Temporal processing: Models of audition and olfaction

AIMS

- Understand how delay lines and coincidence detection can be used to produce responses tuned to inputs with specific time differences.
- Explain how the auditory system of the Barn Owl can detect inter-aural time differences and use this information to determine the azimuthal angle of a sound
- Describe how the rat olfactory system solves the problem of detecting weak odours masked by the presence of strong odours.

READING

- Konishi M `Neural mechanisms of auditory image formation' in: The Cognitive Neurosciences Ed: M S Gazzaniga (MIT press, 1995)
- Ambros-Ingerson J, Granger R, Lynch G (1990) `Simulation of paleocortex performs hierarchical-clustering' Science 247 1344-1348

Summary

1. Sound localisation in the Barn Owl brain stem (Konishi, 1995)
   a) Interaural time difference (ITD) and the cross-correlation model (Jeffress, 1948)
   b) Using tonotopic organisation and delay lines to model the nucleus laminaris.
   c) `Coincidence detection' (multiplication of frequencies, not addition), e.g. leaky integrate-and-fire neuron with short time-constant (Bugmann, 1991; Yin and Chang, 1988).
   d) Convergent (cf divergent) projection to the lateral shell and center-surround projection to central nucleus of the inferior colliculus to remove secondary peaks in cross-correlogram.
   e) Parallel use of iteraural intesity difference (IID)
2. Brief intro. to sensori-motor integration and the superior colliculus
3. Hierarchical clustering in the olfactory system (Ambrose-Ingerson et al., 1990).
   a) Model of the olfactory bulb and piriform cortex.
   b) Hierarchical competitive learning by inhibitory feedback (cf competitive queuing
   c) Solving the `hidden odour' problem.

Further reading

Bugmann G (1991) `Summation and multiplication: two distinct operation domains of leaky integrate-and-fire neurons', Network 2 489-509.

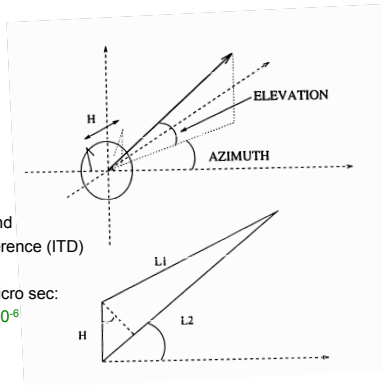
Gerstner W, Kempter R, Van Hemmen J L, Wagner H (1996) `A neuronal learning rule for submillisecond temporal coding' Nature 383 76-78.

Hopfield J J (1995) `Pattern-recognition computation using action-potential timing for stimulus representation' Nature 376 33-36.

Jeffress L A (1948) `A place theory of sound localization' J. Comp. Physiol. Psychol. 41 35-39.

Yin T C T and Chang J C K (1988) `Neural mechanisms underlying interaural time sensitivity to tones and noise, in: Auditory Function Eds: Edelman G M, Gall W E, and Cowan, W M) New York: Wiley pp 385-430.

Sound-localisation & inter-aural time-difference.



$L2 - L1 = V \times \Delta T$

where V = speed of sound

ΔT = interaural time difference (ITD)

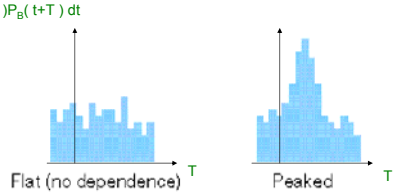
e.g. ITD might be 170 micro sec:

$5.6cm = 330m/s \times 170 \times 10^{-6}$

Using cross-correlation to estimate ITD from noisy spike trains from each cochlear (Jeffress, 1948)

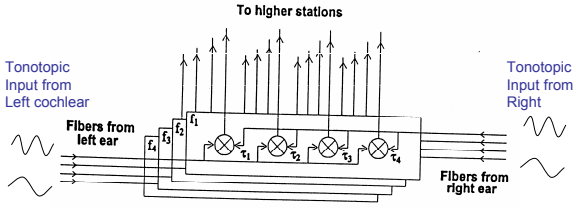
Cross correlation of spike trains A and B:
Probability that a spike in B occurs T secs after a spike in A

$P_{AB}(T) = \int P_A(t) P_B(t+T)\, dt$



Find T that maximises the cross-correlation between signals from the left and right ears

Barn owl nucleus laminaris* does cross-corellation?



- If transmission delay difference matches ITD, signals arrive simultaneously from Left and Right ears.
- Can implement cross-correlation model, but need:
  1. Accurate phase-locking to stimulus onset
  2. Frequency of firing proportional to product of inputs (not sum):

     $o = x_L x_R$ (not $x_L + x_R$)

     if x_L = probability of stimulus onset in left ear.

* In cochlear nucleus of the brainstem

Very leaky 'integrate and fire' neuron model does 'coincidence detection'.

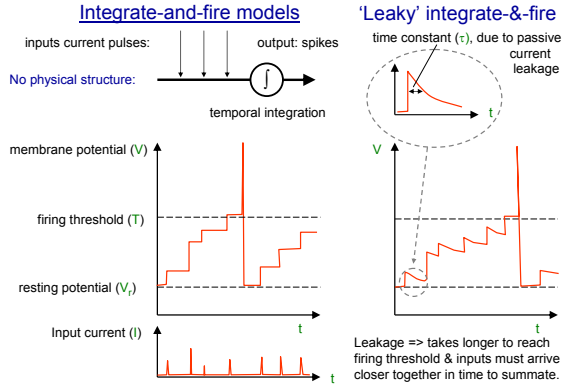
If time constant T << period (1/frequency) of inputs from L or R ear and Threshold is near 2, then model neuron only fires for coincident inputs, and effectively *multiplies* the probabilities of getting a spike on either input

P_{out}(spike in [t, t+T]) = P_L (spike in [t, t+T])x P_R (spike in [t, t+T])

Firing rate = P_{out}(spike in [t, t+T]) / T

Integrate-and-fire models

'Leaky' integrate-&-fire



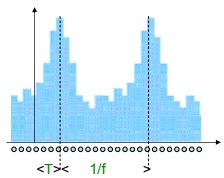
Leakage => takes longer to reach firing threshold & inputs must arrive closer together in time to summate.

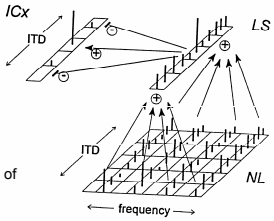
C= q/V; CV=q; CdV/dt = I; $C\,dV/dt = (V_r - V)/\tau + I$, with spike if V = T

Problem of secondary peaks in cross correlation..

..but will be different for each frequency f.

So only the primary peaks will add constructively: giving the greatest net activation:

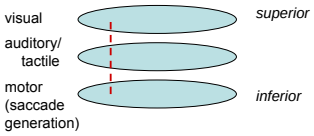




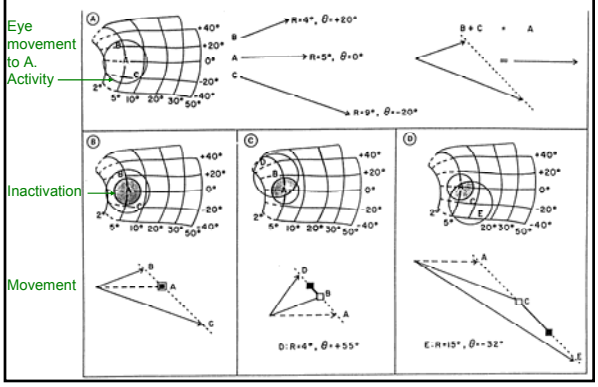
LS = lateral shell of the central nucleus of the inferior colliculus (ICx).

How is auditory map of space used? An example of sensory-motor integration

The *colliculus*: maps aligned in retinal co-ordinates so that auditory (as well as visual) stimuli can generate eye-movements.



Colliculus: retinotopic map for saccade generation: population averaging scheme (Sparks, Holland, Guthrue, 1976)



Temporal processing in olfaction

Features: Sniff cycle (theta rhythm); Odour-masking (Ambrose-Ingerson et al., 1990)

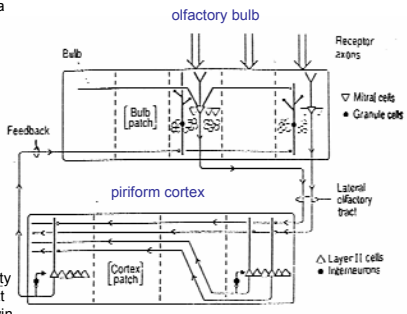
Bulb: cyclic inhibition via medial septum; normalisation of net activity

Cortex: densely supported sub-nets (learned lateral connections)

Connections:
Feedforward: mitral - layer II (+ve);
Feedback: layer II – granule cells (-ve)

Dynamics: winning subnet inhibits activity in bulb, allowing next strongest odour to win

see competitive queuing..



Simulation of solution to odour-masking within sniff-cycle

TABLE 3.1
Sequential Cortical Responses to Learned and Unlearned Odor Mixtures.

	Odor mixture	*Response 1*	*Response 2*
Before learning of odors S or W	S + W	part S, part W	remainder S, W
After learning of odors S and W, individually	S + W	S	W