Force Control in a Brain-Machine Interface

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SUNY DOWNSTATE Medical Center

~~Force~~ Hybrid (torque+position) Control in a Brain-Machine Interface using ipsilateral M1

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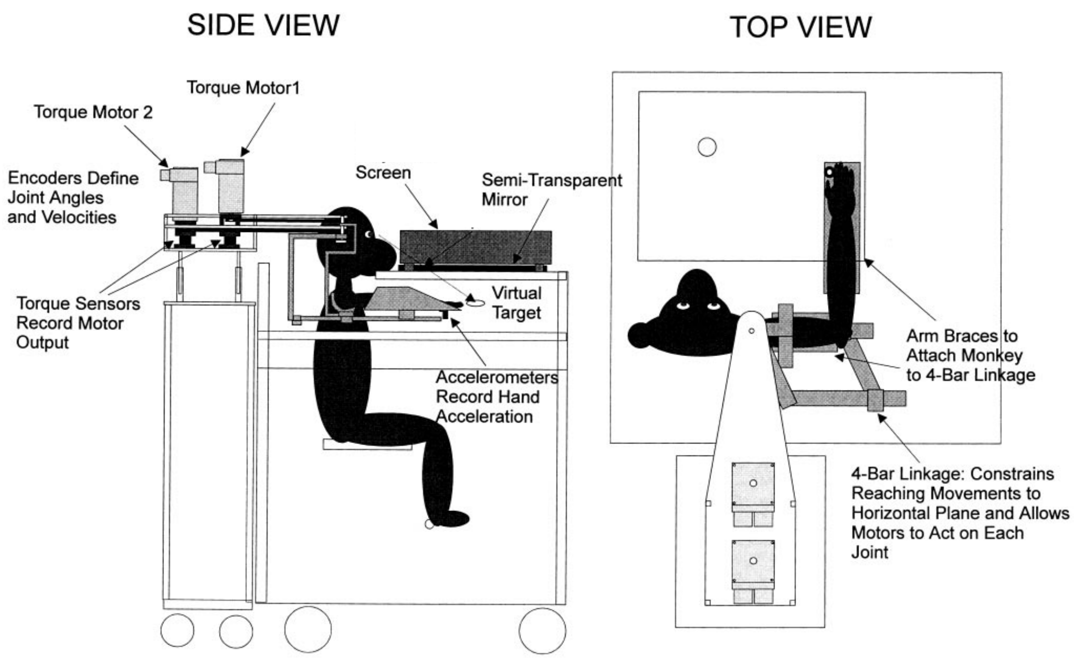
Outline

- Why force/torque
- Experimental setup and cortical implants
- Hybrid torque+position BMI model and video
- Future directions

Why force/torque?

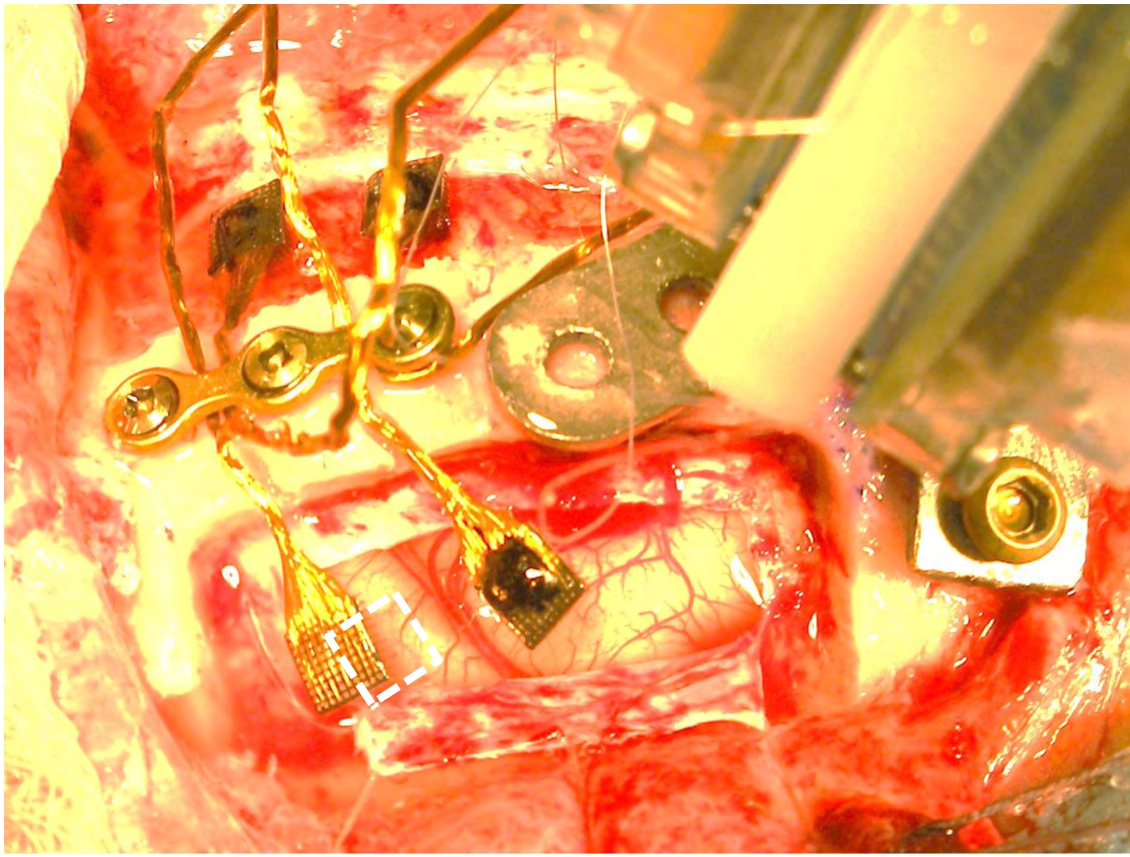
Experimental setup

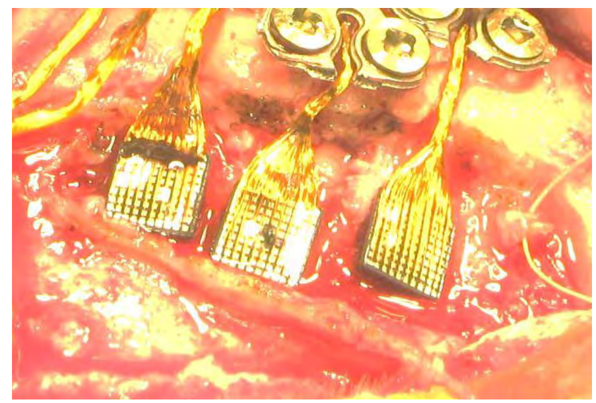


Scott, S. H. (1999). "Apparatus for measuring and perturbing shoulder and elbow joint positions and torques during reaching." J Neurosci Methods **89(2): 119-27.**

- Random target jumps
- Two angular velocity-dependent torque gain field environments
- Shoulder: 0.01 or 0.04 Nm/(rad/s)
- Elbow: 0.05 or 0.2 Nm/(rad/s)

Surgical implantation





Chhatbar, P. Y., L. M. von Kraus, et al. (2010). "A bio-friendly and economical technique for chronic implantation of multiple microelectrode arrays." J Neurosci Methods **188**(2): 187-94.

- using ipsilateral M1 recordings
  - The animal was implanted for the third time on contralateral M1
  - The recordings from contralateral M1 are poor with current implant

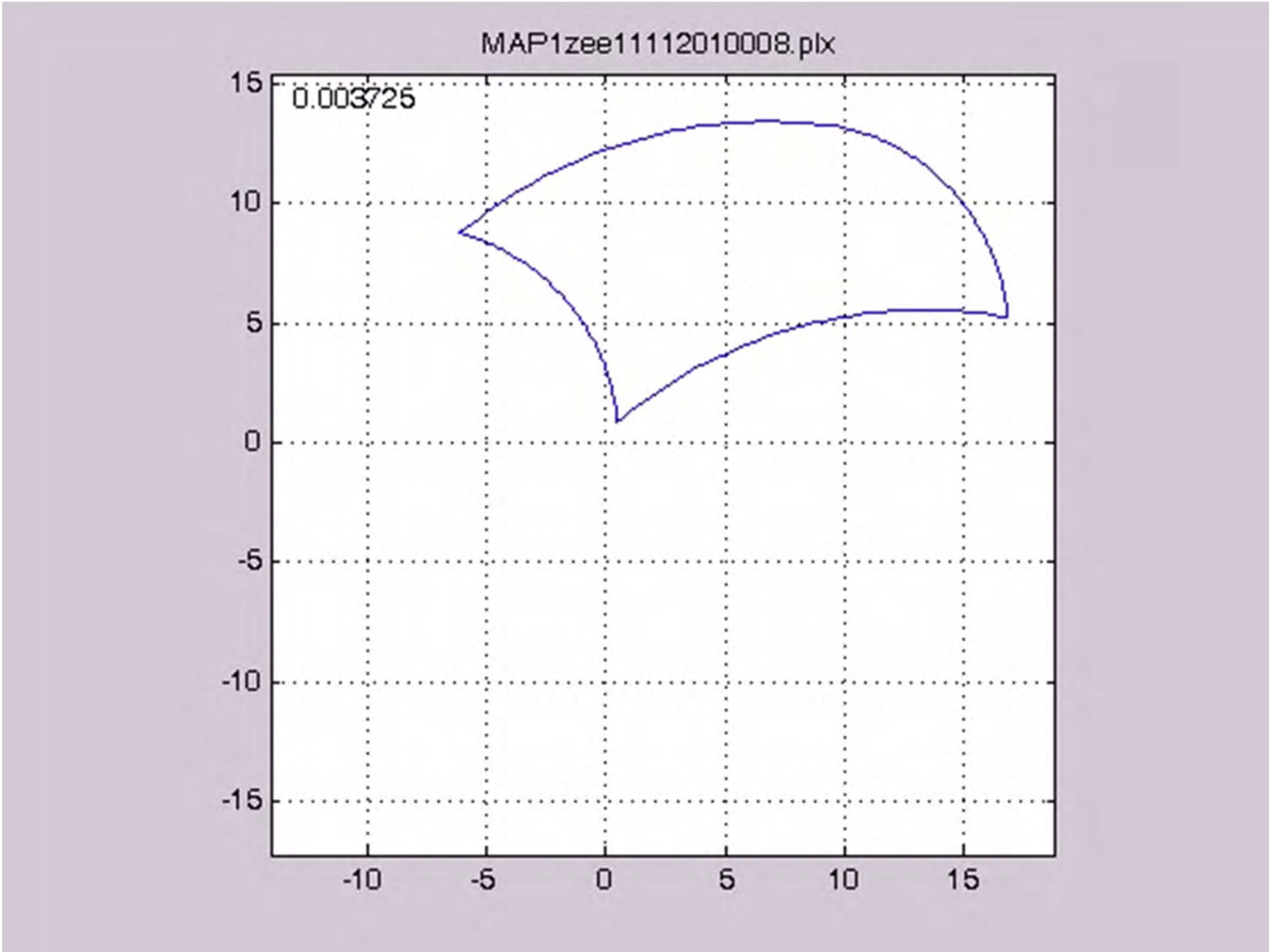
Hybrid (Torque+position) BMI

- Torques are derived from kinematics using inverse dynamics equations of the system
  - $\vec{\tau}$ = M(θ,$\dot{\theta}$,$\ddot{\theta}$) + C(θ,$\dot{\theta}$) + G(θ)
  - $\ddot{\theta} = (\vec{\tau} - C - G)/M$
- Calculation of weights
  - spiking neural activity from ~120-150 units of ipsi-lateral M1 is converted into principal component (PC) space
  - first 20 PCs are used for training (multiple linear regression from fresh manual task data) and predictions
  - 100 ms bins, 10 bins in past (neural activity of past 1 second)
- Predictions
  - both joint torque and joint position predictions are done and sent to the plant simultaneously (every 5-15 ms)
  - plant then calculates next position estimates based on given torque predictions and prior position values (every 1 ms)
  - $$\Theta_{plant}(t) = \Theta_{plant}(t-1) + (1-\alpha)\left(\iint\left(\frac{\hat{\vec{\tau}}(t) - C(t-1) - G(t-1)}{M(t-1)}\right)dtdt - \Theta_{plant}(t-1)\right) + \alpha(\widehat{\Theta}(t) - \Theta_{plant}(t-1))$$

    or put simply, $\Theta_{plant}(t) = (1-\alpha)\left(\widehat{\Theta_{tor}(t)}\right) + \alpha(\widehat{\Theta_{pos}(t)})$
  - α = 1e-5 (0.001%) worked best for us

Hybrid (Torque+position) BMI video

- Video Legend:
  - **Black** colored links with white end-point:
    - Monkey's real arm, under the screen
    - no visual feedback of end-point cursor
  - Cyan colored links:
    - Monkey's 'virtual' arm, based on ongoing BMI predictions
  - Diamond cursor:
    - Cyan when monkey is looking at workspace (using eye-tracking)
    - Yellow when monkey is looking away
    - Size of the cursor is proportional to viscous gain field strength
  - Blue target:
    - Turns green when 'virtual' arm hits it successfully
  - Workspace boundaries:
    - Applies to 'virtual' end-point


MAP1zee11112010008.plx
0.003725
15
10
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15

Future directions

- Effect of continued BMI training on performance
- Inclusion of eye-tracking information in BMI
- Inclusion of states (attentive, distracted etc.) in BMI

Thank You

- Lab members
  - Advisors
    - Dr. John Chapin
    - Dr. Joseph Francis
  - Colleagues
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    - Lee von Kraus
    - John Choi
    - Marcello DiStasio
    - Brandi Marsh
    - Jordan Iordanou
  - Post-docs / Past Graduates
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    - Dr. Lei Li
    - Dr. Anna Rozenboym
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    - Dr. Kwangtaek Kim
  - Support
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  - Dr. Subrata Saha
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  - Dr. Nandor Ludvig
  - Dr. Andre Fenton

Questions?

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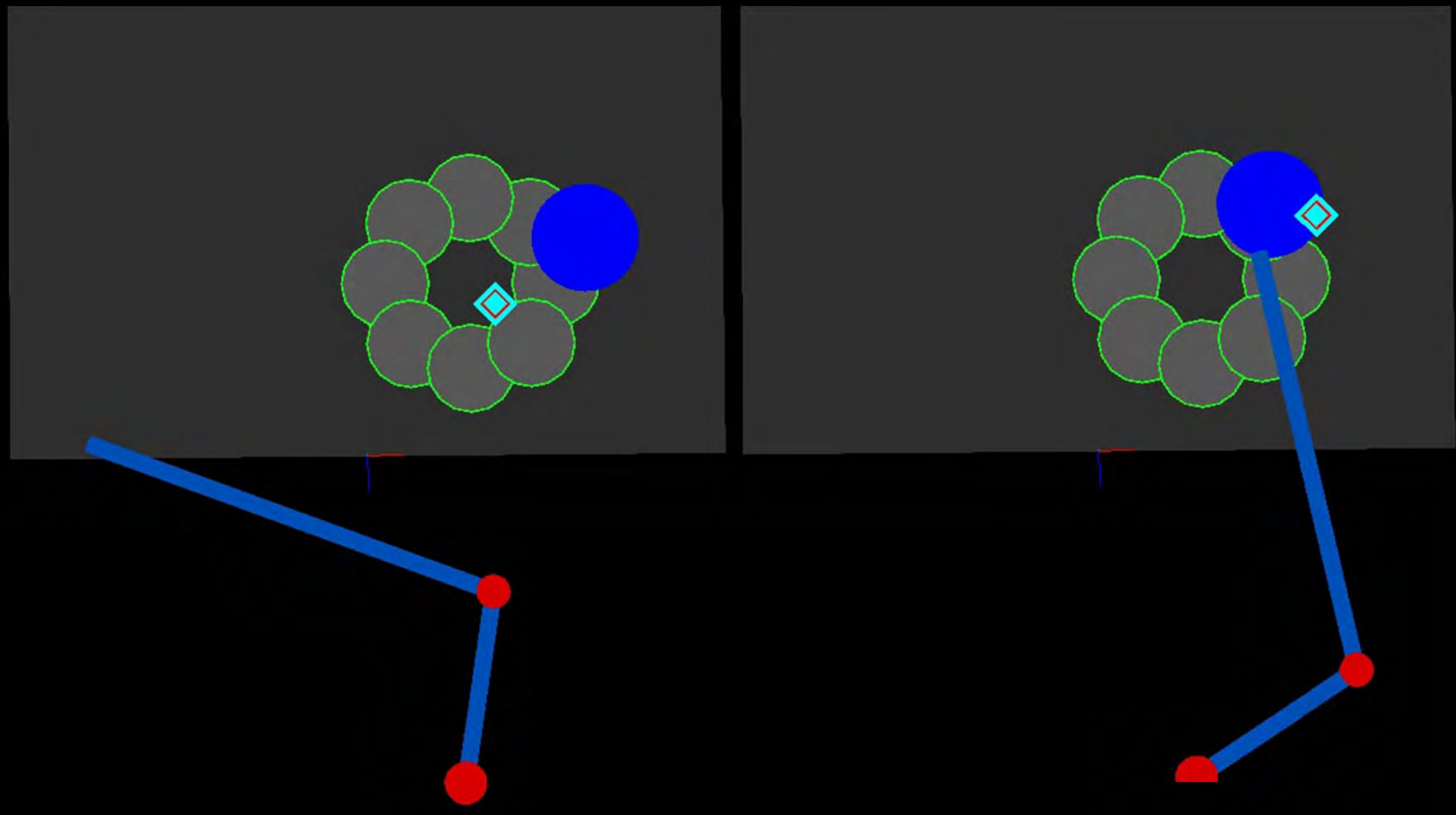
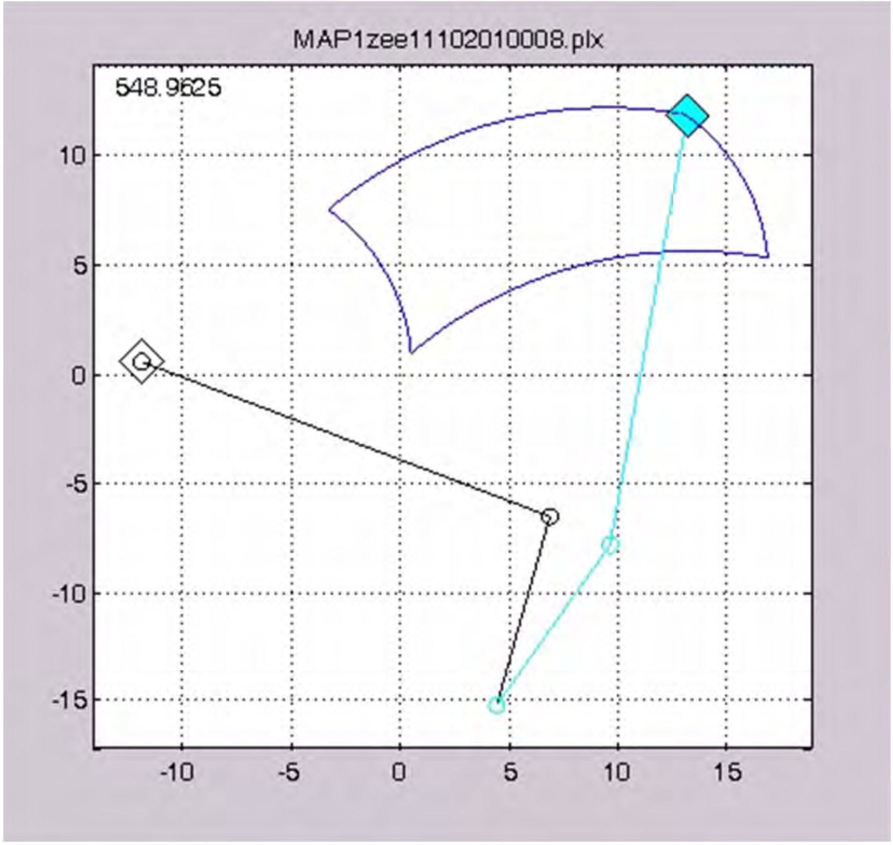
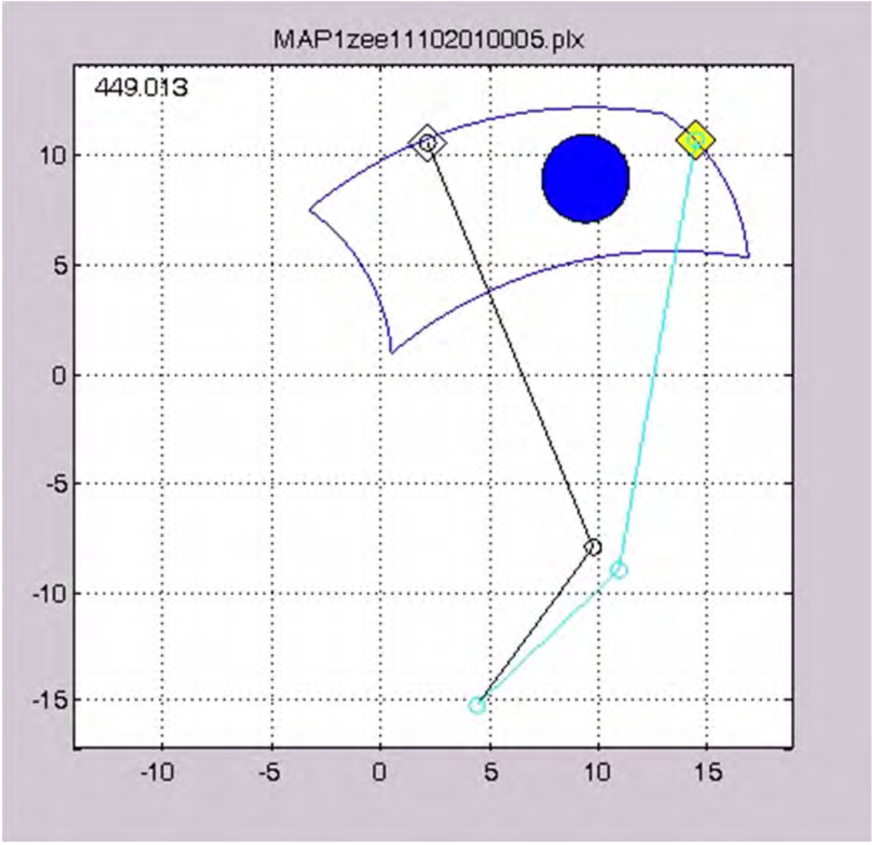
User Interface screen capture of BMI
(no BMI cursor color change based on attention; real arm visual feedback suppressed)
Left: arm pinned; Right: freely moving arm



Torque control only





Force-related parameters
and their relationship to kinematics

- **Torque** and force

  $\vec{\tau}$ = M(θ,$\dot{\theta}$,$\ddot{\theta}$) + C(θ,$\dot{\theta}$) + G(θ)

  $\vec{\tau}$ = $\vec{r}$ x $\vec{F}$

- Torque to acceleration

  $\ddot{\theta} = (\vec{\tau} - C - G)/M$

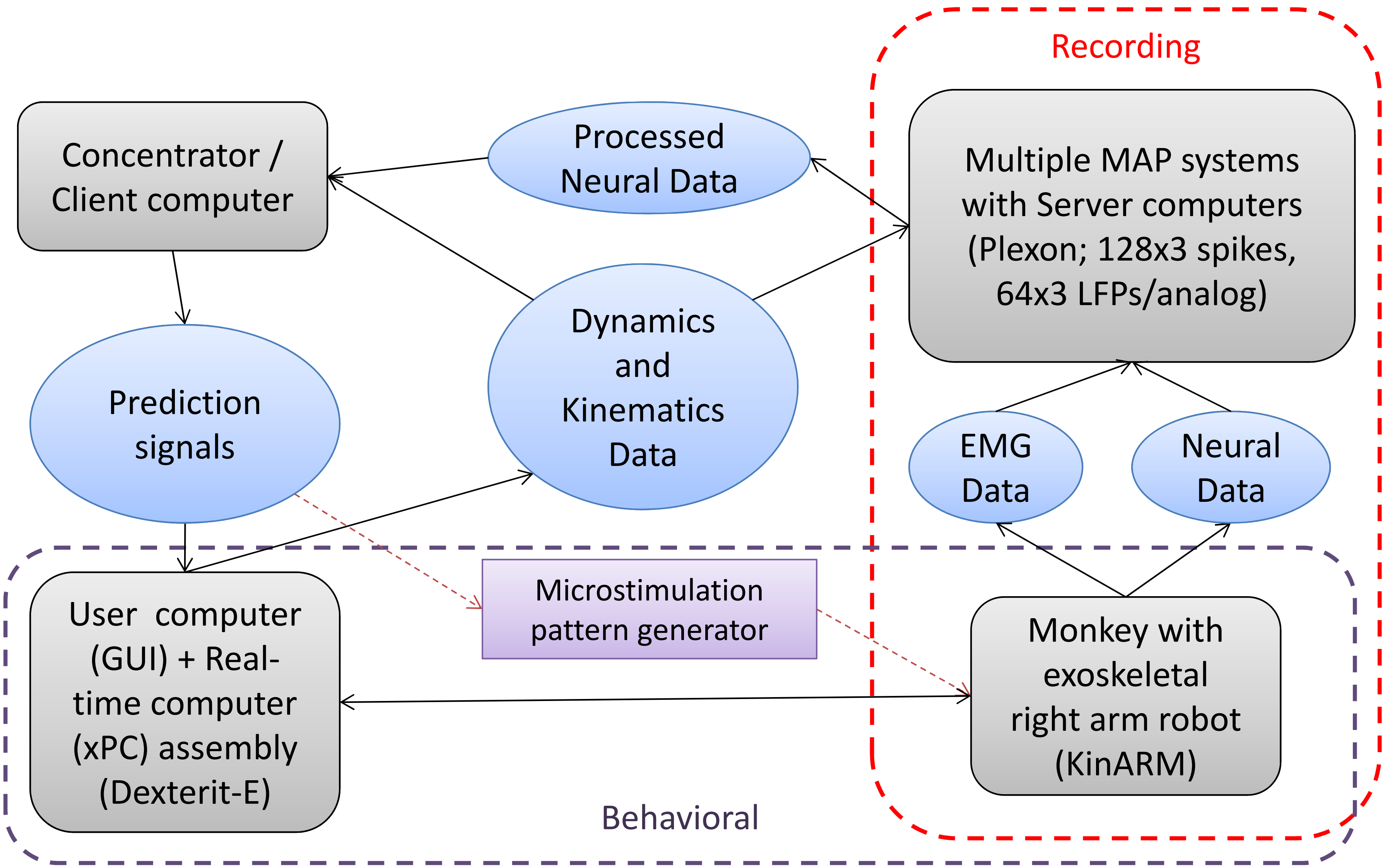
- Work

  W = $\vec{F} \cdot \vec{d}$ or $\vec{\tau} \cdot \theta$

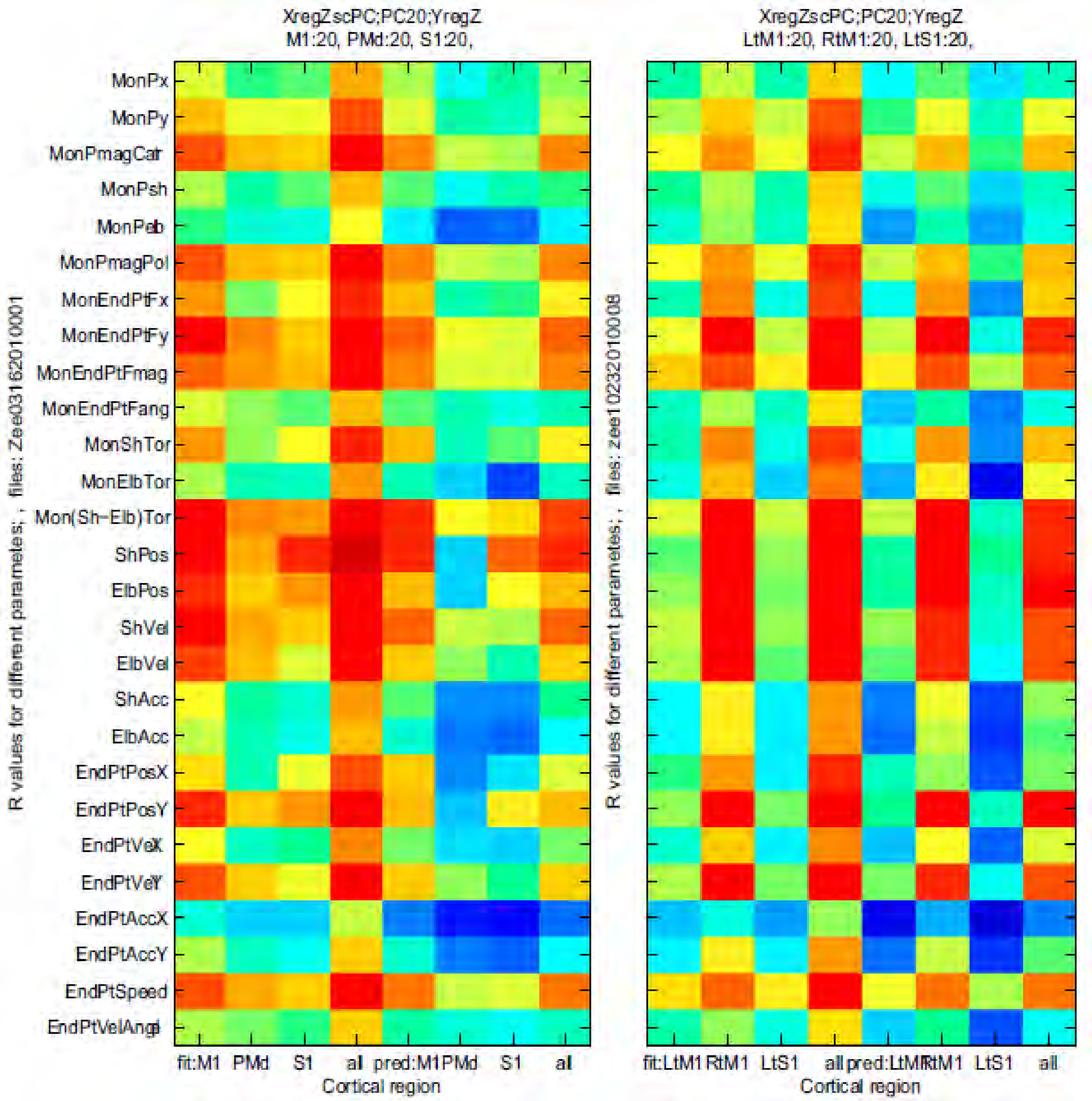
- Power

  P = W/t or $\vec{F} \cdot \vec{v}$ or $\vec{\tau} \cdot \dot{\theta}$

BMI Setup


Recording
Concentrator / Client computer
Processed Neural Data
Multiple MAP systems with Server computers (Plexon; 128x3 spikes, 64x3 LFPs/analog)
Dynamics and Kinematics Data
Prediction signals
EMG Data
Neural Data
Microstimulation pattern generator
User computer (GUI) + Real-time computer (xPC) assembly (Dexterit-E)
Monkey with exoskeletal right arm robot (KinARM)
Behavioral

Comparison of R-values



Predictions generalizability across different external dynamic environments