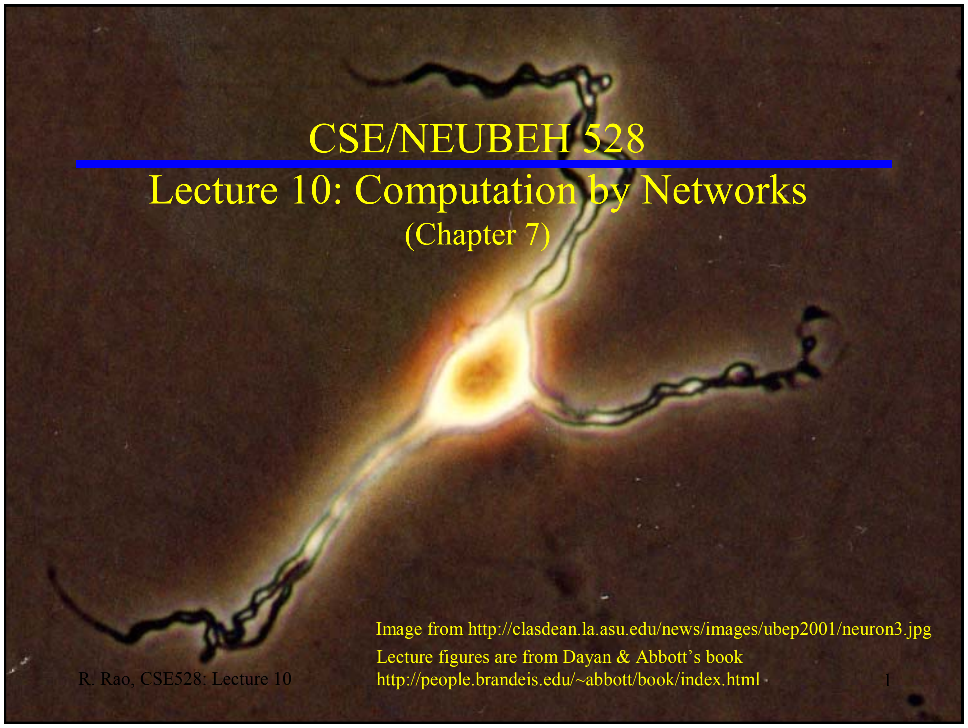


CSE/NEUBEH 528

Lecture 10: Computation by Networks

(Chapter 7)

Image from http://clasdean.la.asu.edu/news/images/ubep2001/neuron3.jpg

Lecture figures are from Dayan & Abbott's book http://people.brandeis.edu/~abbott/book/index.html

What have we covered so far?

- Neural Encoding
  - What makes a neuron fire? (e.g., spike triggered average)
  - Poisson model
- Neural Decoding
  - Stimulus Discrimination based on firing rate
  - Spike-train based decoding of stimulus
  - Population decoding (Bayesian estimation)
- Single Neuron Models
  - RC circuit model of membrane
  - Integrate-and-fire model
  - Conductance-based Compartmental Models

Today's Agenda

- Computation in Networks of Neurons
  - From spiking to firing-rate based networks
  - Feedforward Networks
    - E.g. Coordinate transformations in the brain
  - Linear Recurrent Networks
    - Can amplify inputs
    - Can integrate inputs
    - Can function as short-term memory

Simulating Networks of Neurons

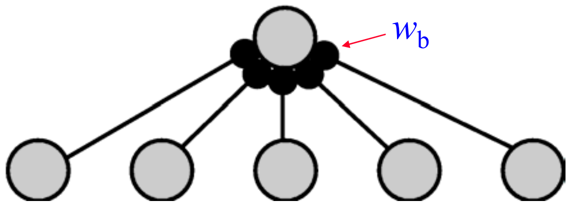
- Option 1: Use *spiking* neurons (e.g. I & F neurons)
  - *Advantages*: Allows computation and learning based on:
    - Spike Timing
    - Spike Correlations/Synchrony between neurons
  - *Disadvantages*: Computationally expensive
- Option 2: Use neurons with *firing-rate outputs*
  - *Advantages*: Greater efficiency, scales well to large networks
  - *Disadvantages*: Ignores spike timing issues
- Question: How are these two approaches related?

Network Notation

output v

weights $\mathbf{w}$

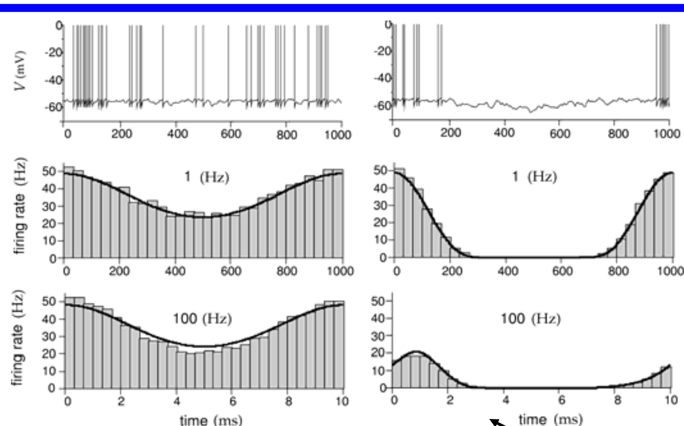
input $\mathbf{u}$



Synaptic input $$I_b(t) = w_b \int_{-\infty}^{t} K(t-\tau)\rho_b(\tau)d\tau$$ Spike train ρ_b(t)

$$\approx w_b \int_{-\infty}^{t} K(t-\tau)u_b(\tau)d\tau$$ Firing rate u_b(t)

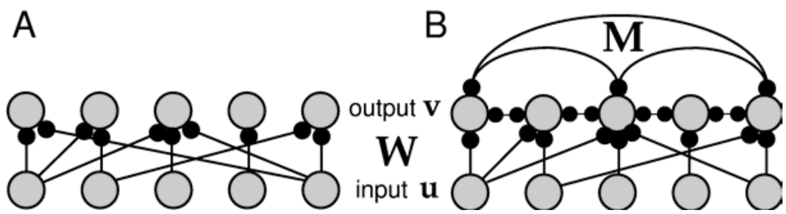
How good are the Firing Rate Models?



V(t) = F(I(t)) describes this well but not this case

Input I(t) = $I_0 + I_1\cos(\omega t)$

Feedforward versus Recurrent Networks

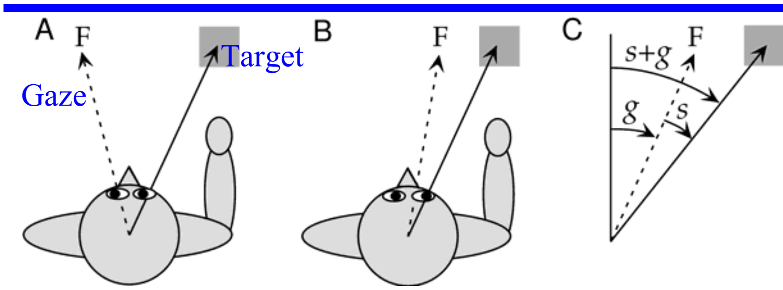


$$\tau \frac{d\mathbf{v}}{dt} = -\mathbf{v} + F(\mathrm{W}\mathbf{u} + \mathrm{M}\mathbf{v})$$

Output Decay Input Feedback

(For feedforward networks, matrix M = 0)

The Problem of Coordinate Transformations



g = gaze angle *relative to body*

s = stimulus or target angle *relative to gaze (retinal coordinates)*

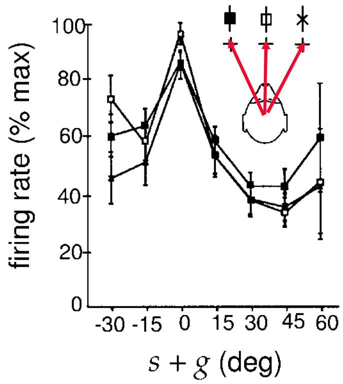
s+g = stimulus relative to body

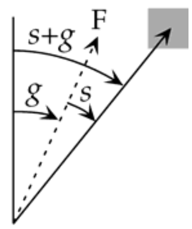
Same arm movement required in A and B but s and g are different

How does the brain solve this problem?

Body-Based Representation in the Monkey

Head fixed
gaze shifted to g_1 g_2 g_3





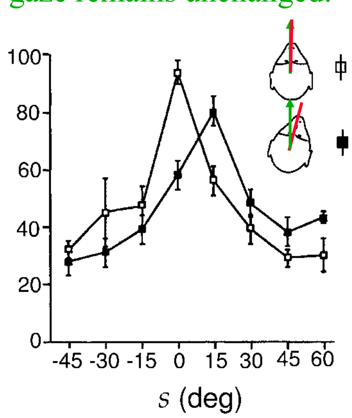
Objects approaching
at different angles

Same tuning curve regardless of
gaze angle

Premotor cortex neuron responds
to stimulus location *relative to body*, not retinal image location

Body-Based Representation in the Monkey

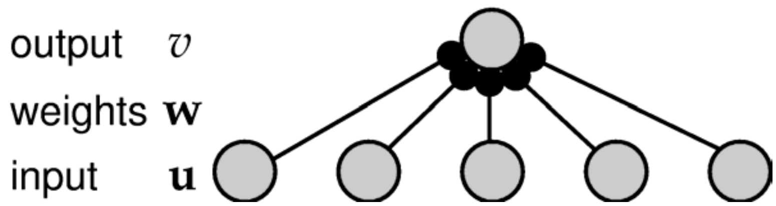
When head is moved but
gaze remains unchanged:



After head is moved 15°,
objects approaching at 15°
in retinal image now elicit
the highest response →
Tuning curve in retinal
coordinates has shifted

Suggested Feedforward Network

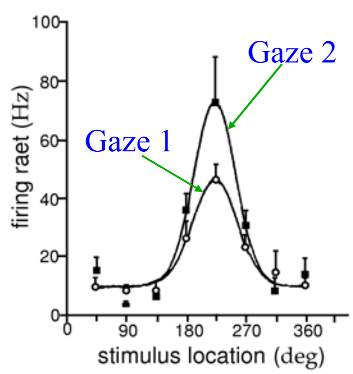
Output: Premotor Cortex Neuron with Body-Based Tuning Curves



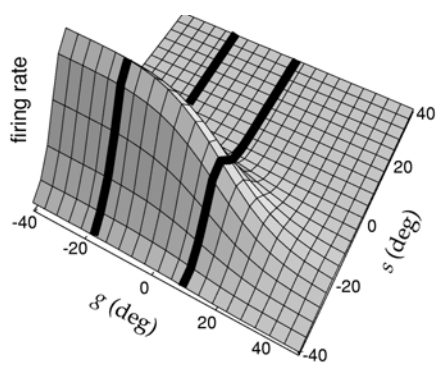
Input: Area 7a Neurons with Gaze-Dependent Tuning Curves

Input neurons exhibit *gaze-dependent gain modulation*

Gaze-Dependent Gain Modulation

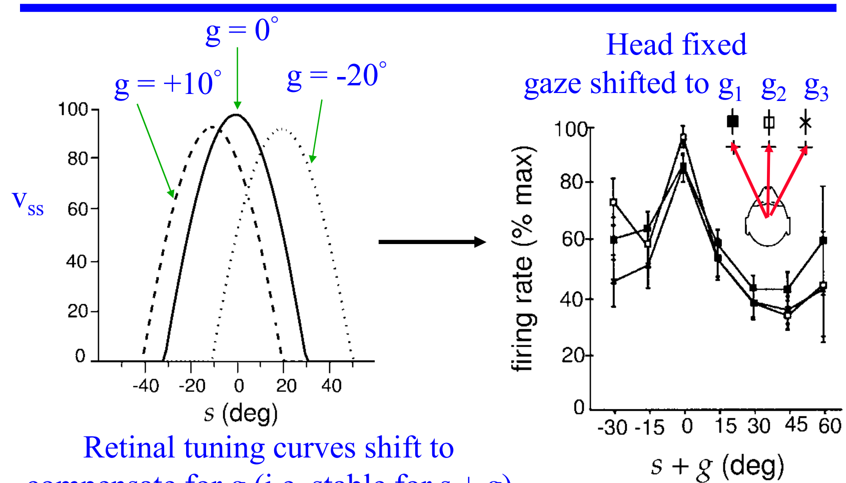


Responses of Area 7a neuron



Example of a gain-modulated tuning curve

Output of a Simulated Feedforward Network

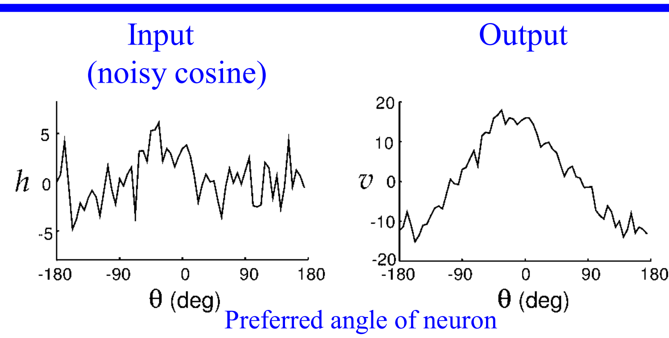


Retinal tuning curves shift to compensate for g (i.e. stable for s + g)

What can a Linear Recurrent Network do?

Analysis on board based on eigenvectors of recurrent weight matrix

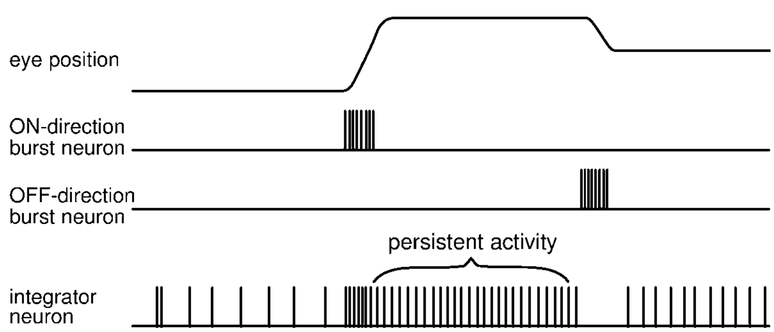
Amplification in a Linear Recurrent Network



$$M(\theta,\theta') \propto \cos(\theta-\theta')$$

All eigenvalues = 0 except $\lambda_1 = 0.9$ i.e. amplification $= \dfrac{1}{1-\lambda_1} = 10$

Input Integration for Maintaining Eye Position



Input: Bursts of spikes from brain stem oculomotor neurons
Output: Memory of eye position in medial vestibular nucleus

Next Class: More on Networks

- Things to do:
  - Finish reading Chapter 7
  - Homework #3 due next class
  - Start working on mini-project