CSE 40171: Artificial Intelligence

Artificial Neural Networks with Functional Fidelity: Models of Neural Network Dynamics
Homework #7 has been released
It is due at 11:59PM on 12/2
Project Updates are Due **tonight** at 11:59PM

(See Course Website for Instructions)
Molecular Mechanisms

Ion Concentration Gradients
- $\text{Na}^+$
- $\text{K}^+$
- $\text{Cl}^-$

Charge Separation

Across Membrane

Extracellular

Intracellular

Cell membrane
Spike Trains

Action potentials convey information through their timing:

Firing Rates Approximated by Different Procedures

Dayan and Abbott 2001
Reminder of Tuning Curves

Figure 4.8 Response of a single cortical cell to bars presented at various orientations.

Hubel and Wiesel 1968
Modeling a Tuning Curve

Gaussian Tuning Curve:

\[
f(s) = r_{\text{max}} \exp\left( -\frac{1}{2} \left( \frac{s - s_{\text{max}}}{\sigma_f} \right)^2 \right)
\]

- Orientation angle of light bar
- Max. avg. response rate
- Orientation evoking max. response
- Determines width of tuning curve
Modeling a Tuning Curve

Dayan and Abbott 2001 (original: Wandell 1995)
Note: Spike Count Variability

- Tuning curves allows us to predict the average firing rate.
- They do not describe how the spike-count firing rate $r$ varies about its mean value from trial to trial.
  - Likely that single-trial responses can only be modeled probabilistically.
Describing the stimulus

Neurons responding to stimuli must encode parameters that can vary over a large dynamic range.

**Weber’s law:** how different two stimuli have to be to be reliably discriminated. The just noticeable difference $\Delta s$ is proportional to the magnitude of the stimulus $s$, such that $\Delta s / s$ is constant.

**Fechner’s law:** noticeable differences set the scale for perceived stimulus intensities. Integrating Weber’s law, the perceived intensity of a stimulus of absolute intensity $s$ varies as $\log s$. 
Adapting to the stimulus

Sensory systems make numerous adaptations to adjust to the average level of stimulus intensity.

Model this by describing responses to fluctuations about a mean stimulus level.

$s(t)$ is defined so that its time average over the duration of the trial is 0:

$$\int_0^T dt \ s(t)/T = 0$$
Stimuli and Time Averages

Scenario 1: 🍎🍎...🍎

Scenario 2: 🍎🍊...香蕉

Spike-Triggered Average:

\[ C(\tau) = \left\langle \frac{1}{n} \sum_{i=1}^{n} s(t_i - \tau) \right\rangle \approx \frac{1}{\langle n \rangle} \left\langle \sum_{i=1}^{n} s(t_i - \tau) \right\rangle \]

time interval
Computing the spike-triggered average stimulus

Dayan and Abbott 2001
What does incorporating these dynamics into an artificial neural network provide us with?
Spiking Artificial Neural Networks

Advantage of Spiking Artificial Neural Nets

• Neuroscientists believe that information is encoded and decoded by a spike train
  ‣ Do neurons communicate with a rate or temporal code?

• Temporal coding suggests that a single spiking neuron could replace hundreds of hidden units in a conventional artificial neural network
The Neural Code

Image Credit: Alan Litke
Spiking neural networks consider temporal information

- Not all neurons are activated in every iteration of propagation
- A neuron is activated when its “membrane potential” reaches a threshold
- After activation, a signal is produced that is sent to connected neurons, raising or lowering their membrane potential
Unit in a Spiking Artificial Neural Network

Image Credit: https://lis2.epfl.ch/CompletedResearchProjects/EvolutionOfAdaptiveSpikingCircuits/
Neuromorphic Architectures

Image Credit: IBM Corporation
Key advantages of neuromorphic hardware

• Energy efficiency
• Execution speed
• Tolerance to local failures
• Ability to learn
Neurogrid (Stanford)

- Analog computation to emulate ion channel activity
- Digital communication for structured connectivity patterns
- Simulates 1 million neurons and 6 billion synapses
- Consumes less than 2 watts of power

Image Credit: Brains in Silicon Group, Stanford University
BrainScaleS (Human Brain Project)

- 200,000 neurons and 40 million synapses per system
- 20 such systems in the first version of the system
- Simulation of plasticity models
- Runs 10,000x faster than real time

Image Credit: https://flagship.kip.uni-heidelberg.de/public/BrainScaleS/
Image Credit: Schemmel et al. ISCAS 2010
SpiNNaker (Human Brain Project)

- Custom chips based on ARM
- Each chip has 18 cores and 128M of shared local RAM
- Over 1,000,000 cores available
- Based on numerical models of neuron dynamics

Image Credit: University of Manchester
TrueNorth (IBM)

- 4,096 cores, each with 256 programmable neurons (~1,000,000 neurons)
- ~268M programmable synapses
- 5.4B transistors, but only consumes 70 milliwatts of power
- Typical CPU: 1.4B transistors and 35+ watts of power
- Designed for pattern recognition
Second Order Effects: What is the model of computation?