Hodgkin-Huxley model

\[ I = \sum_{i} \left( \left( E - a \Lambda \right) m_n h \left( V - E_N \right) + \left( a \Lambda - E_N \right) n^4 \right) I_c \]

\[ m, n: \text{voltage-gating variables with their own dynamics that determine when channels open and close} \]

Bias weight
Hodgkin-Huxley model

\[ I = g_{\text{Na}} m^3 h (V_m - E_{\text{Na}}) + g_{\text{K}} n^4 (V_m - E_{\text{K}}) + (V_m - E_l) \]

\( m, n, h, \) voltage gating variables with their own dynamics that determine when channels open and close

General cell excitability is plastic, regardless of particular synaptic inputs (weights). See review by Mozzaachido & Byrne, 2009 *TINS* on non-synaptic plasticity.

Bias weight

Left over from units...
see also Shadlen & Newsome 98.
Networks
Layers and layers of detectors...
1. Biology of networks: The cortex

2. Excitation:
   - Unidirectional (transformations)
   - Bidirectional (pattern completion, amplification)

3. Inhibition: Controlling bidirectional excitation.

4. Constraint Satisfaction: Putting it all together.

Networks
Two separate populations:

- Inhibitory (GABA): Chandelier, Basket.
- Excitatory (Glutamate): Pyramidal, Spiny stellate.
Excitatory vs Inhibitory Neurons

- Excitatory neurons both project locally and make long-range projections between different cortical areas.
- Inhibitory neurons primarily project within small, localized regions of cortex.
- Excitatory neurons carry the information flow (long-range projections).
- Inhibitory neurons are responsible for (locally) regulating the activation of excitatory neurons.
- Excitatory neurons both project locally and make long-range projections between different cortical areas.
Laminar Structure of Cortex
Layers

- Layer = a bunch of neurons with similar connectivity
- Localized to a particular region (physically contiguous)
- All cells within a layer receive input from approximately the same places (i.e., from a common collection of layers)
- All cells within a layer send their outputs to approximately the same places (i.e., to a common collection of layers)
- Layer = a bunch of neurons with similar connectivity
Laminar Structure of Cortex

Three Functional Layers
Hidden Layer transforms input-output mappings

Three Functional Layers

Laminar Structure of Cortex
Laminar Structure of Cortex

Three Functional Layers

More hidden layers → richer transformations

Hidden Layer transforms input-output mappings
Laminar Structure of Cortex

Three Functional Layers

More hidden layers → richer transformations
Hidden Layer transforms input-output mappings

← less reflex-like... smarter... more "free"?
1. Biology: Cortical layers and neurons
2. Excitation: Unidirectional excitations
   - Unidirectional (transformations)
   - Bidirectional (pattern completion, amplification)
3. Inhibition: Controlling bidirectional excitations
4. Constraint Satisfaction: Putting it all together
Excitation (Unidirectional): Transformations
Detectors work in parallel to transform input activity pattern to hidden activity pattern.
Emphasizes some distinctions, collapses across others.

Excitation (Unidirectional): Transformations
- Function of what detectors detect (and what they ignore).
- Emphasizes some distinctions, collapses across others.
Emphasizing/Collapsing Distinctions
Other (more interesting) examples...
• tested with noisy digits
• tested with letters
Cluster Plots

Cluster plots provide a means of visualizing similarity relationships between patterns of activity in a network. Cluster plots are constructed based on the distances between patterns of activity. The Euclidean distance is calculated as follows:

\[
\sqrt{\sum_{i}(x_i - y_i)^2} = d
\]

In activity of all units (across all units of the squared difference) sum = Euclidean distance. Cluster plots are constructed based on the distances between patterns of activity in a network. Cluster plots provide a means of visualizing similarity relationships.
Making Friends With Cluster Plots
Making Friends With Cluster Plots
cluster plots (digits, noisy digits, hidden).
Emphasizing/Collapsing Distinctions: Categorization
Emphasizing distinctions: digits separated, even though they have perceptual overlap.
Emphasizing/Collapsing Distinctions: Categorization

Emphasize distinctions: digits separated, even though they have perceptual differences.

Collapse distinctions: Noisy digits categorized as same, even though they have perceptual overlap.
What are these??
Networks: Bidirectional Connectivity

connectivity matrices

Sporns & Zwi 04
Networks: Bidirectional Excitation
1. Top-down expectations about low-level features.

Networks: Bidirectional Excitation
1. Top-down expectations about low-level features.
2. Pattern completion.
Top-Down Processing (Imagery)
Top-Down Processing (Imagery)
Top-Down Processing (Imagery)
Pattern Completion
Pattern Completion
Pattern Completion

- Tiger
- Striped
- Orange
- Sharp
- Teeth
- Furry
Word Superiority Effect: Top-Down Amplification
Word Superiority Effect: Top-Down Amplification

DEST (slower)

NEST (faster)

Identify second letter in:
Word Superiority Effect: Top-Down Amplification?

Weird! You have to recognize the letter before you can recognize the word.

DEST (slower)

NEST (faster)

Identify second letter in:

faster (faster)
Figure 1. Interactive Activation Network Model (after McClelland and Rumelhart, 1981).

Application to Word Superiority Effect
Bidirectional Dynamics
Networks: Bidirectional Excitation

1. Top-down processing ("imagery").

2. Pattern completion.

3. Amplification/bootstrapping.
Networks: Bidirectional Excitation

1. Top-down processing ("imagery").
2. Pattern completion.
3. Amplification/bootsraping.
4. Need inhibition!
Localist vs. Distributed Representations
Localist vs. Distributed Representations

- Localist = 1 unit responds to 1 thing (e.g., digits, grandmother cell).

  •
Localist vs. Distributed Representations

- Localist = 1 unit responds to 1 thing, one unit responds to few things.
- Distributed = Many units respond to 1 thing (e.g., digits, grandmother cell).
Localist vs. Distributed Representations

- Localist: 1 unit responds to 1 thing (e.g., digits, grandmother cell).
- Distributed: Many units respond to 1 thing, one unit responds to many things.

With distributed representations, units correspond to stimulus features as opposed to complete stimulus.

• Distributed = Many units respond to 1 thing, one unit responds to many things.
• Localist = 1 unit responds to 1 thing (e.g., digits, grandmother cell).

Localist vs. Distributed Representations
Digits With Distributed Representations
Advantages of Distributed Representations

Efficiency: Fewer Units Required
Advantages of Distributed Representations

Efficiency: Fewer Units Required

The digits network can represent 10 digits using 5 "feature" units.

3, 4, 5, 2, 1, 0

Each digit is a unique combination of the 5 features, e.g.,

There are < 1 million unique ways to combine 20 features.

There are 32 unique ways to combine 5 features.

The digits network can represent 10 digits using 5 "feature" units.
Advantages of Distributed Representations

Similarity and Generalization:
Advantages of Distributed Representations

Similarity and Generalization:

If you represent stimuli in terms of their constituent features, stimuli with similar features get assigned similar representations. This allows you to generalize to novel stimuli based on their similarity to previously encountered stimuli.
Woodpecker

Localist = no generalization

orole

flies
Advantages of Distributed Representations

Robustness (Graceful Degradation):
Advantages of Distributed Representations

**Robustness (Graceful Degradation):**

Damage has less of an effect on networks with distributed (vs. localist) representations
Advantages of Distributed Representations

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Damage has less of an effect on networks with distributed (vs. localist) representations.
Advantages of Distributed Representations

Accuracy: By coarse-coding (e.g., color, position)
Advantages of Distributed Representations

Accuracy: By coarse-coding (e.g., color, position)

These tuning curves are commonly seen, e.g., in V1:

\[ <(s) > \rightarrow s \]
Advantages of Distributed Representations
Advantages of Distributed Representations

- **Efficiency**: Fewer total units required.
- **Similarity**: As a function of overlap.
- **Generalization**: Can use novel combinations.
- **Robustness**: Redundancy: damage has less of an effect.
- **Accuracy**: By coarse-coding.
1. Biology: The cortex
2. Excitation:
   • Unidirectional (transformations)
   • Bidirectional (top-down processing, pattern completion, amplification)
   • Unidirectional (transformations)
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