Neural Encoding and Decoding

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Encoding / Decoding by Symbols

From D. Kahn, The Code Breakers

Encoding / Decoding by Hardware

From D. Kahn, The Code Breakers
Rules of Encoding & Decoding - 1

Encoder - decoder is a matrix with numbered Rows and Columns
Encode letters as a RC combination
Decode a RC combination by look-up in the matrix

\[ a = 11, \ b = 12, \ c = 13, \ldots, \ m = 32, \ldots, \ y = 54, \ z = 55 \]

From D. Kahn, The Code Breakers

Rules of Encoding & Decoding - 2
Transmission of Encoded Information - 4

\[ Y = a + bX \]

Transmission of Encoded Information - 5

\[ \text{Sensation} = kS^b \]

Transmission of Encoded Information - 6

\[ \text{Movement made} \approx \text{Intended movement} \]
An Example from the Motor System

- Neural encoding and decoding of the direction of movement in space
- Encoding: Directional tuning of single cells
- Decoding: Population vector, neural trajectory

Encoding, Processing & Decoding Movement in Space

Behavioral Variable: Direction of Arm Movement in Space

Georgopoulos et al. 1982

2-D

Schwartz et al. 1988

3-D

Neural Encoding: Directional Tuning

Georgopoulos et al. 1982

Neural Decoding: Neuronal Population Vector - I

Georgopoulos et al. 1984
Cell vectors
Population vector

Georgopoulos et al. 1983

Time-varying Neuronal Population Vector

Georgopoulos et al. 1984

Neural Decoding: Neuronal Population Vector - 2

Georgopoulos et al. 1986

Science
Georgopoulos et al. 1988

Movement Trajectory

~100 ms neural lead

Schwartz, 1994

The MEG instrument at the Minneapolis Domenici Center
(Magnes 3600WH, 4-D Neuroimaging, San Diego, CA)

- 248 axial gradiometers (low noise)
- 1 kHz sampling rate

MAGNETOENCEPHALOGRAPHY

The Dewar
Liquid helium
Actual (green) and predicted (red) movement trajectory using constant 50 MEG samples back (~50 ms) & cubic spline smoothing of the output.

Decoding of Movement Trajectory from MEG Signals - 1

Decoding of Movement Trajectory from MEG Signals - 2
Decoding Serial Order

Decoding Serial Position

Carpenter et al. 1999

fMRI

Neural encoding of mental tracing

Gourtzelidis et al. 2005
Superior Parietal Lobule

Gourtzelidis et al. 2005

Encoding of mental tracing in single voxels

Gourtzelidis et al. 2005

Decoding of mental tracing by the Population Vector

Gourtzelidis et al. 2005
Decoding of mental tracing by the Population Vector in small ensembles

Average Absolute Angular Error (deg)

Number of Voxels

Gourtzelidis et al. 2005

Single Cell Recordings

Neural encoding of maze path direction in parietal cortex

Crowe et al. 2004
Neural decoding of maze path direction by the Population Vector.

Crowe et al. 2005
Neural Encoding of Information

- Systematic variation of neural activity with respect to a behavioral variable (e.g., stimulus-response function)
- Typically applied to single cell activity
- Standard statistics

Neural Decoding of Information

- Extract the value of the variable from the neural activity
- Typically extracted from neuronal populations using multivariate statistical analyses
  - Population vector for continuous variables
  - Discriminant classification analysis for discrete variables

Smart Neuroprostheses

- “Smart” at any level:
  - Encoder
  - Channel
  - Decoder
- Specific applications
  - Realistic motor prostheses: As smart as the spinal cord
  - Cortical prostheses: As smart as the cortex
  - Sensory prostheses: As smart as the sensory organ
Challenges in Motor Neuroprostheses

- Quality of the neural control signal
- Signal processing to match "smart" prosthesis
- Training of the neural control signal by feedback from the prosthesis → "smart system"
- The future: November 9-11, 2006

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The End