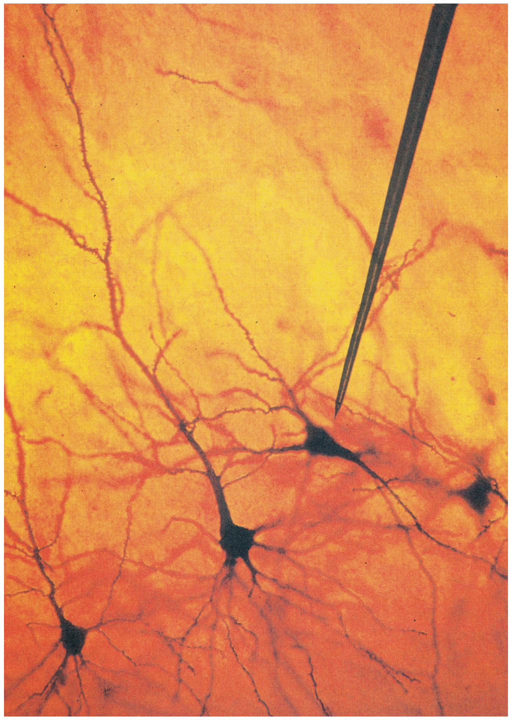
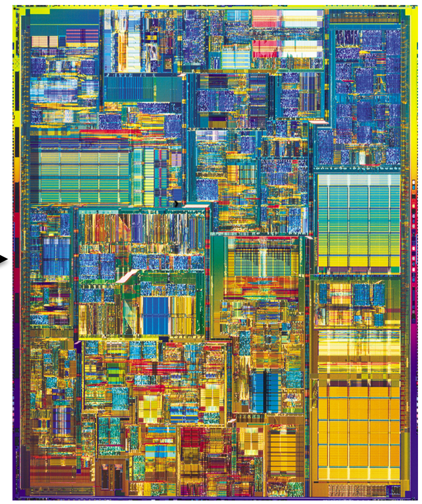
Brain-machine interfaces





Byron Yu

Assistant Professor

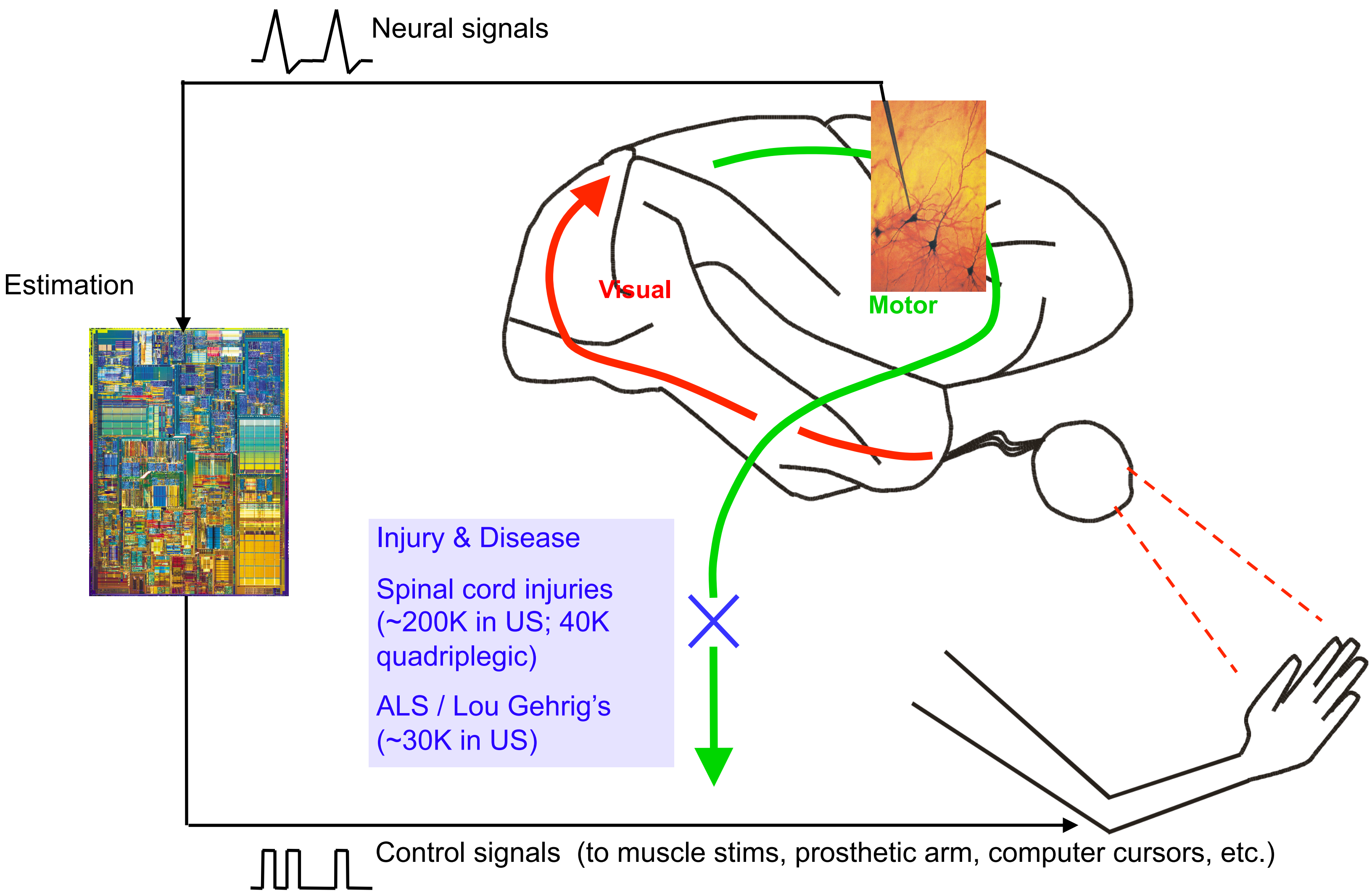
Electrical & Computer Engineering and Biomedical Engineering

Carnegie Mellon

Introduction

• Problem: Hundreds of thousands are unable to move or communicate due to injury/disease.

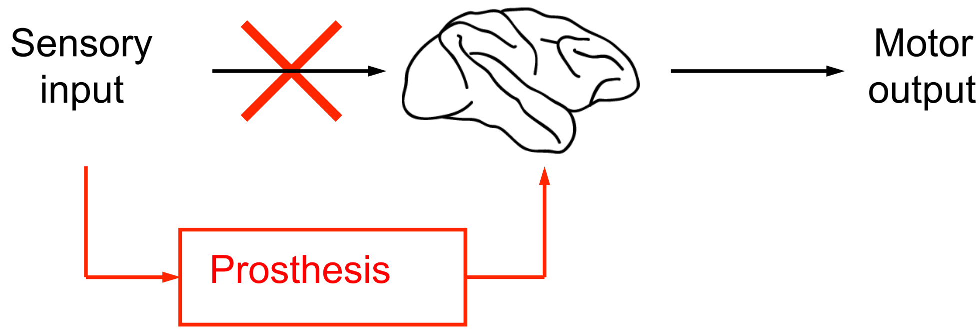
• Potential solution: Neural prostheses translate cortical signals into control signals.



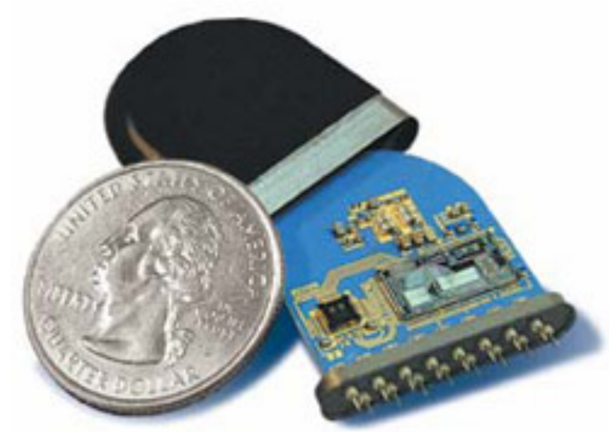
Brain-machine interfaces

Cyberkinetics, Inc.

Cochlear implants

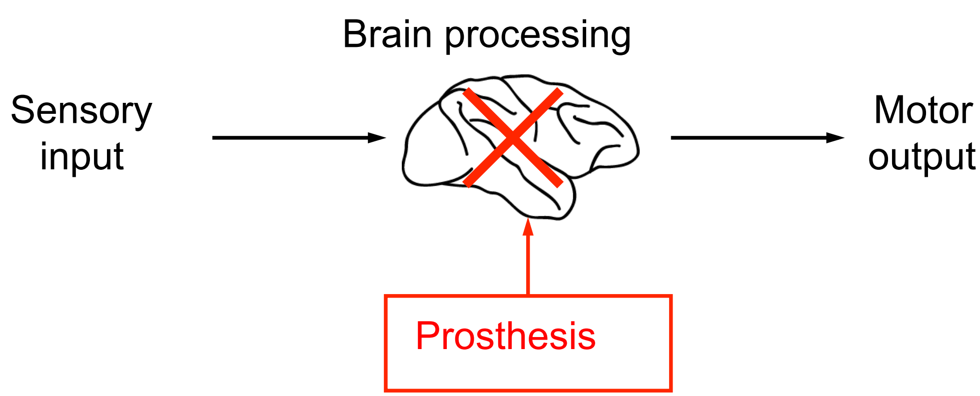


- Provides sense of hearing by stimulating auditory nerves
- ~150,000 patients worldwide have received cochlear implants



Advanced Bionics Corp.

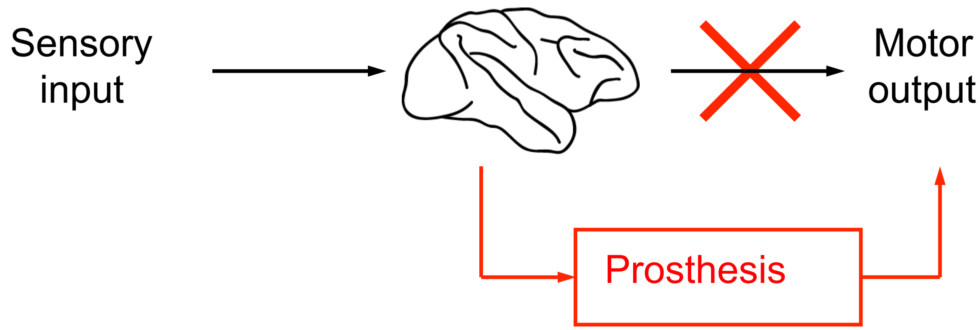
Deep brain stimulation (DBS)



- Alleviates symptoms of Parkinson’s disease by stimulating basal ganglia
- >55,000 patients worldwide have received DBS therapy

Medtronic, Inc.

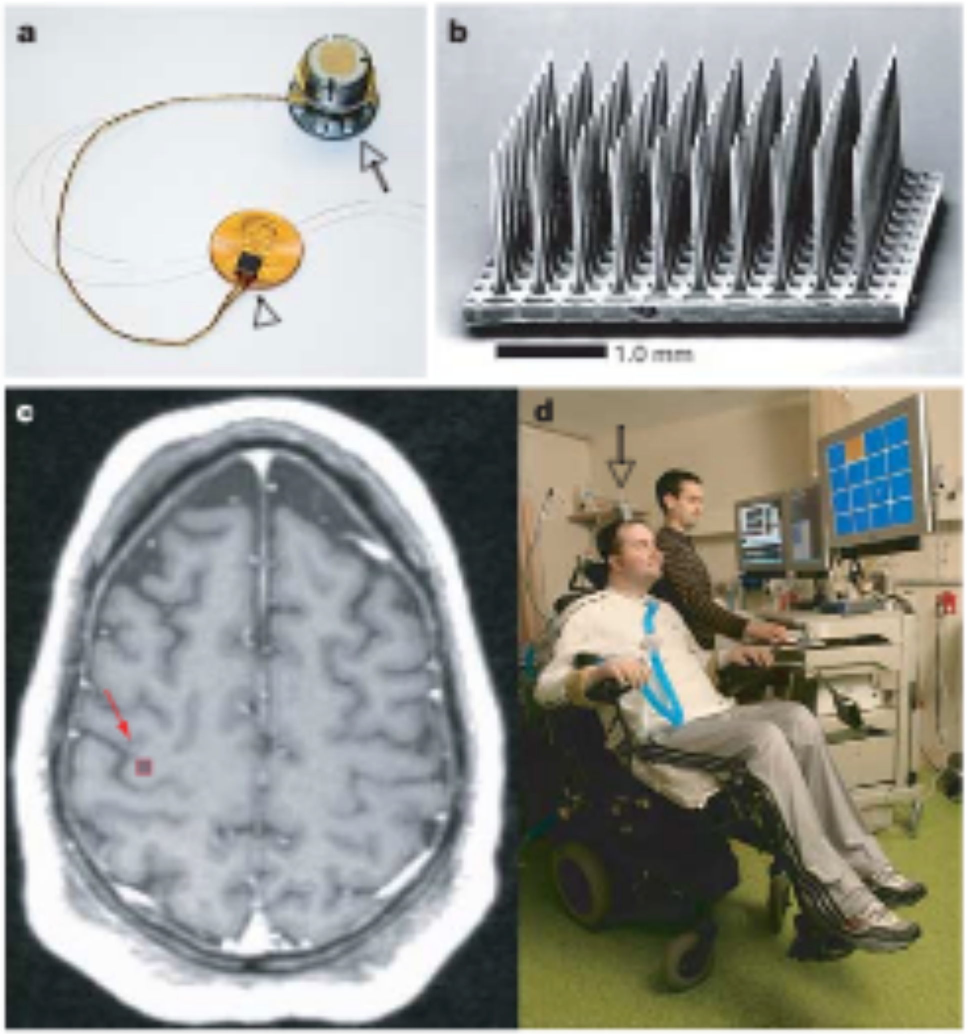
Motor prosthetics



- Allows paralyzed patients to control prosthetic limbs, computer icons
- In US, ~150k with spinal cord injuries,
  ~120k quadriplegic,
  ~30k with ALS / Lou Gehrig's

Cyberkinetics, Inc.

Brain-machine interfaces



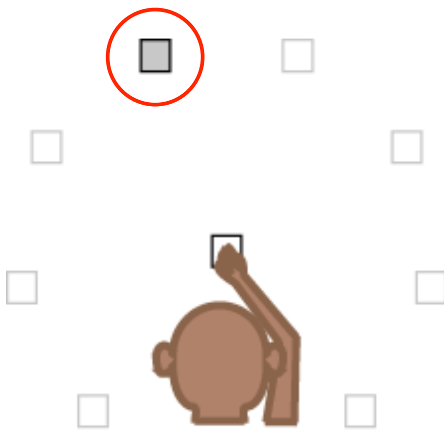
Hochberg et al., *Nature*, 2006.

Email	TV	Music
Lights		Wheel chair
Heater	Window	Food

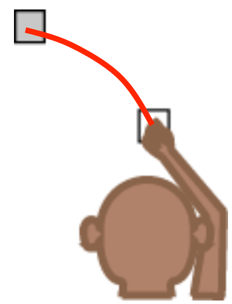
Patient's workspace

Two different control strategies

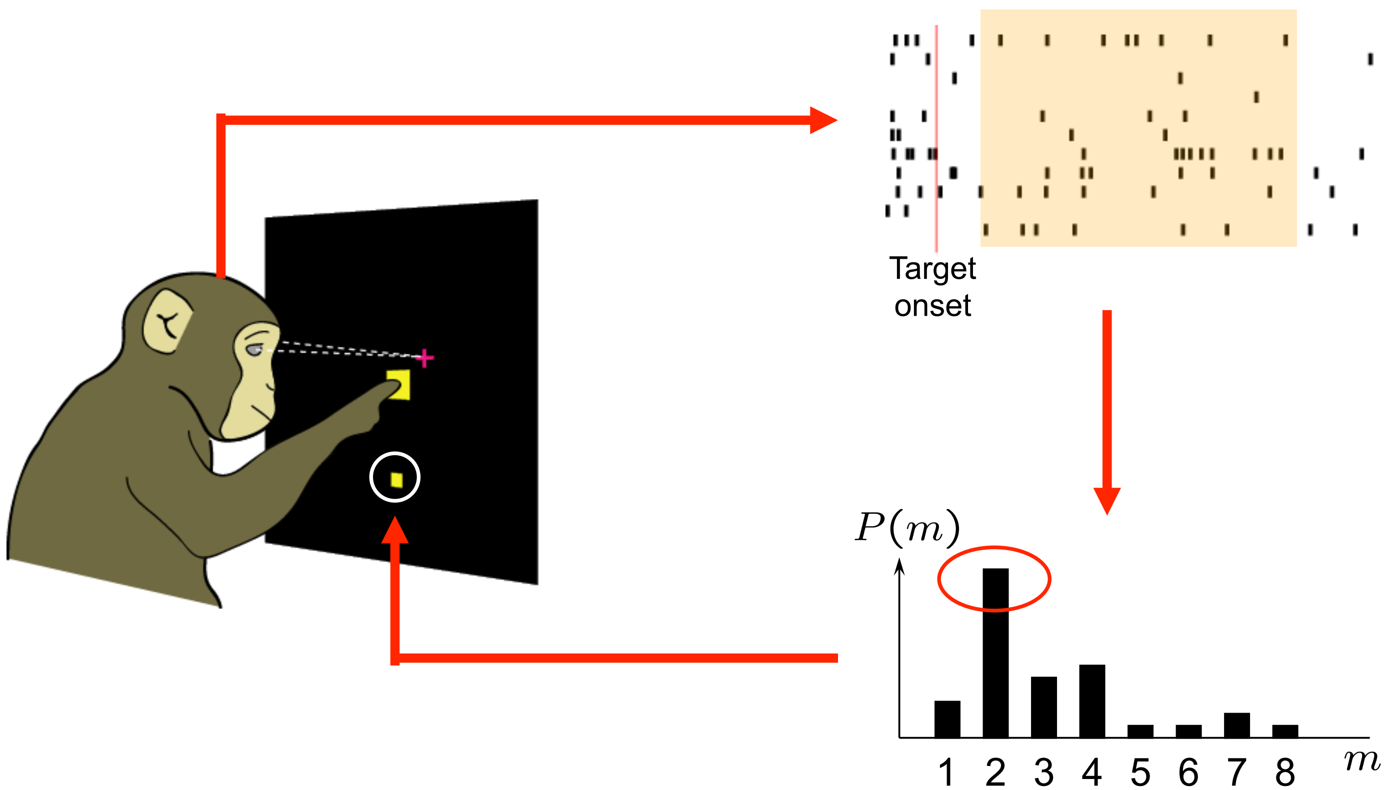
Discrete: decode reach goal location



Continuous: decode moment-by-moment arm trajectory



High-speed key selection device

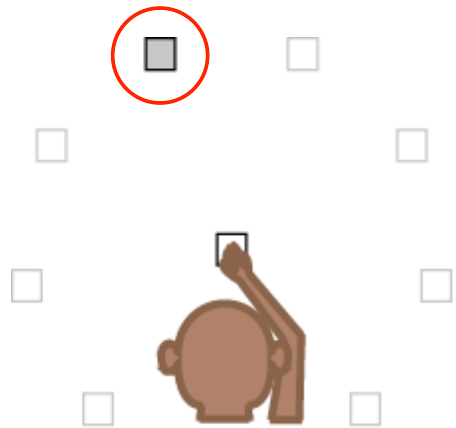


6.5 bits / sec, equivalent to typing ~15 words / min

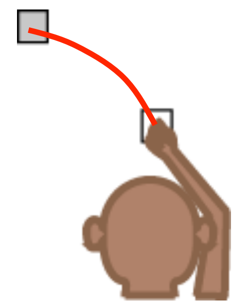
Santhanam, Ryu, Yu, Afshar, Shenoy. *Nature*, 2006.

Two different control strategies

Discrete: decode reach goal location



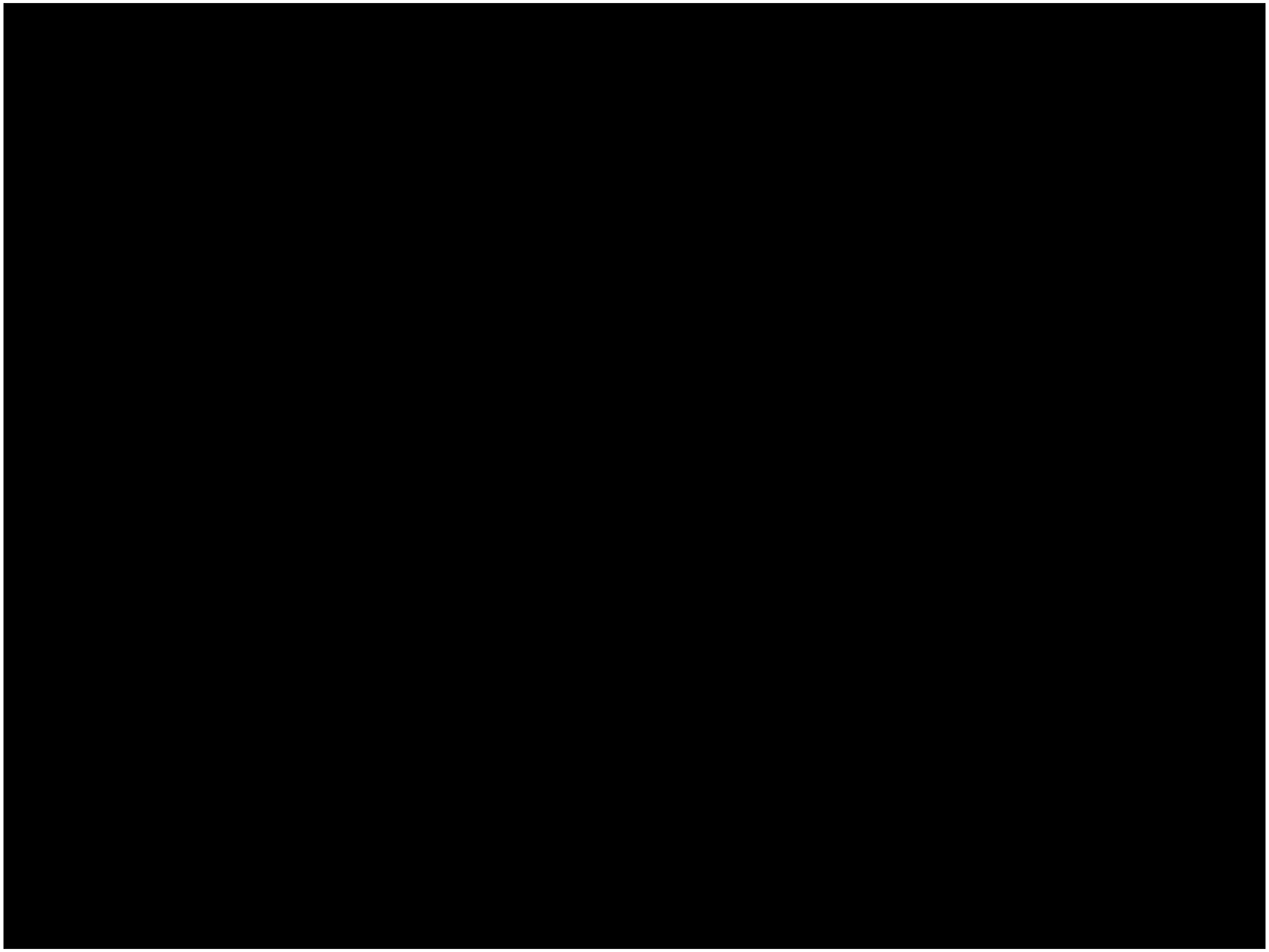
Continuous: decode moment-by-moment arm trajectory



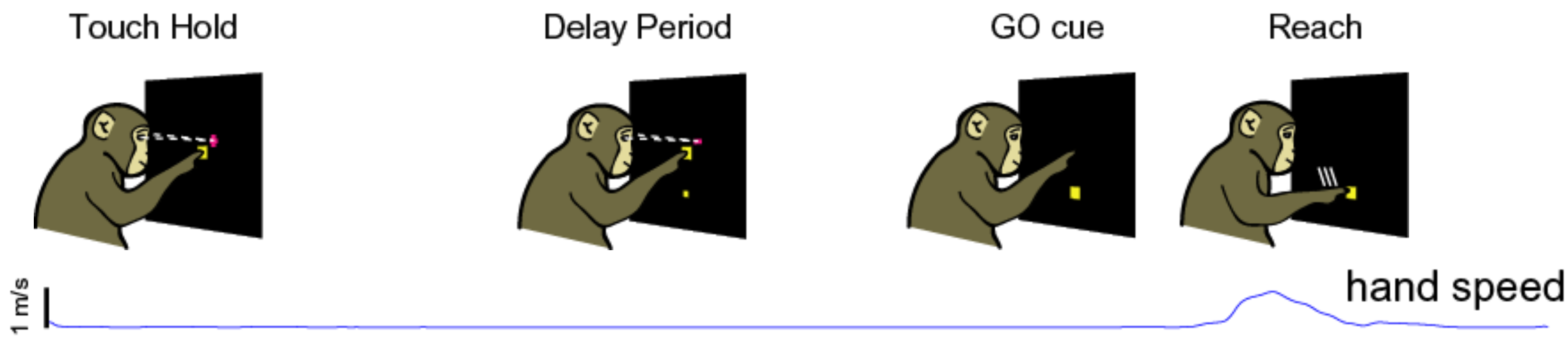
Controlling a robotic arm

Velliste et al., *Nature*, 2008.

FDA-approved human trials



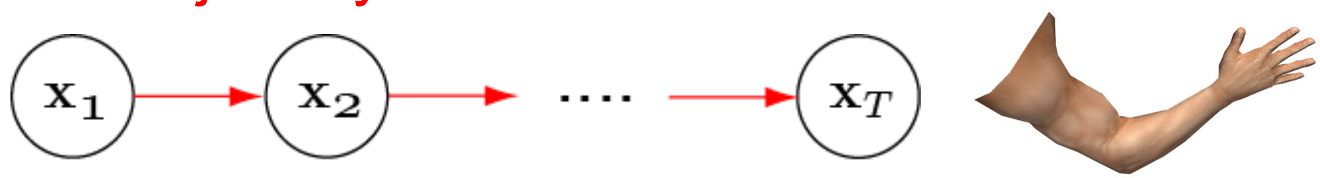
Hochberg et al., *Nature*, 2006.



$$\text{arm state } \mathbf{x}_t = \begin{bmatrix} \text{position} \\ \text{velocity} \\ \text{acceleration} \end{bmatrix}$$

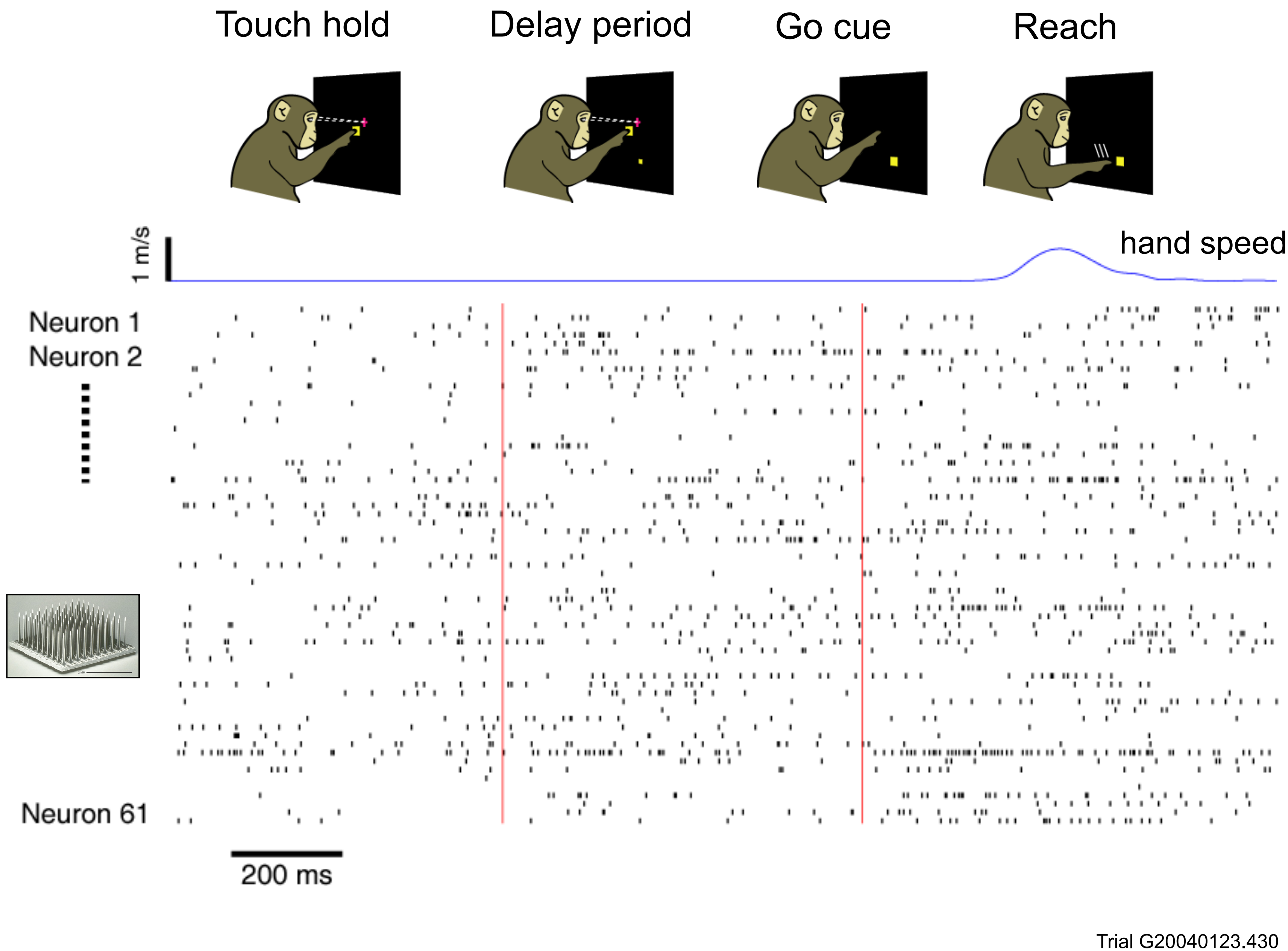
Dynamical model

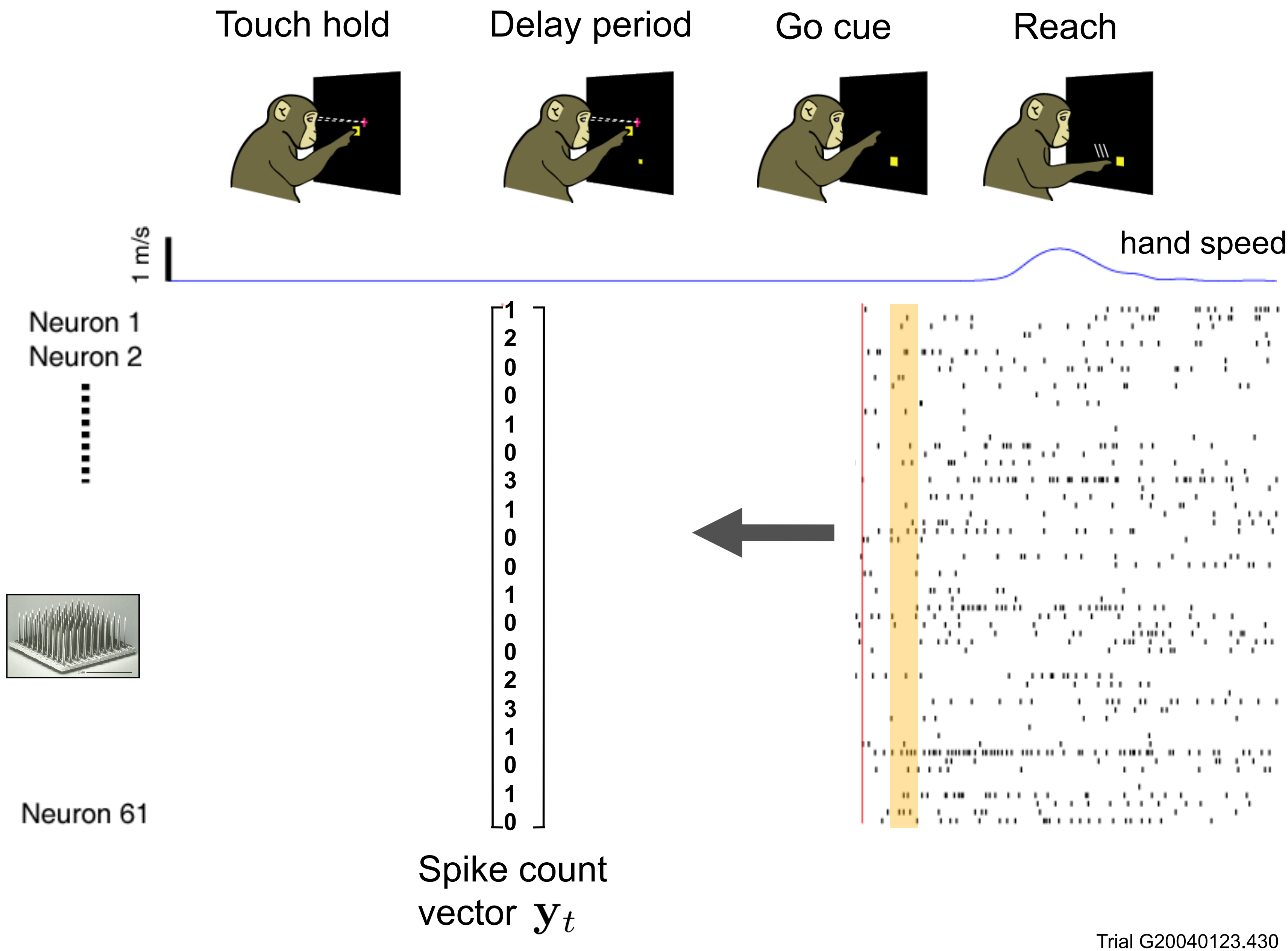
Trajectory model

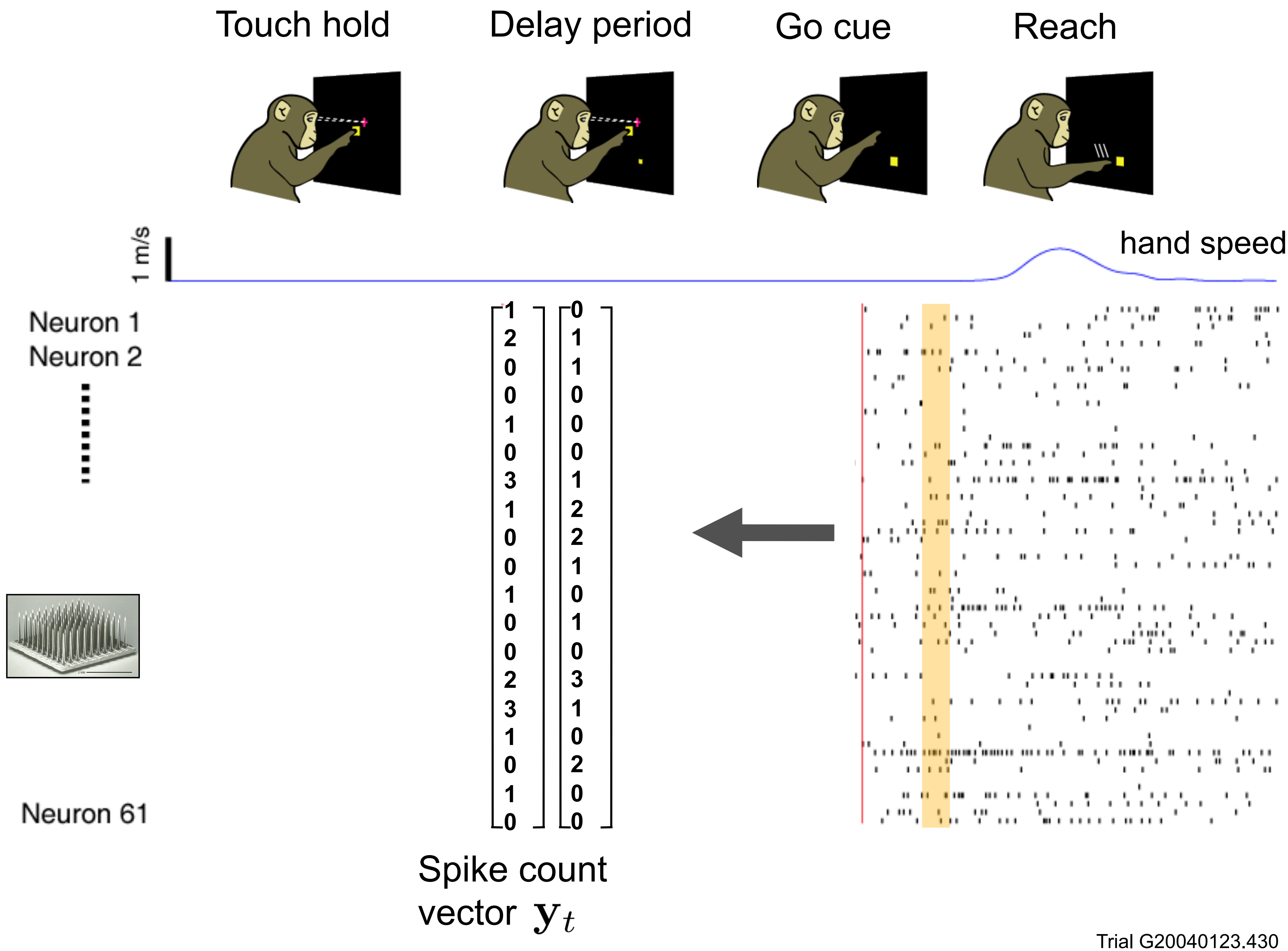


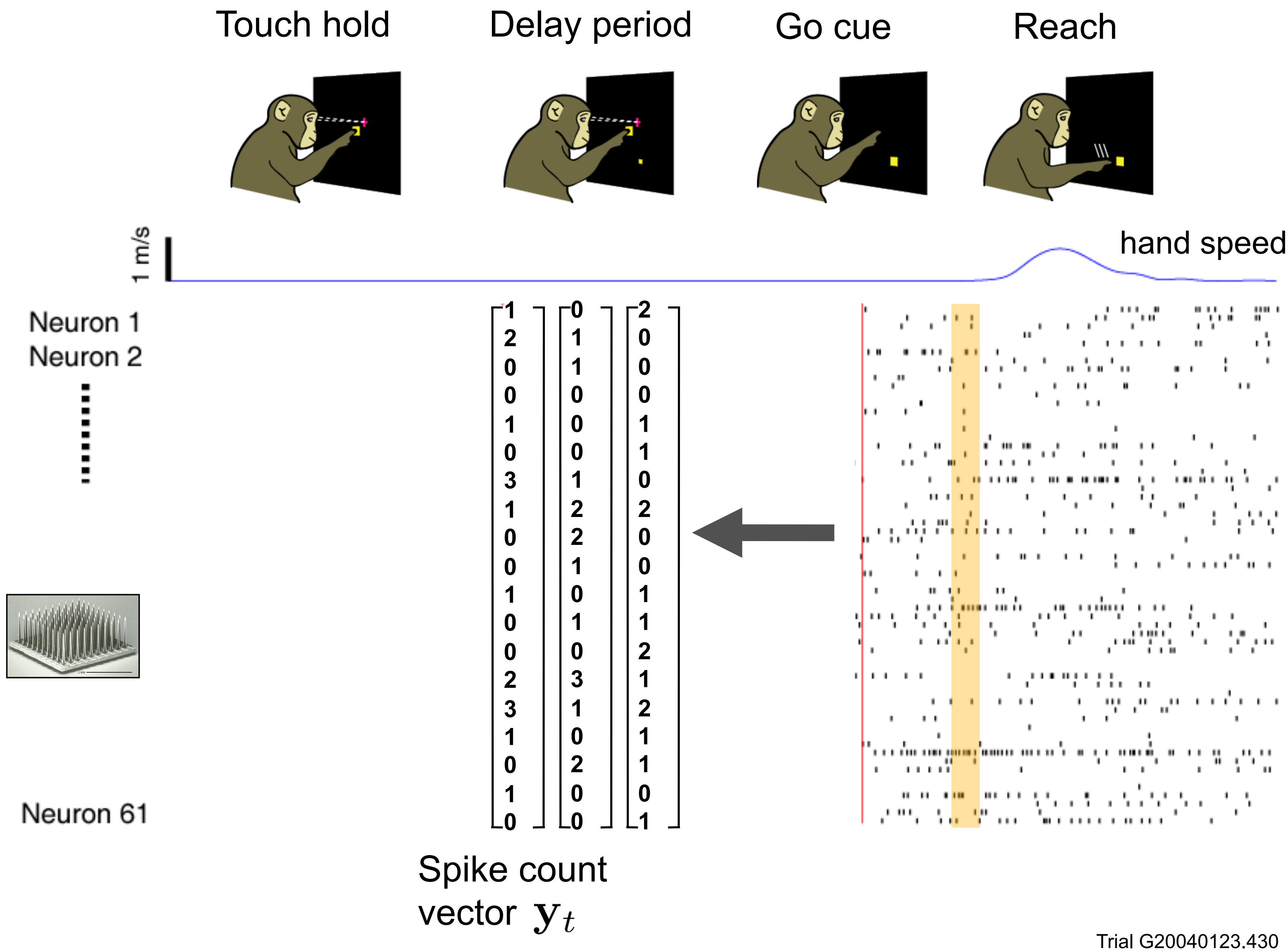
Linear Gaussian model:

$$\mathbf{x}_t \mid \mathbf{x}_{t-1} \sim \mathcal{N}\left(A\mathbf{x}_{t-1},\ Q\right)$$

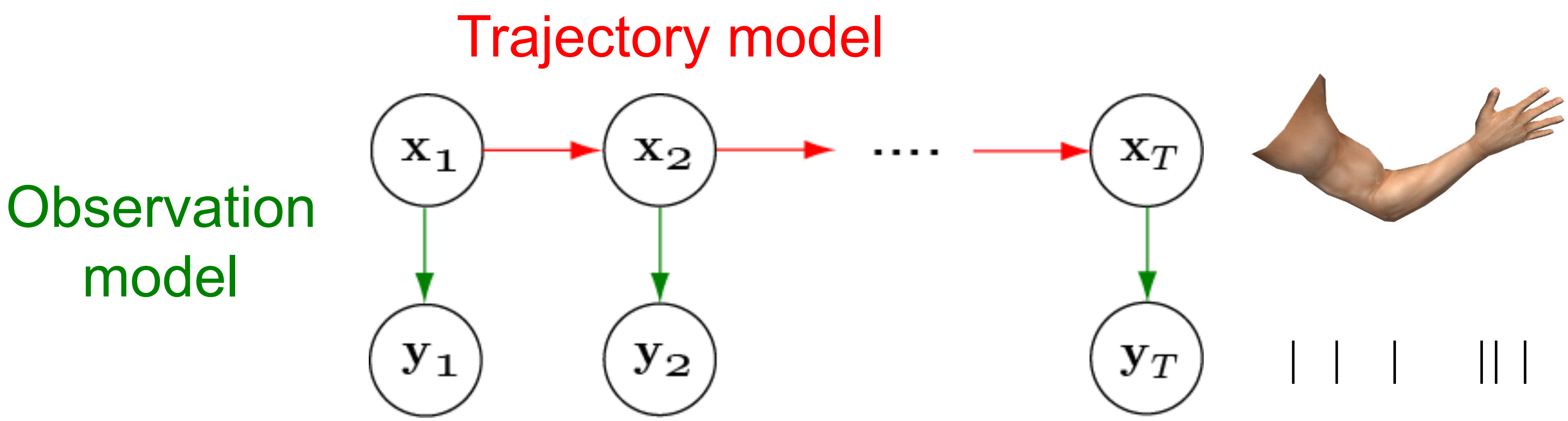

Touch hold
Delay period
Go cue
Reach
1 m/s
hand speed
Neuron 1
Neuron 2
Neuron 61
200 ms
Trial G20040123.430


Touch hold
Delay period
Go cue
Reach
1 m/s
hand speed
Neuron 1
Neuron 2
Neuron 61
1
2
0
0
1
0
3
1
0
0
1
0
0
2
3
1
0
1
0
Spike count vector $\mathbf{y}_t$
Trial G20040123.430


Touch hold
Delay period
Go cue
Reach
1 m/s
hand speed
Neuron 1
Neuron 2
Neuron 61
1 2 0 0 1 0 3 1 0 0 1 0 0 2 3 1 0 1 0
0 1 1 0 0 0 1 2 2 1 0 1 0 3 1 0 2 0 0
Spike count
vector $\mathbf{y}_t$
Trial G20040123.430


Touch hold
Delay period
Go cue
Reach
1 m/s
hand speed
Neuron 1
Neuron 2
Neuron 61
1 2 0 0 1 0 3 1 0 0 1 0 0 2 3 1 0 1 0
0 1 1 0 0 0 1 2 2 1 0 1 0 3 1 0 2 0 0
2 0 0 0 1 1 0 2 0 0 1 1 2 1 2 1 1 0 1
Spike count
vector $\mathbf{y}_t$
Trial G20040123.430

Dynamical model



$$\mathbf{y}_t \mid \mathbf{x}_t \sim \mathcal{N}\left(C\mathbf{x}_{t-1},\ R\right)$$

Kalman Filter

Using the trajectory model and observation model, we compute at each timepoint:

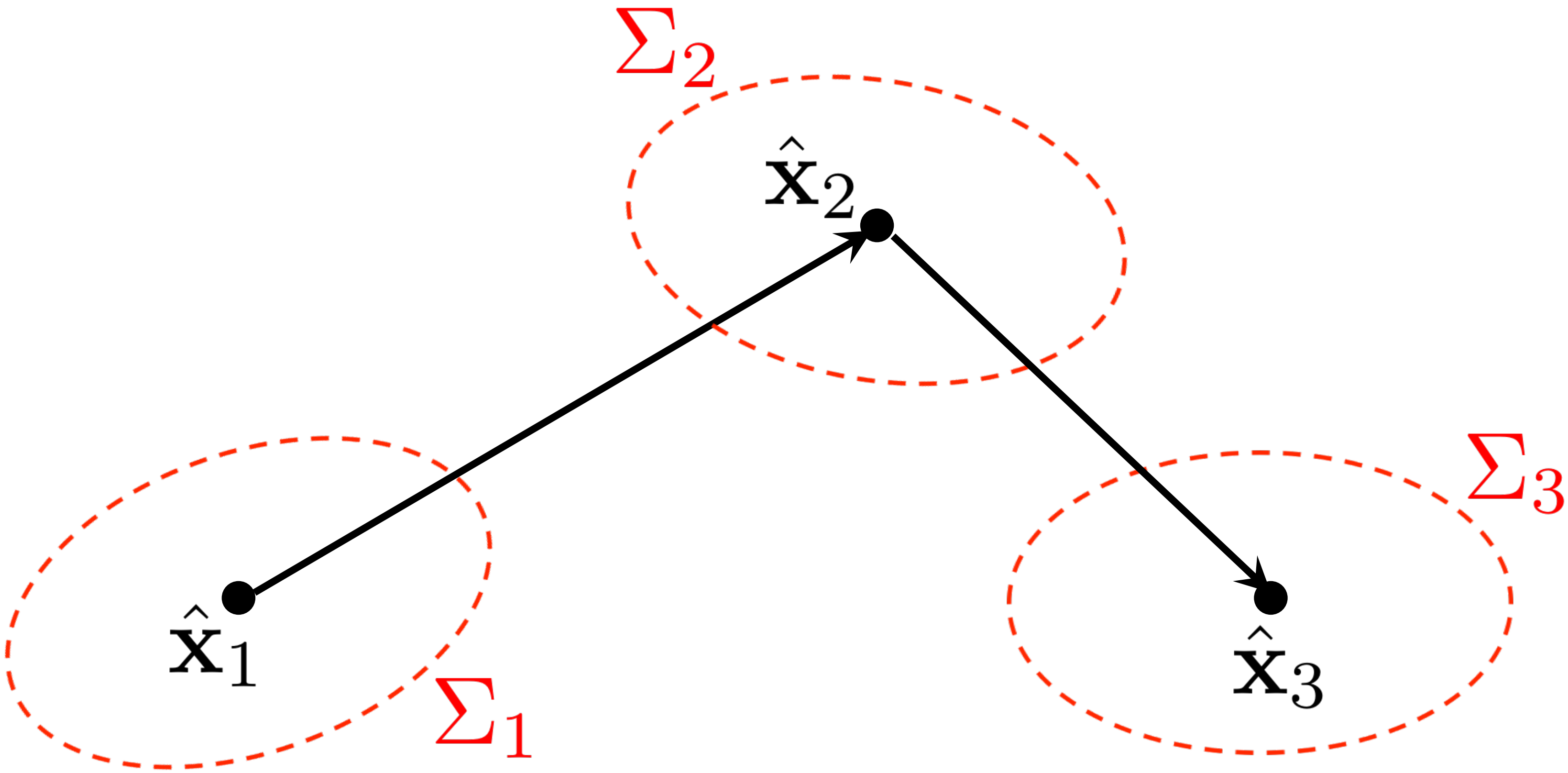
Arm state estimate

$$\hat{\mathbf{x}}_t = E[\mathbf{x}_t \mid \mathbf{y}_1, \ldots, \mathbf{y}_t]$$

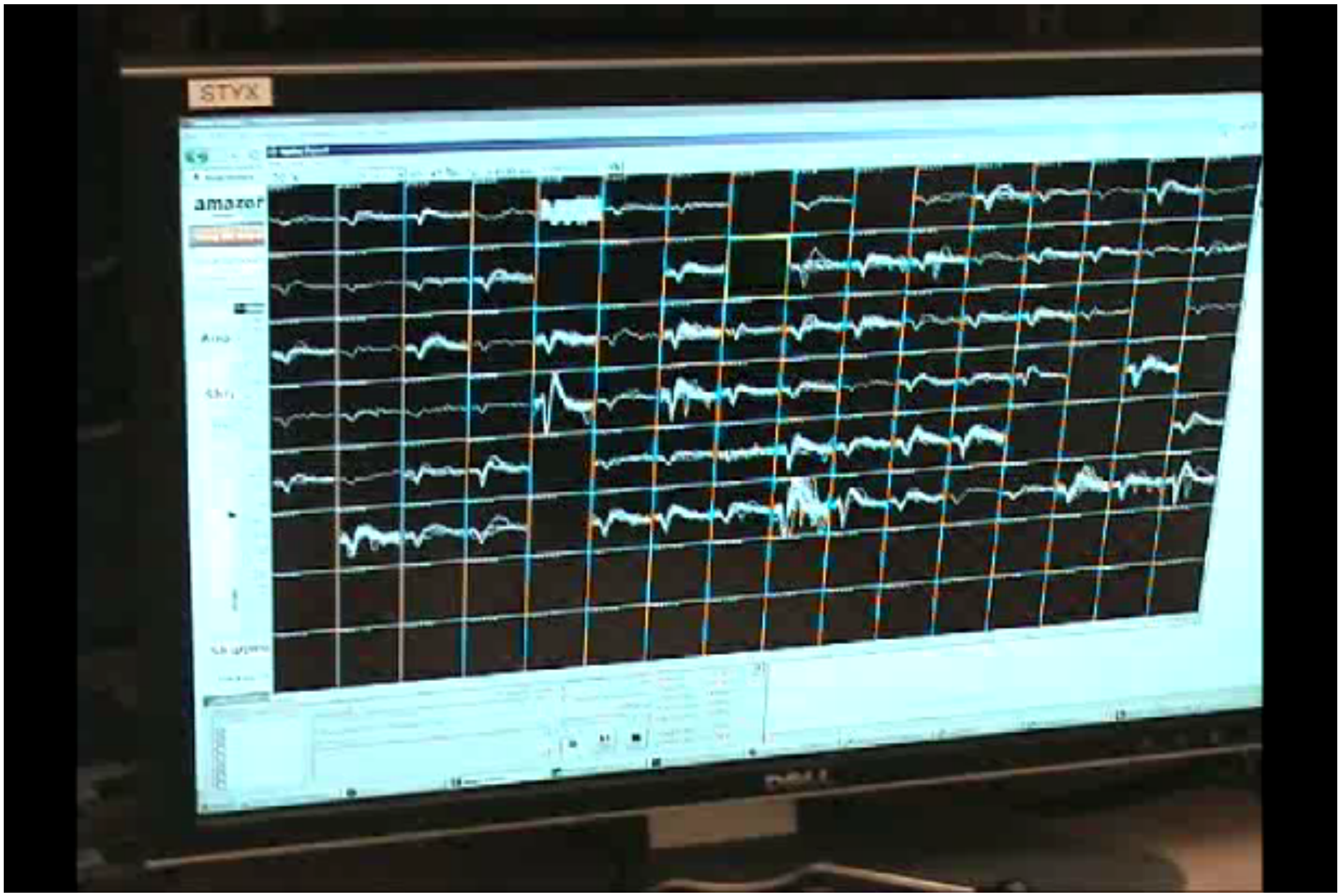
Confidence region

$$\Sigma_t = \mathrm{cov}(\mathbf{x}_t \mid \mathbf{y}_1, \ldots, \mathbf{y}_t)$$

Kalman Filter



Closed-loop cursor control using Kalman filter



Gilja, Nuyujukian, Chestek, Cunningham, Yu, Ryu, Shenoy

Cursor control along instructed paths

Sadtler, Ryu, Yu, Batista, *IEEE Neural Engineering*, 2011.

Road ahead

There is still much work to be done to get decoded movements to rival natural movements.

Monkey **hand-controlling** a virtual cursor

Credit: Churchland, Kaufman, Shenoy

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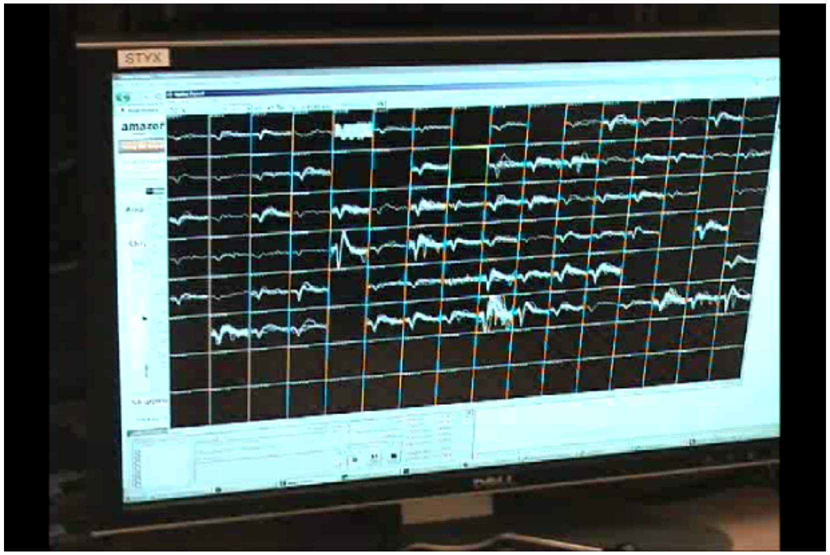

Monkey **brain-controlling** a virtual cursor

Credit: Gilja, Nuyujukian, Chestek, Cunningham, Yu, Ryu, Shenoy

Clinical progress & challenges ahead

Hochberg et al., *Nature* 2006.

<u>Clinical trials:</u>

- Braingate (Brown, MGH, Stanford)
- University of Pittsburgh

<u>Challenges:</u>

- Increase decoding performance (algorithms)
- Minimize surgical invasiveness
- Increase electrode lifetime
- Increase electrode recording stability (adaptive algorithms)
- Fully implantable, low-power electronics
- Replace connector/wires with telemetry
- Increase capabilities of prosthetic devices

See “Kalman Filter” notes