Population Vector Decoding

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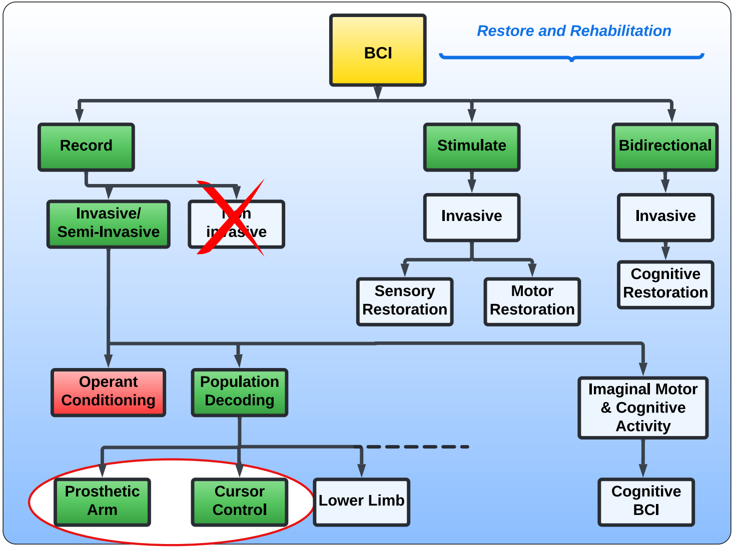
Recap: Population Vector Decoding



Population Vector Decoding

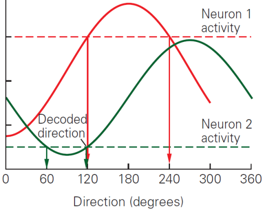
I. Discrete Decoder

- Performs **classification problems** in statistics.
- It can estimate **Movement goals**.

II. Continuous Decoder

- Solves a **regression problems** in statistics.
- It can estimate **moment-by-moment details** of a movement trajectory.

I. Discrete Decoder: Calibration Phase



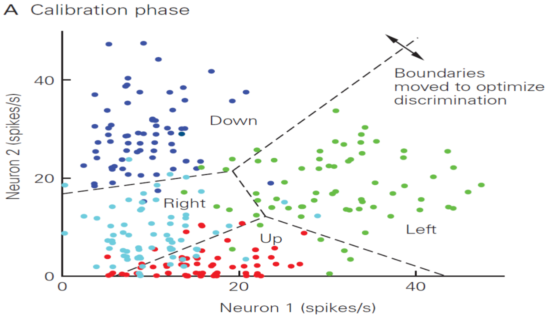


Figure: Population activity space for two neurons, where each axis is the firing rate of one neuron. On each trial, the activity of the two neurons together defines one point. A statistical model determines decision boundaries (dashed lines) to optimize discrimination among the movement goals

I. Discrete Decoder: Ongoing use phase

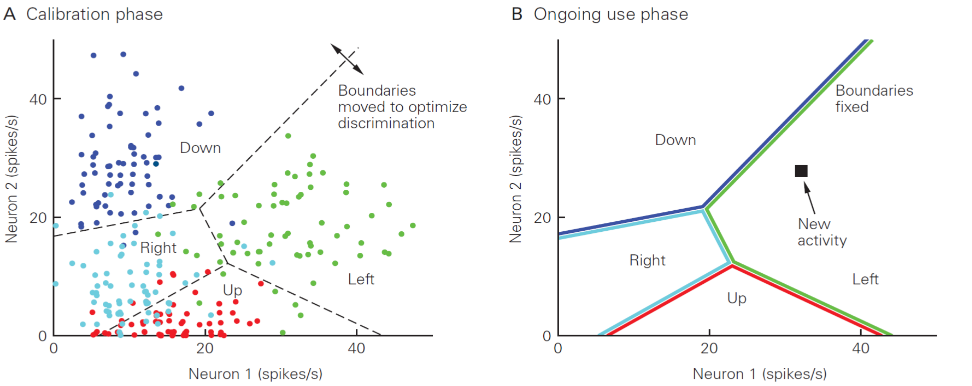


Figure: During this phase, the decision boundaries are fixed. If we record new neural activity (square) for which the movement goal is unknown, the movement goal is determined by the region in which the neural activity lies.

Example: Computer cursor control (2006)

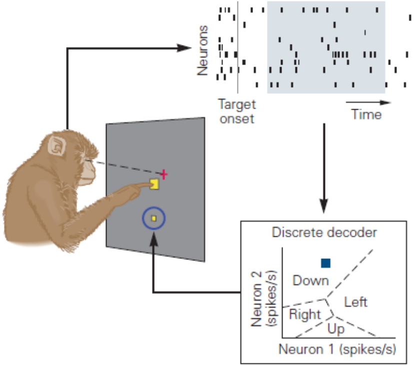
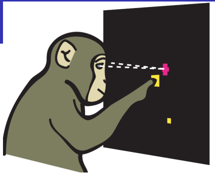


Figure: After a monkey touched a central target and fixated a central point(red), a peripheral target (yellow square) appeared and while a monkey was about to reach that spike count was taken and fed into decoder.[4]

Shortcoming of Discrete Decoder



Drawback

- Only 1D/2D controlling task can be performed.
- Can't estimate Moment-by-moment Details of Movements.
- Difficult/impossible to achieve control over complex devices.

II. Continuous Decoder: Calibration Phase

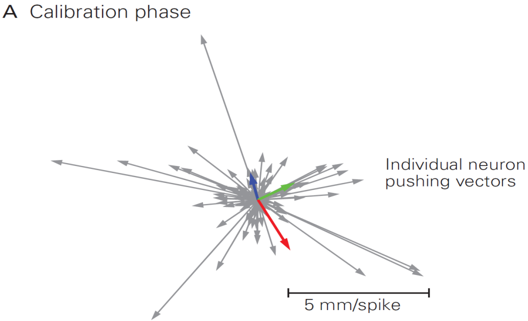
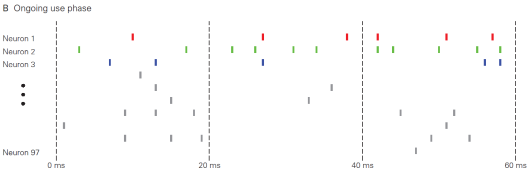
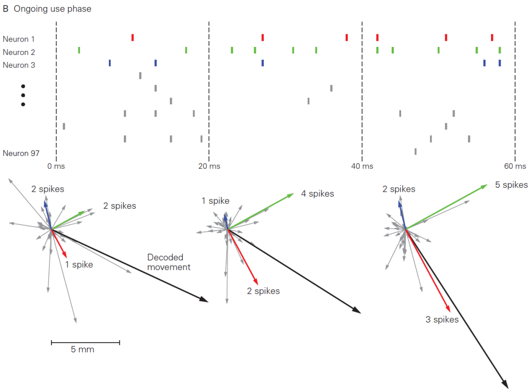


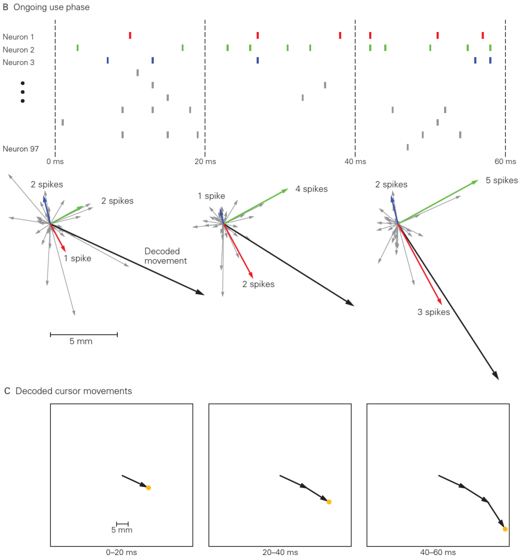
Figure: Each vector of neuron represents a change in position per time step (ie, velocity). Thus units of plot are mm/spike during one-time step. Different neurons have pushing vectors of different magnitudes and directions.

II. Continuous Decoder: Ongoing use phase



II. Continuous Decoder: Ongoing use phase




B Ongoing use phase
Neuron 1
Neuron 2
Neuron 3
Neuron 97
0 ms
20 ms
40 ms
60 ms
2 spikes
2 spikes
1 spike
Decoded movement
1 spike
4 spikes
2 spikes
2 spikes
5 spikes
3 spikes
5 mm
C Decoded cursor movements
5 mm
0–20 ms
20–40 ms
40–60 ms

Example: Neuralink (2021) Youtube Link

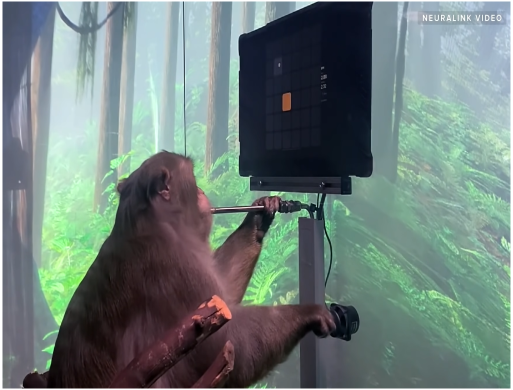


Figure: Calibration Phase (Decoder being trained)

Figure: Ongoing use Phase [1]

[1] Neuralink implanted in each side of brain of macaque named pager.

Example: Robot/Prosthetic Arm control (2000)

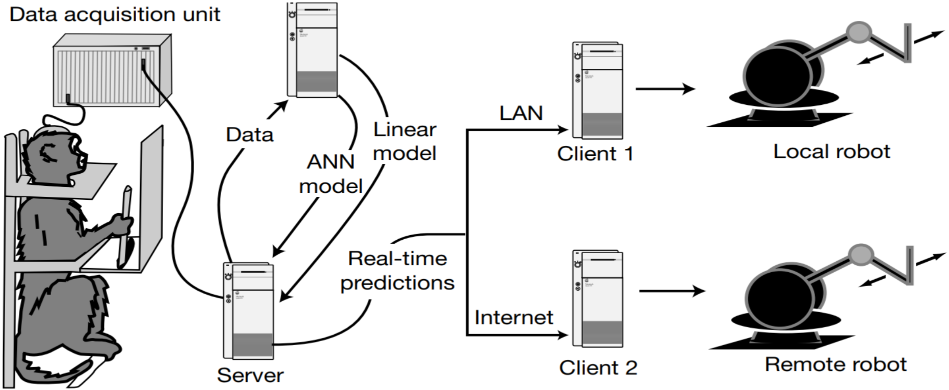
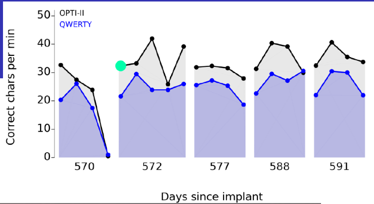


Figure: Monkey making 1D hand movements to control local and remote robotic arms. **Linear regression and ANN model were used as statistical models.** **Both performances were equally good.**[5]

Example: Cursor control (2017)



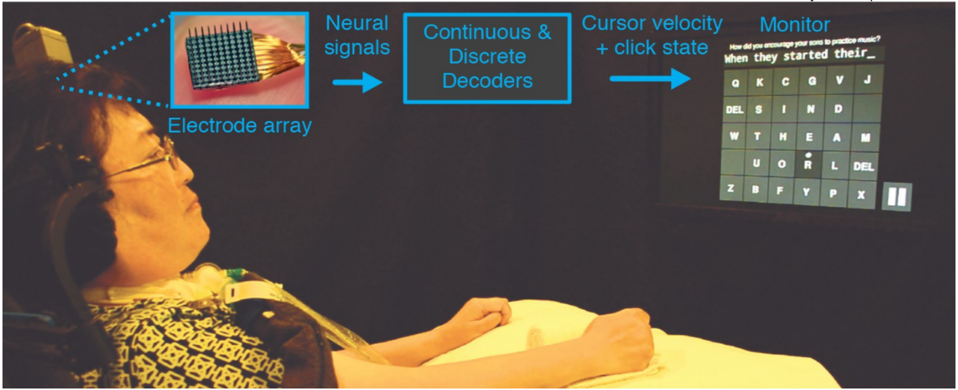
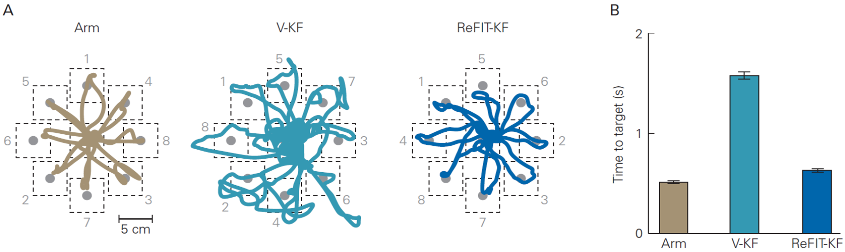


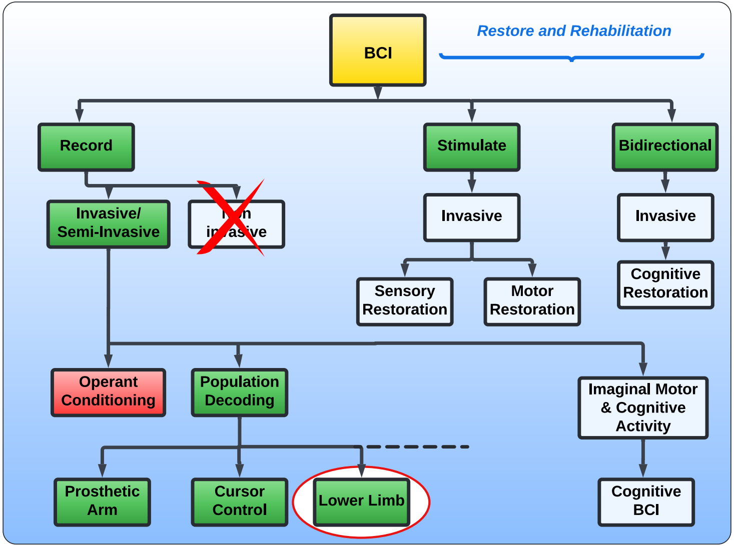
Figure: 53 years old female with **amyotrophic later sclerosis(ALS)** using a BMI to answer a question.[3]

Comparisons of Decoder model

	CC (x, y)	*MSE (cm²)*
Pinball task		
Method	*CC* (*x*, *y*)	*MSE* (cm²)
Population vector	(0.26, 0.21)	75.0
Linear filter (*N* = 14)	(0.79, 0.93)	6.48
Kalman Δt = 140 ms, nonuniform lag	**(0.84, 0.93)**	**4.55**



Lower Limb Control



Lower Limb Control

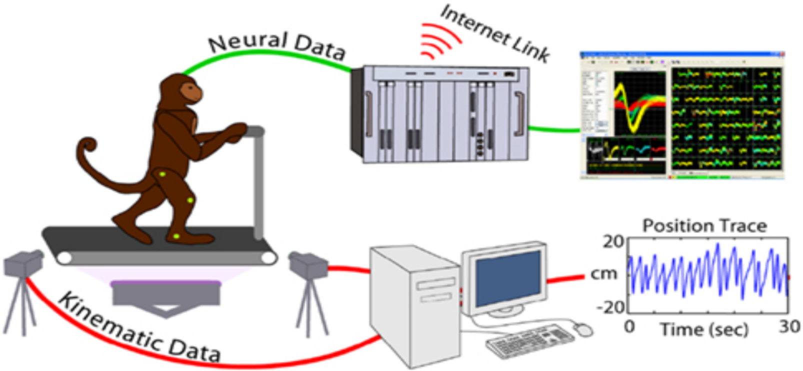
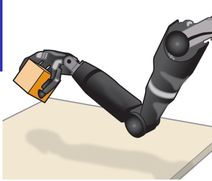
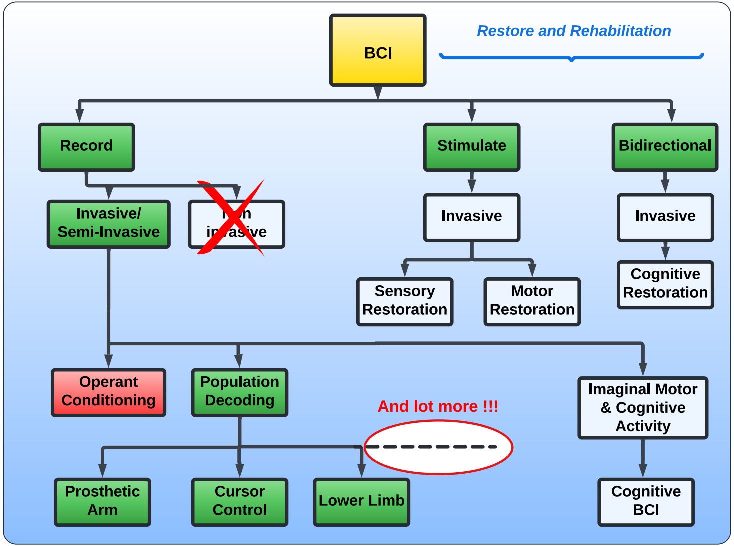


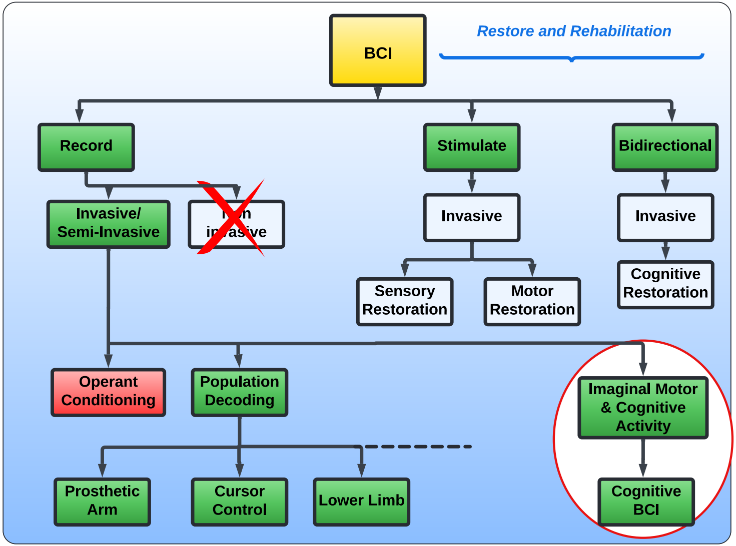
Figure: Predicting lower-limb kinematics using neural activity.[2]

Probable Applications of BCI

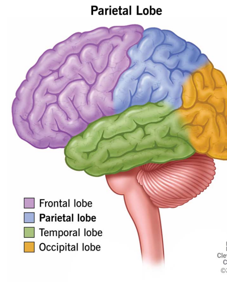




Probable Applications of BCI



Cognitive BCI



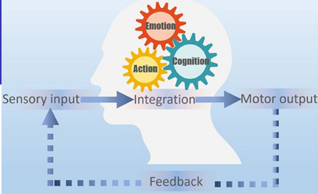
Why Cognitive?

- Advanced statistical and signal processing techniques such as:
  - Bayesian decoding, Population vector decoding(PVA)
  - ANN model, Kalman filter Decoding & **so on**.
- However, a scientific understanding of the brain processes being performed by different regions of the brain is necessary.

Cognitive (Intended) BCI

- Tapping of brain signals that are neither motor execution commands nor sensory signals, but rather **higher-level cognitive signals.**
- Signals are tap in from Posterior parietal cortex(PPC)

Reaching Task [4](2006)



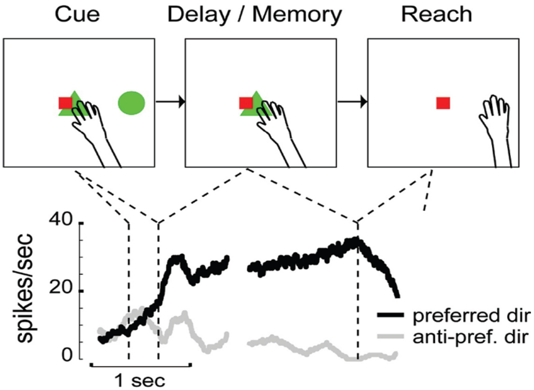


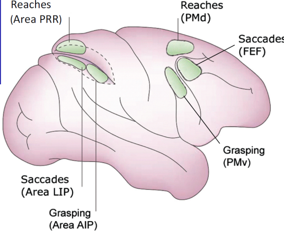
Figure: Representation of delayed goal-directed reach task in parietal reach region (PRR).[1]

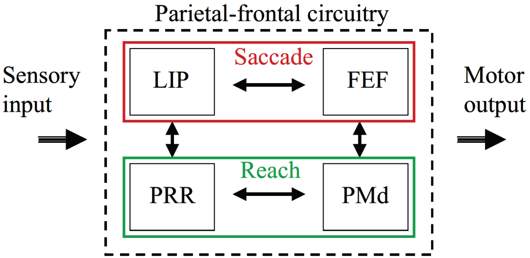
1)Red Square- Center of Screen 2)Green Circle- Goal 3)Green Triangle- Go Signal

Parietal-Frontal Circuitry

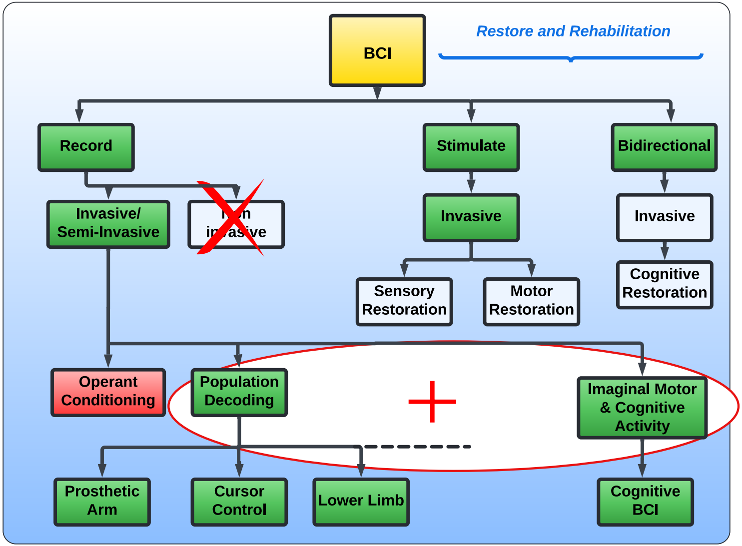
Brain Signals

- Motor Cortex — Real Movements
- Posterior Parietal Cortex — Imaginary Movements





Parietal + Frontal (9 times Better Performing)



Biggest Bottleneck

- **Onchip Classification**: **Binary classification** such as cursor control are no big deal but...
- **Multi Class Cassification**: Although recent onchip multiclass classification by Mahsa Shoaran lab looks appealing.
- Compression[1] can be a solution but yet lossy. (Arindam's and ~~Mahsa's~~ lab are actively looking on this front)

[1] Compression challenge such as https://content.neuralink.com/compression-challenge/README.html has been floated by neuralink to solve the bottleneck.

References

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[2] Nathan A. Fitzsimmons et al. “Extracting kinematic parameters for monkey bipedal walking from cortical neuronal ensemble activity”. In: *Frontiers in Integrative Neuroscience* 3.MAR (Mar. 2009), p. 501. ISSN: 16625145. DOI: 10.3389/NEURO.07.003.2009/BIBTEX.

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[6] Jun Zhuang et al. “Decoding 3-D reach and grasp kinematics from high-frequency local field potentials in primate primary motor cortex”. In: *IEEE Transactions on Biomedical Engineering* 57.7 (2010), pp. 1774–1784. ISSN: 00189294. DOI: 10.1109/TBME.2010.2047015.

Thank You!

Bonus Content: LFP Vs AP

Information content of:

AP 👉 Firing rate.
LFP 👉 Spectral power in particular frequency band.

🙌(Zhuang et al., 2010) characterized the information content of seven different LFP frequency bands in the 0.3-400 Hz range. They found that higher frequency bands (100-200Hz and 200-400Hz) carried the most information about recorded kinematics.[6]

LFP for kinematics

Hence, LFP data revealed that broad-band high-frequency **LFPs performed best** in constructing reach kinematics, grasp aperture, and aperture velocity.

Then, why not use both LFP and AP?

Challenges?