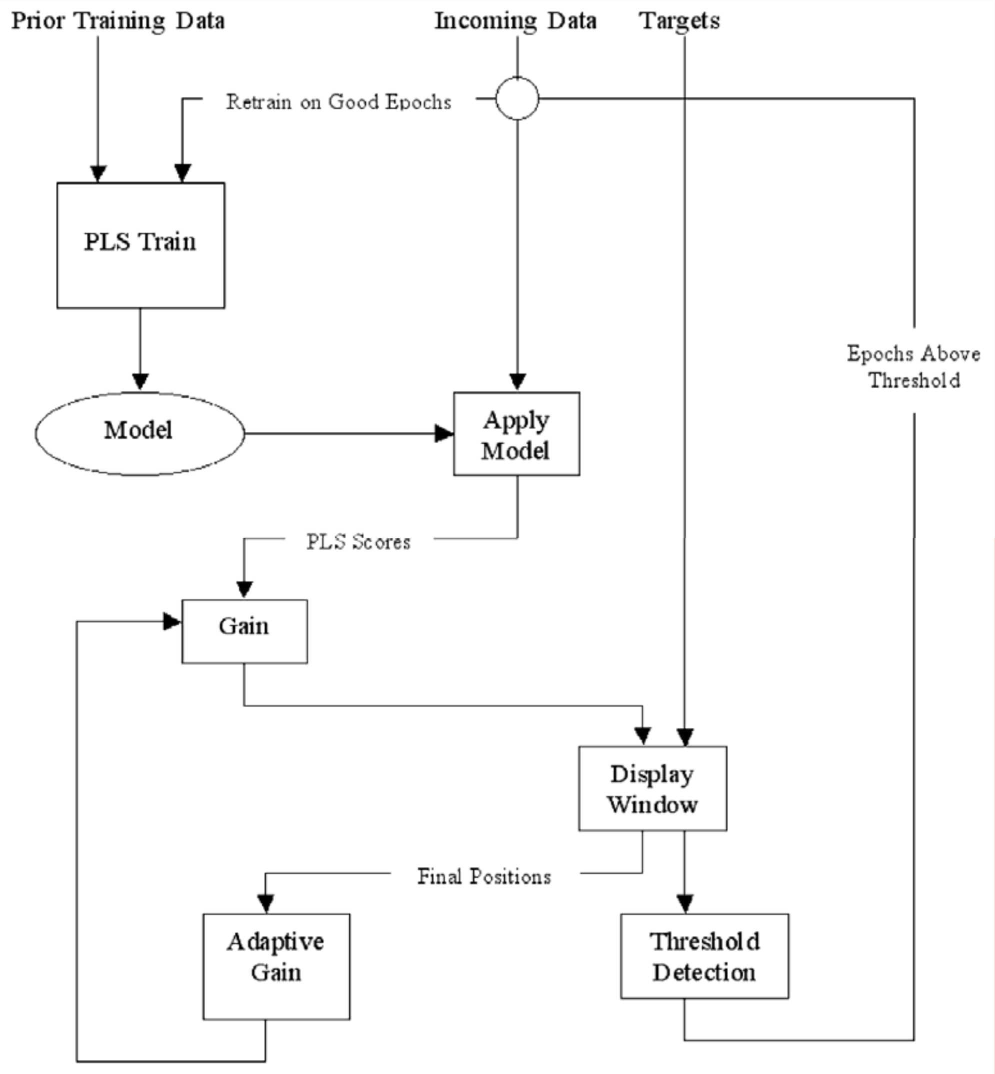
PLS-based EEG Processing

- PLS maximizes the covariance between the components of the explanatory variables and class membership.
- We use the nonlinear iterative partial least squares algorithm (NIPALS), which finds weight vectors **w, c** such that

$$max_{|r| = |s| = 1}[cov(\mathbf{Xr}, \mathbf{Ys})]^2 = [cov(\mathbf{Xw}, \mathbf{Yc})]^2 = [cov(\mathbf{t}, \mathbf{u})]^2$$

- $cov(\mathbf{t}, \mathbf{u}) = \mathbf{t}^T\mathbf{u}/n$ denotes the sample covariance between the score vectors **t** and **u.**
- Application of the weight vectors to normalized data produces component scores that serve as inputs to a classifier.
- We have tested both discretized linear regression (DLR) and support vector classifiers (SVC).

On-line PLS EEG Processor

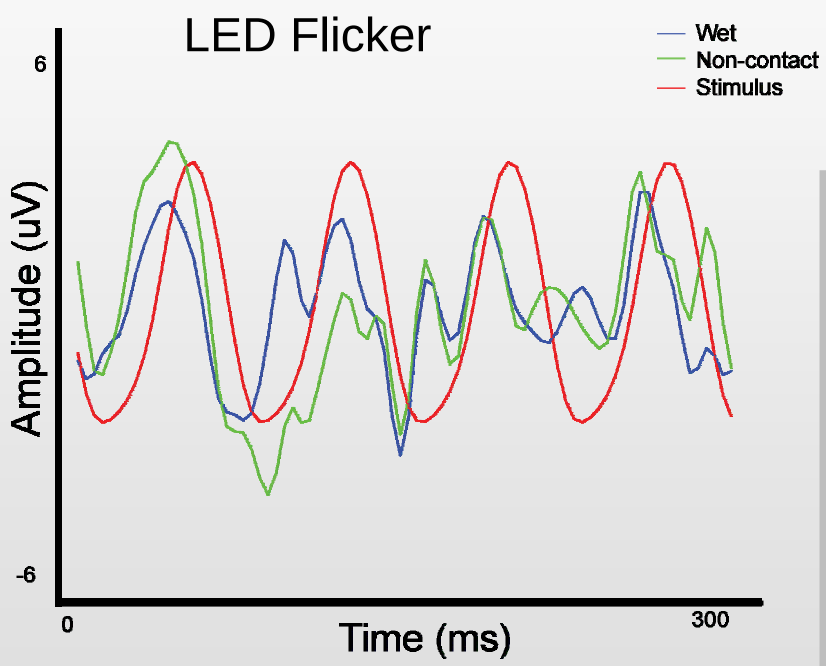


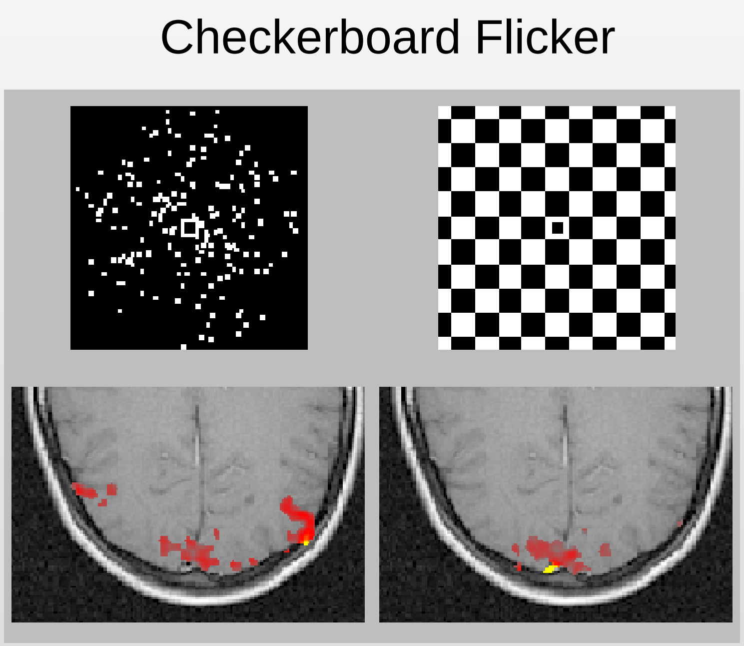
Control System for Target Practice

- Trial-by-trial classification (left, right)
  - 250 ms display update
- Dual adaptive controller design
  - Adaptive PLS pattern recognition
  - Adaptive gain control for motion

Biophysical Basis of Steady-State VEP

Repetitive patterned visual stimulation produces a frequency-following (or doubling) response in primary visual cortex, which is easily recorded by occipital EEG electrodes.

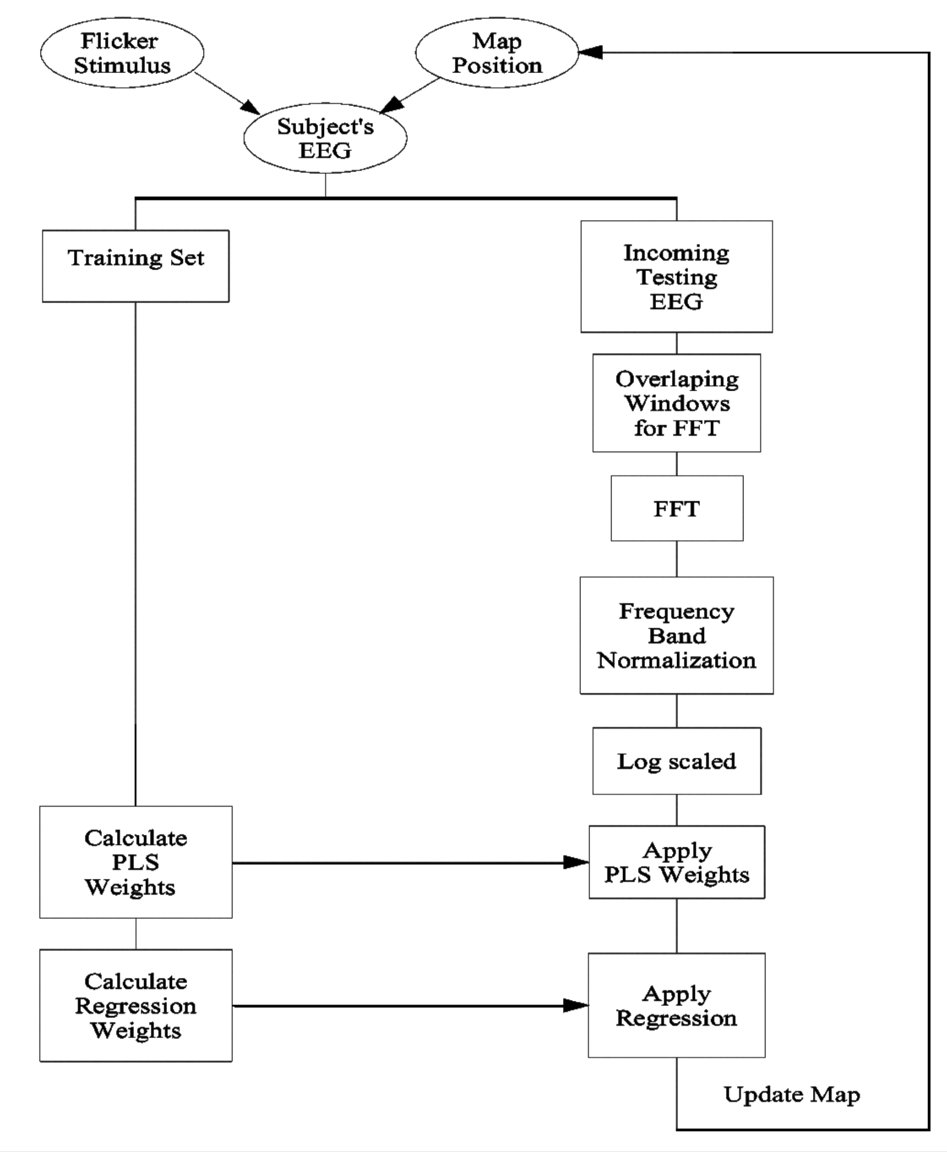




Demo from David Heeger's lab at NYU
http://www.cns.nyu.edu/~david/fmri-demos/V1MTmovie.mpg

SSVEP-based BCI

On-line PLS EEG Processor



Summary and Conclusion

Successful demonstrations of 1-D and 2-D control

- Voluntary control of EEG
- SSVEP based BCI
- On-line adaptive feature extraction/classification

Future applications

- Telerobotics
- Virtual or restricted environments
- Restricted environments
- Disabled personnel