Optimal information processing in neural populations.

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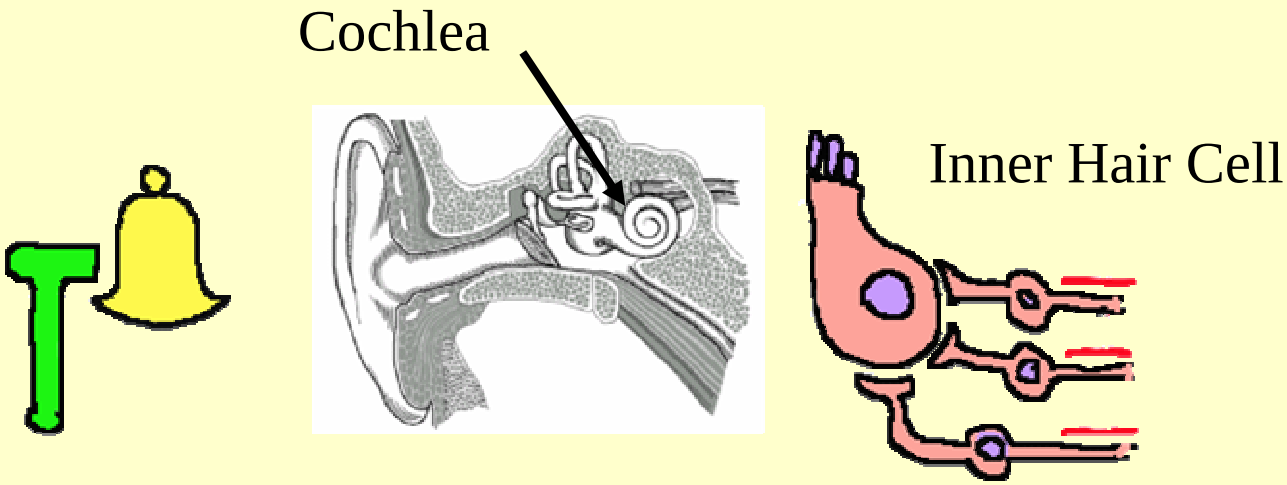
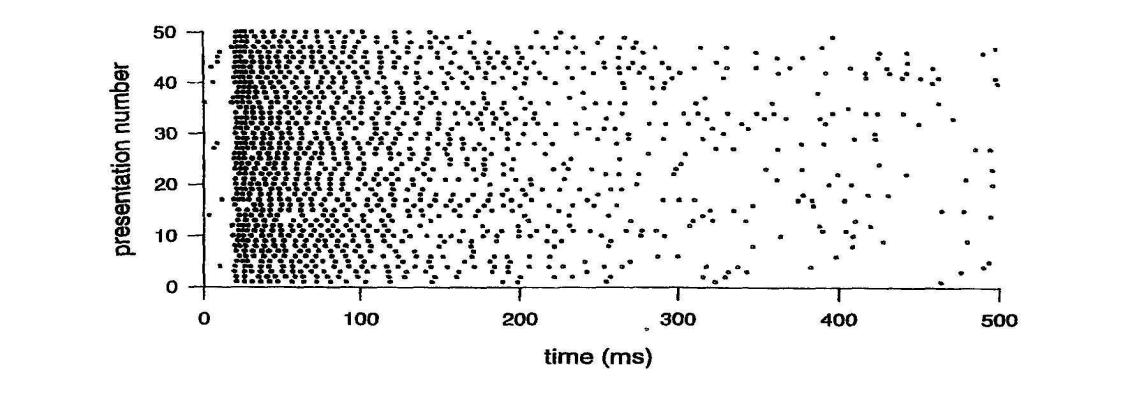
Sensory signal transduction



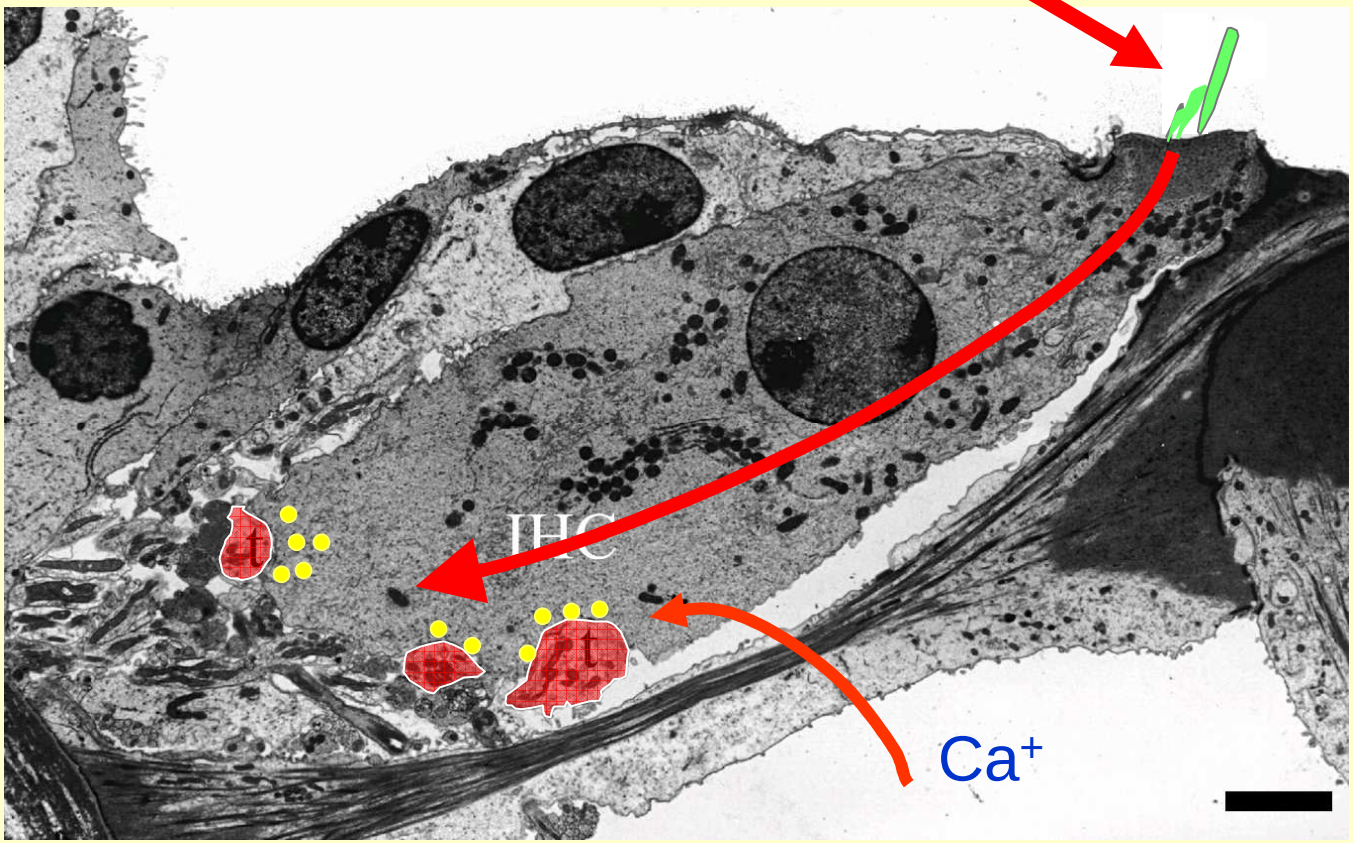


Data from H1 neuron of fly
(taken from ‘Spikes’, Rieke *et al*)

HAIR CELLS
(mechanical transducers)

Stereocilia
("hairs")

K^+



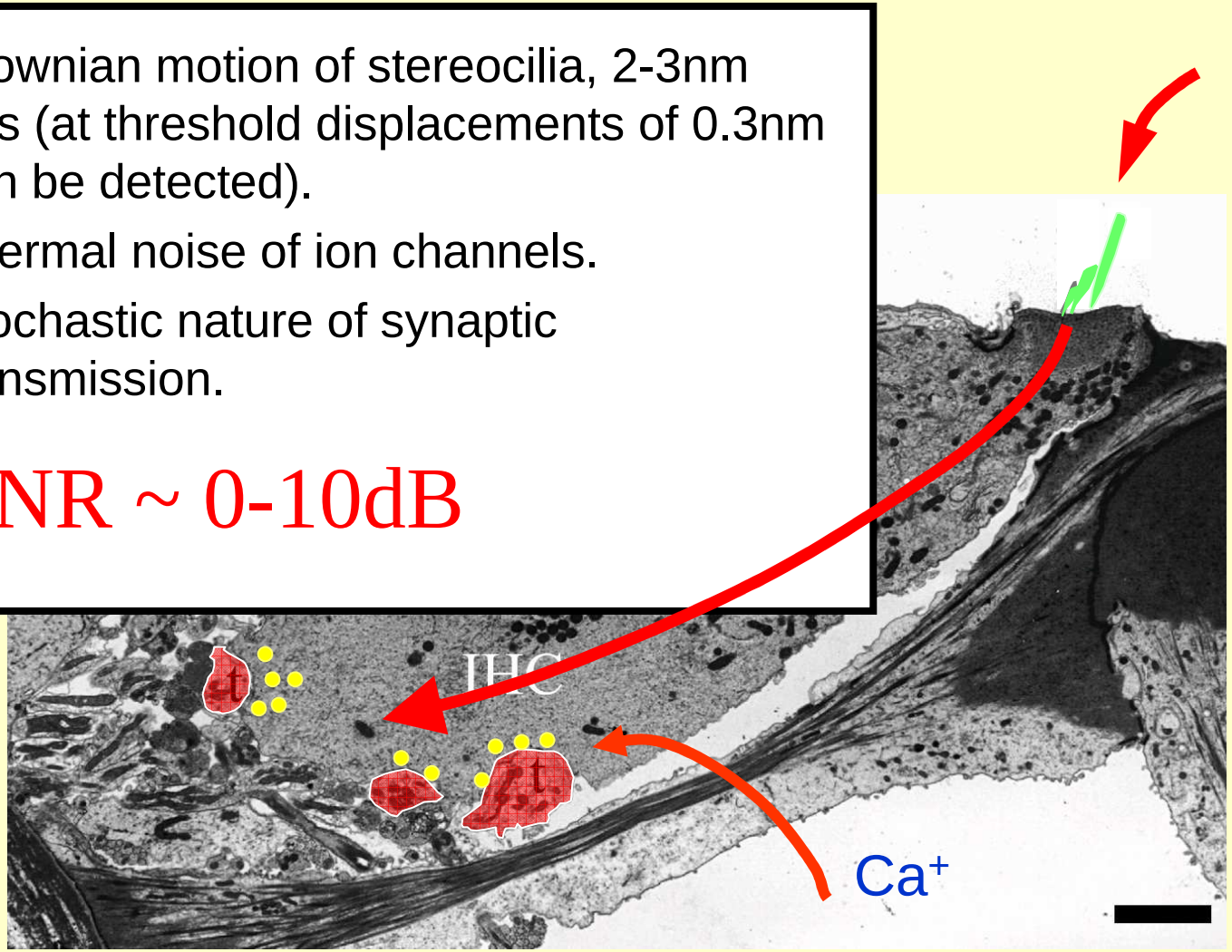
5 μm

Electron microscope image courtesy of Dr. David Furness, Keele University.

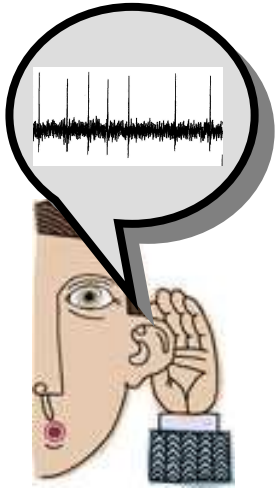
Noise sources

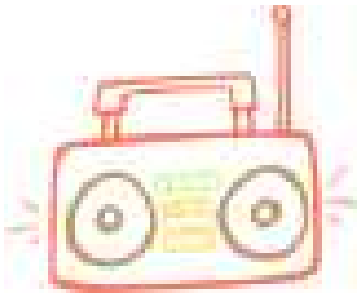
- Brownian motion of stereocilia, 2-3nm rms (at threshold displacements of 0.3nm can be detected).
- Thermal noise of ion channels.
- Stochastic nature of synaptic transmission.

SNR ~ 0-10dB



Electron microscope images courtesy of Dr. David Furness, Keele University.





SNR ~ 0dB

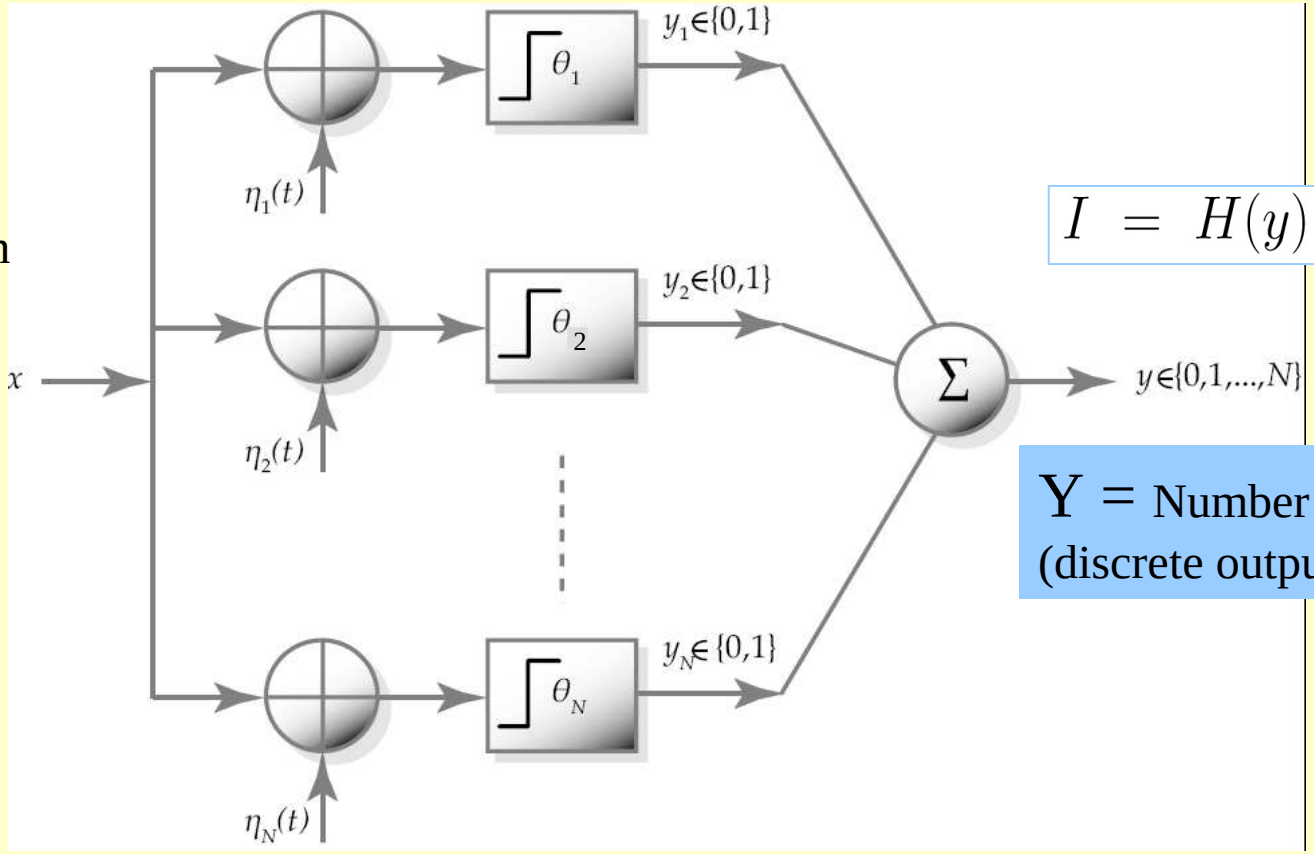
SNR ~ 70dB

To understand performance need to consider collective behaviour of neurons.

How do we maximise information flow through a population of noisy neurons?

Array of *N* McCulloch-Pitts Neurons

Random Gaussian signal



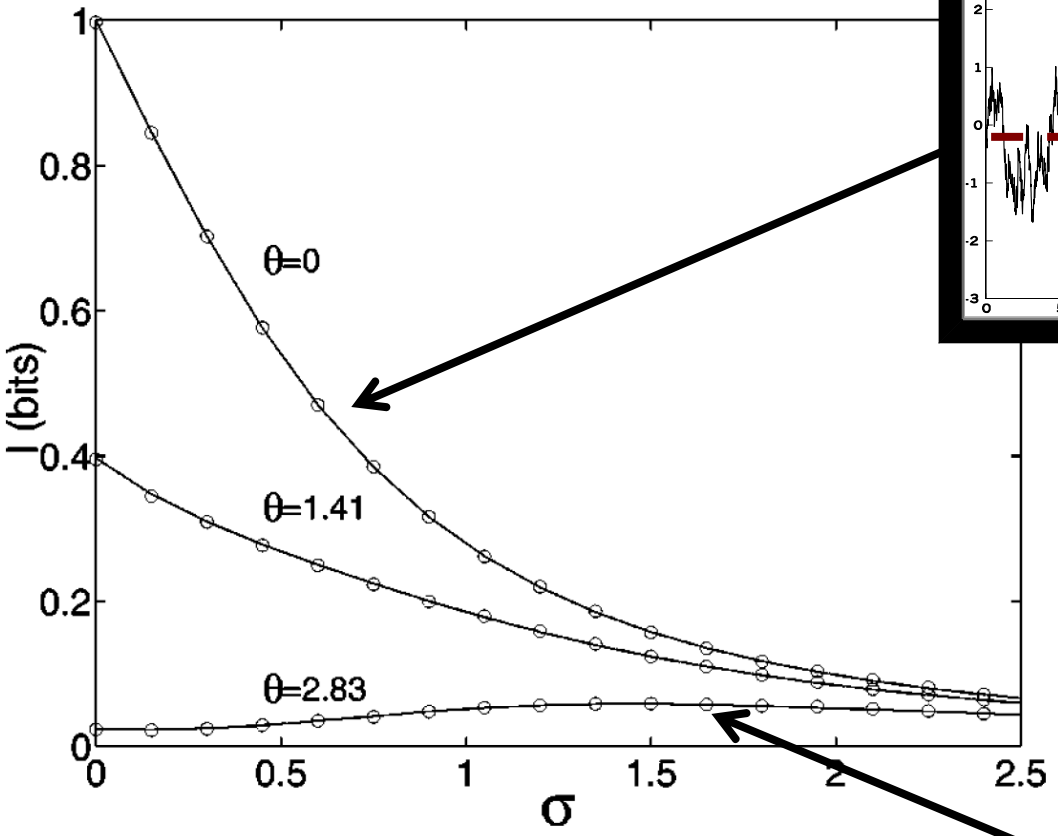
$$I = H(y) - H(y|x)$$

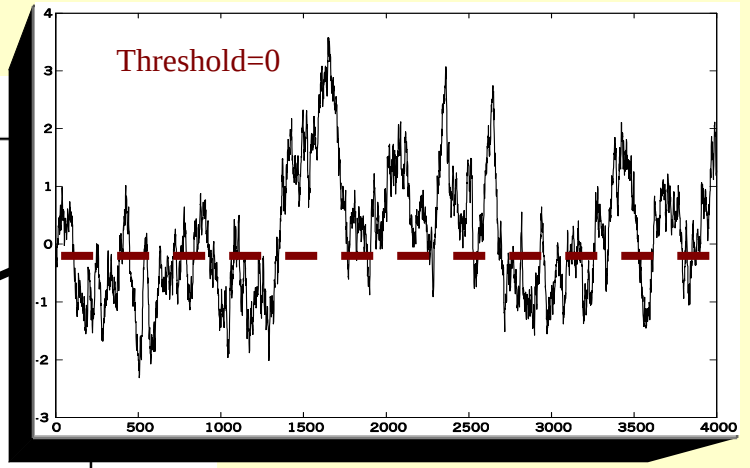
Y = Number of units 'on' (discrete output)

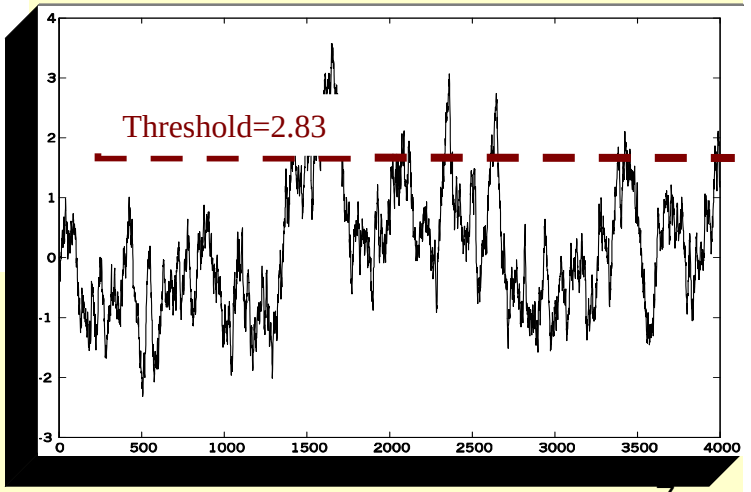
Each unit has the transfer function given by

$$y_i = \begin{cases} 1 & \text{if} \quad \mathrm{X} + \eta_i > \theta_i \\ 0 & \text{if} \quad \mathrm{X}) + \eta_i < \theta_i \end{cases}$$

N=1 (single neuron)





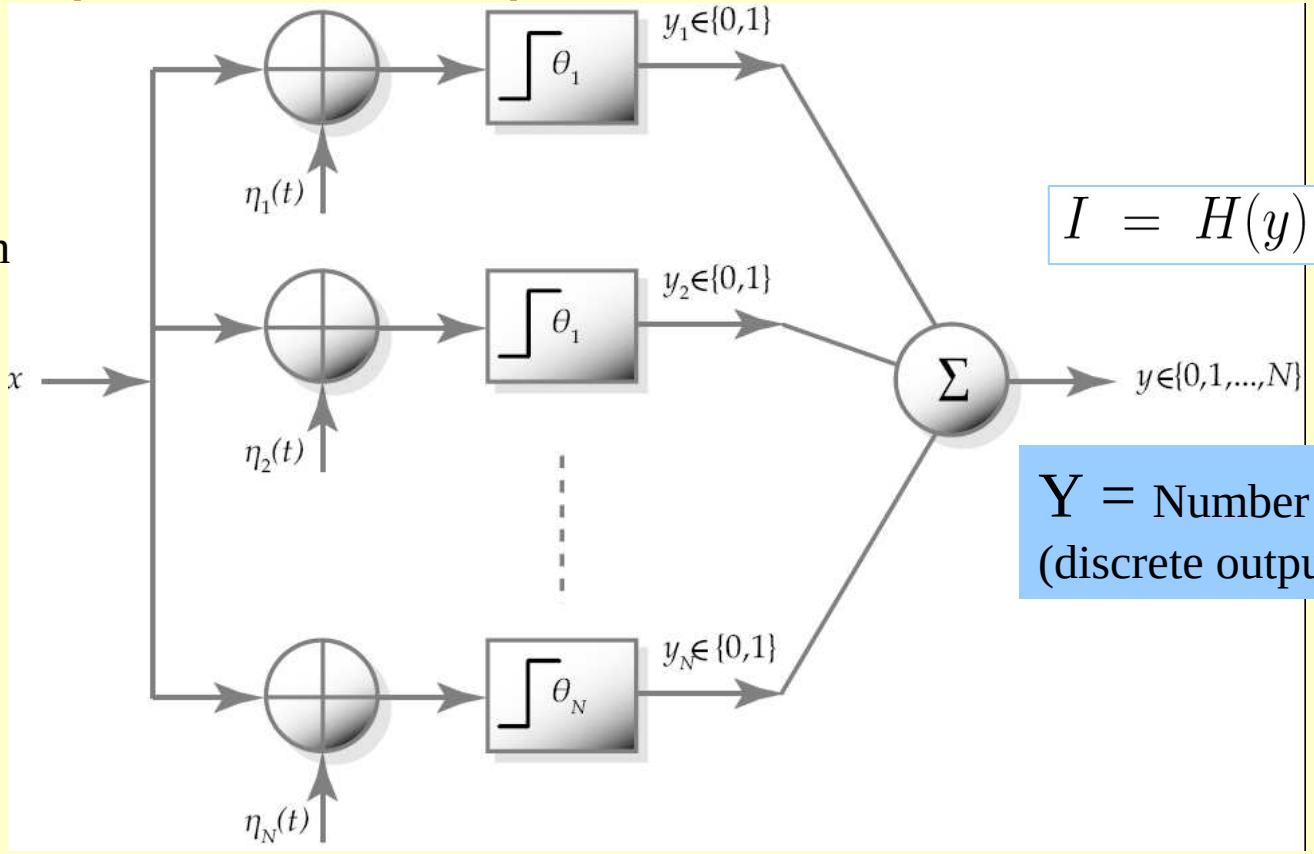


$$\sigma = \frac{\text{noise power}}{\text{signal power}}$$

Maximising Information for identical thresholds

Array of *N* McCulloch-Pitts Neurons (comparators)

Random Gaussian signal



$$I = H(y) - H(y|x)$$

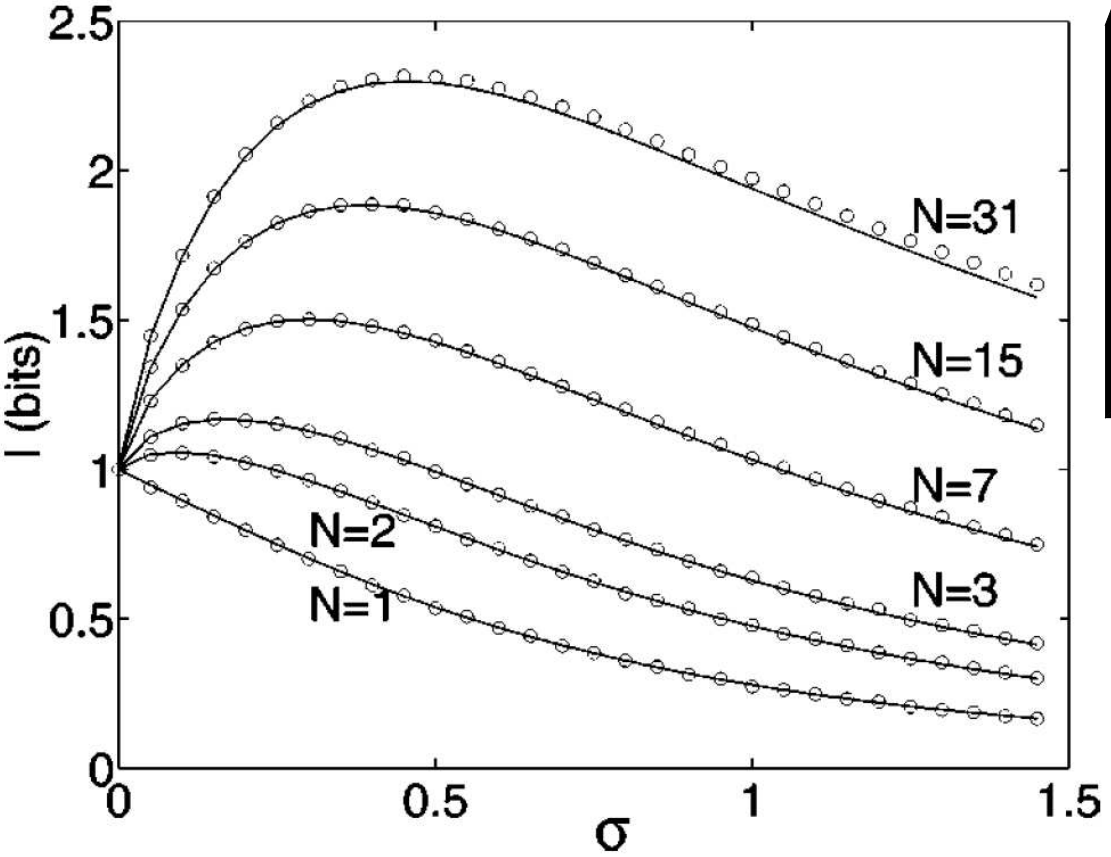
Y = Number of units 'on' (discrete output)

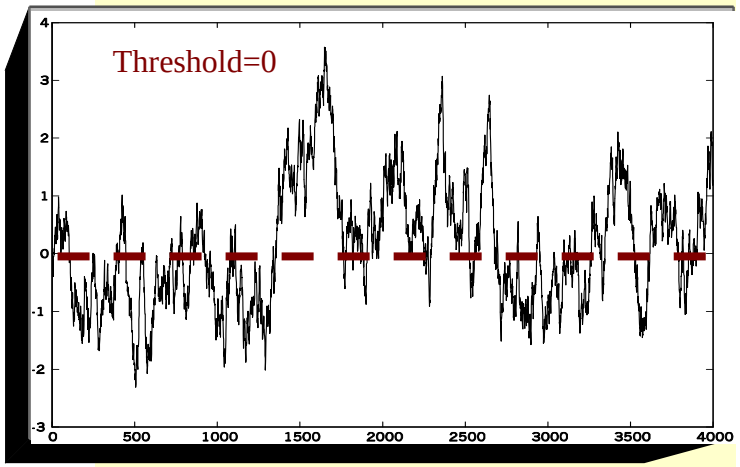
Each unit has the transfer function given by

$$y_i = \begin{cases} 1 & if \quad X + \eta_i > \theta_i \\ 0 & if \quad X + \eta_i < \theta_i \end{cases}$$

N>1 and $\{\vartheta_i\}=0$

Suprathreshold Stochastic Resonance (SSR)

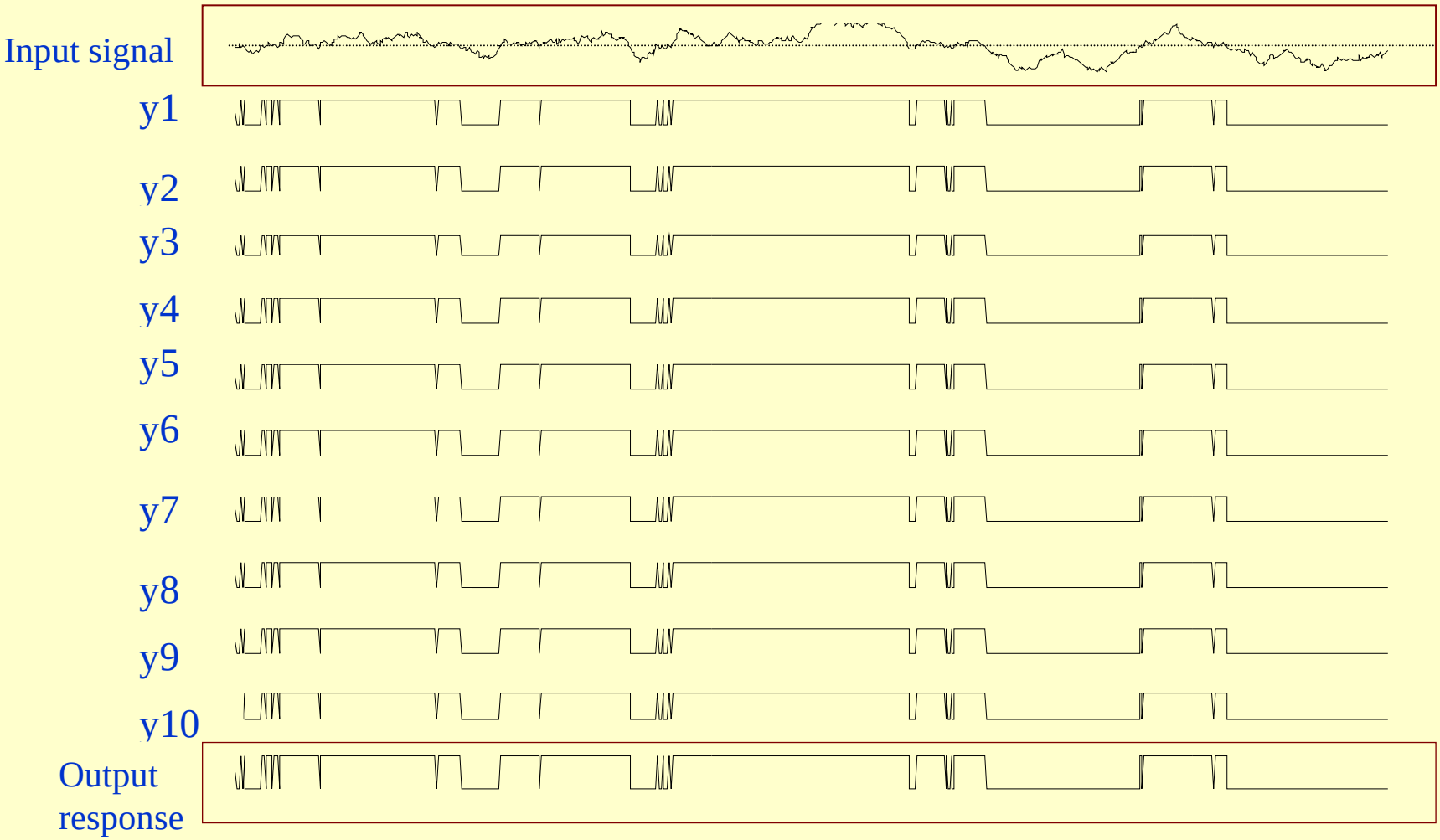




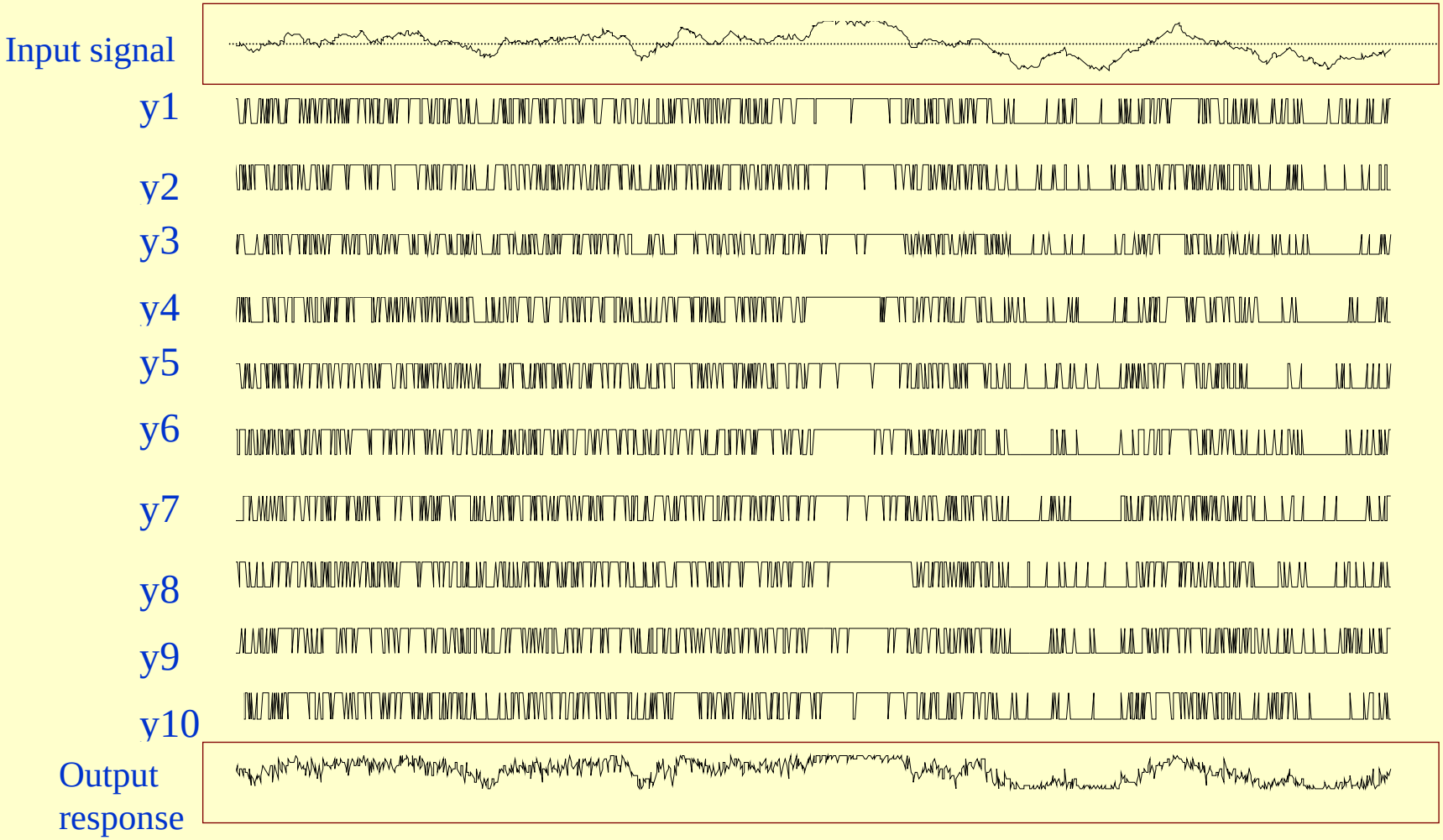
Threshold=0

N. G. Stocks, *Phys. Rev. Lett* ***84***, *2310 (2000)*

10 comparators without noise



10 comparators with noise

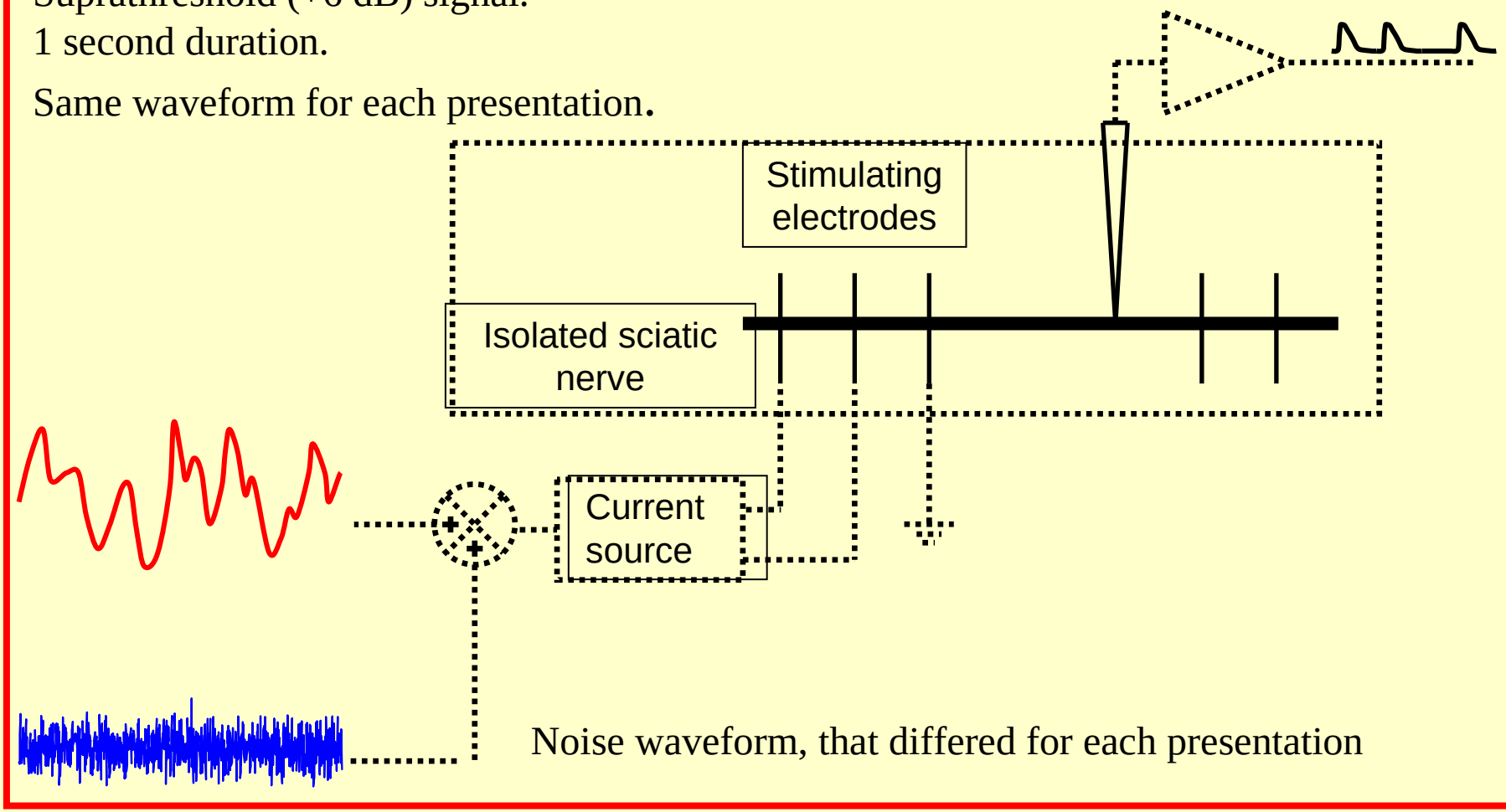


SSR in Real Neurons

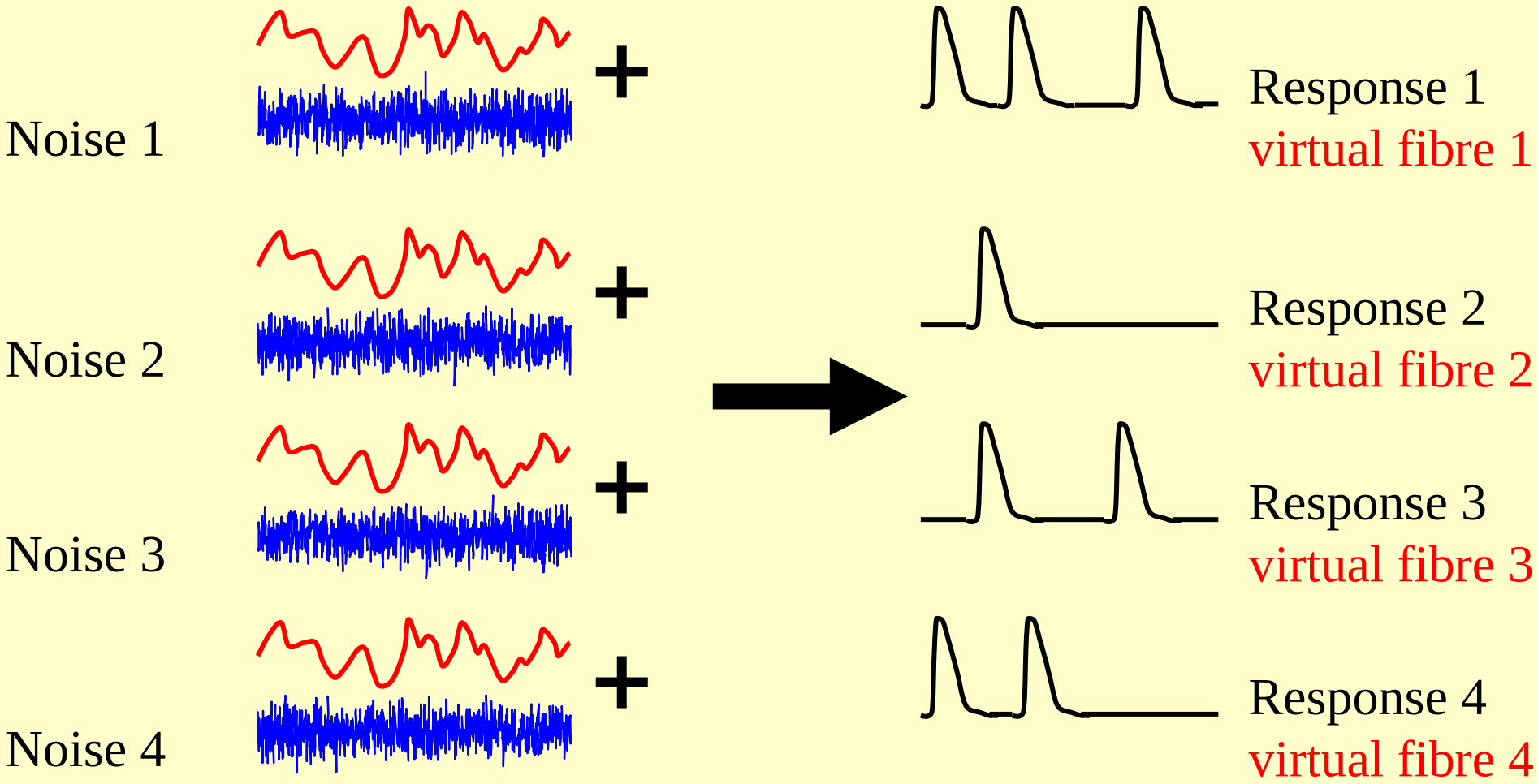
Experiments with additive noise

Suprathreshold (+6 dB) signal.
1 second duration.

Same waveform for each presentation.



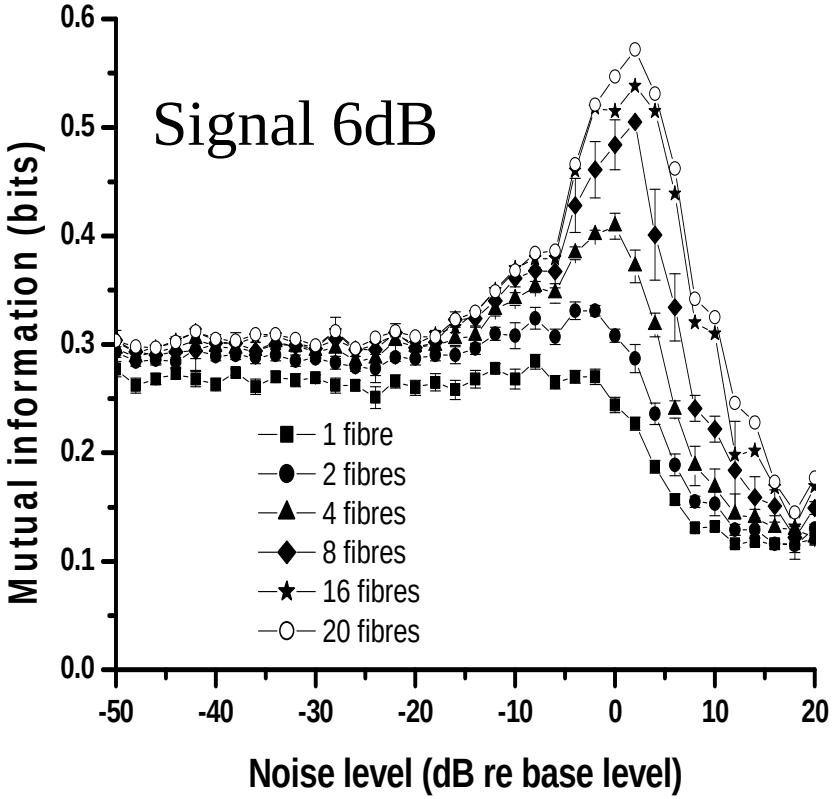
Information transmission with additive noise



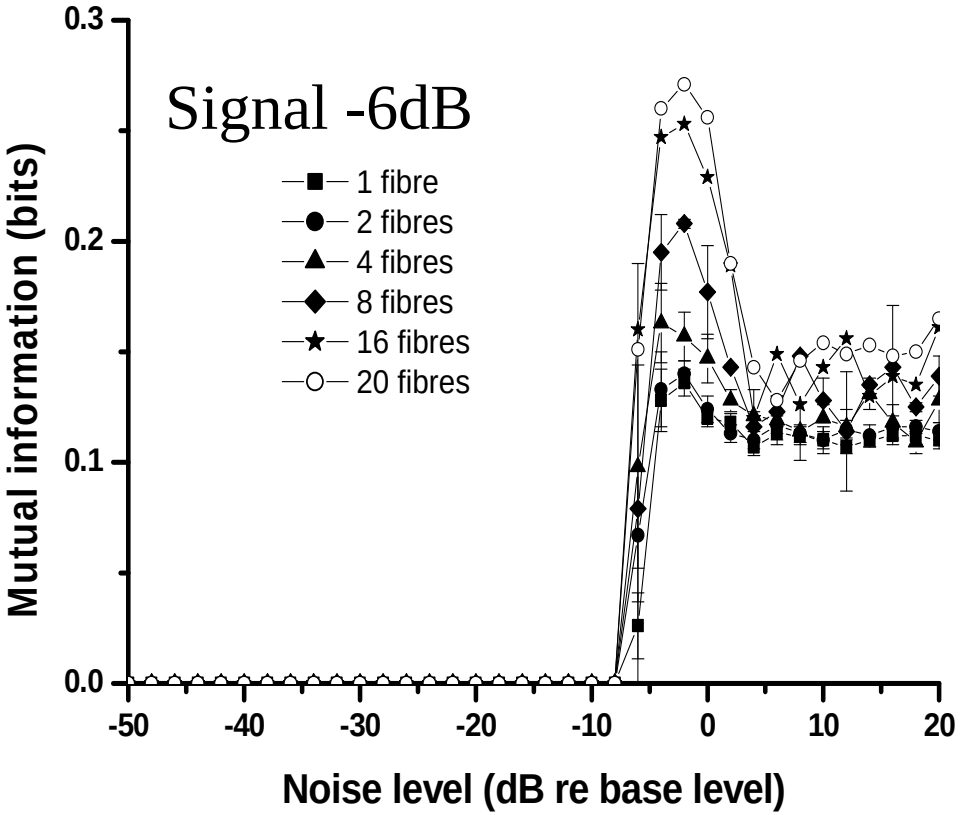
Responses from 1 sciatic nerve fibre

Experimental Results

SSR

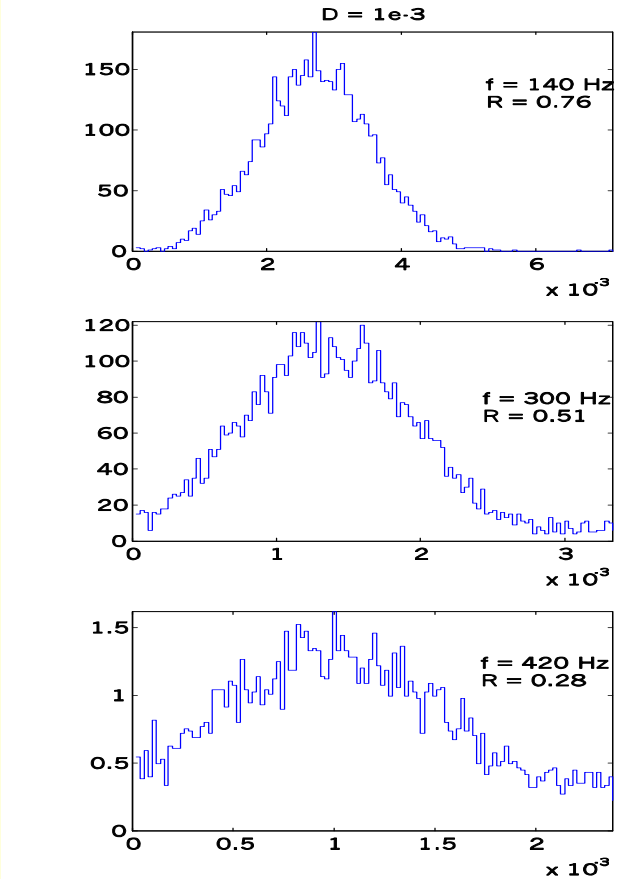


Classical SR



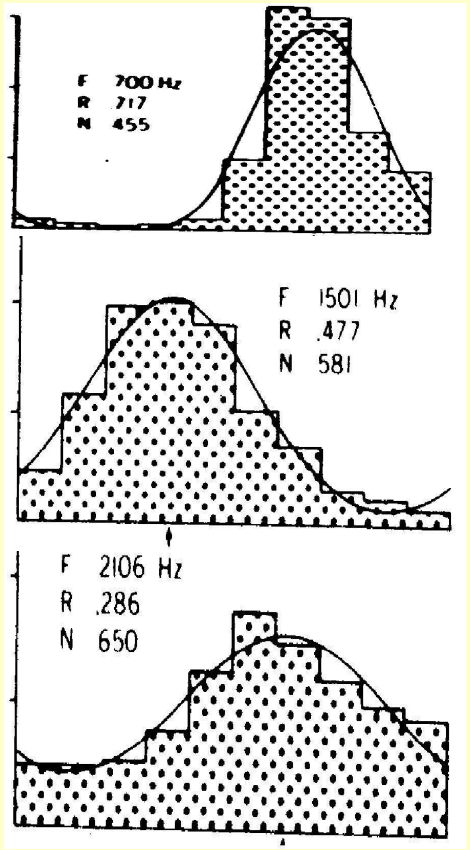
Period histograms. Comparison of single fibre acoustic data to LIF model

Model

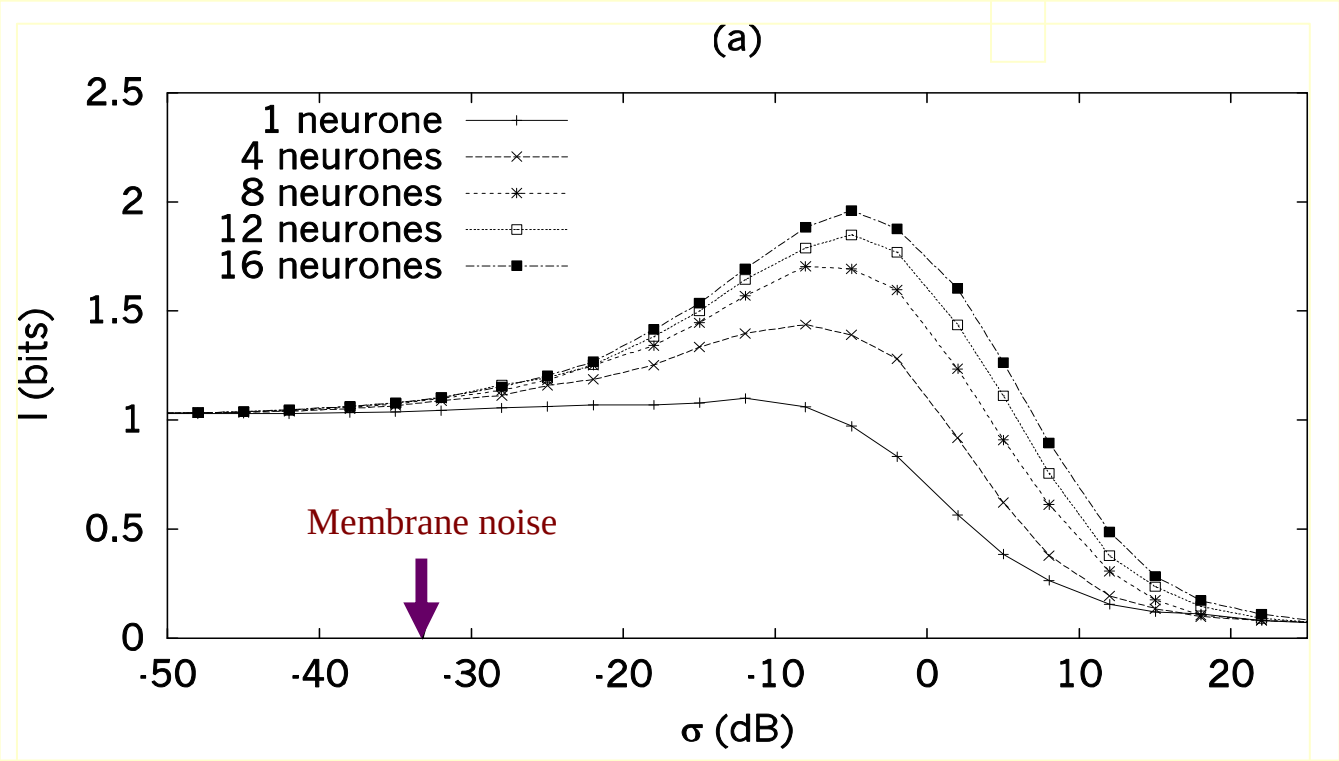


Squirrel Monkey

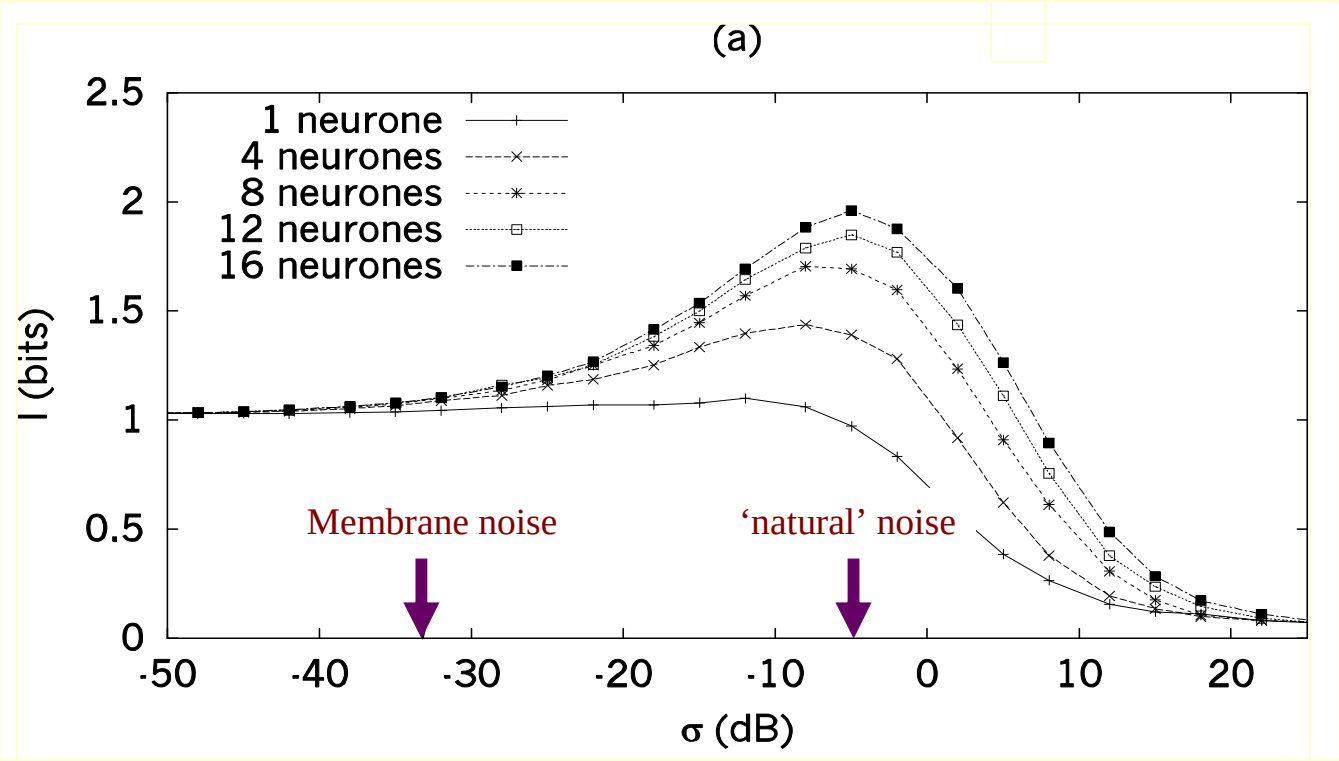
Anderson D.J, *J. Acoustic Soc. Of Am.* **54,** 361 (1973)

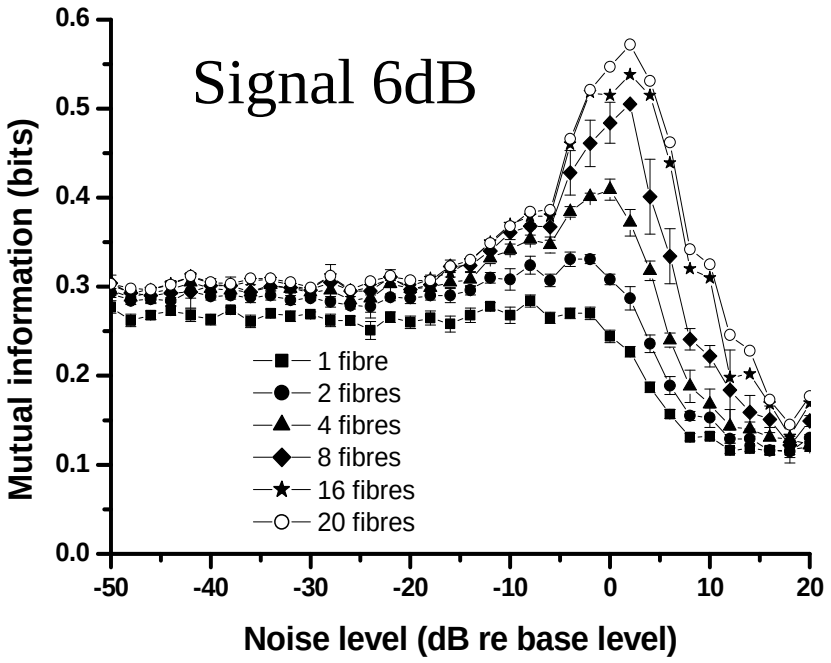


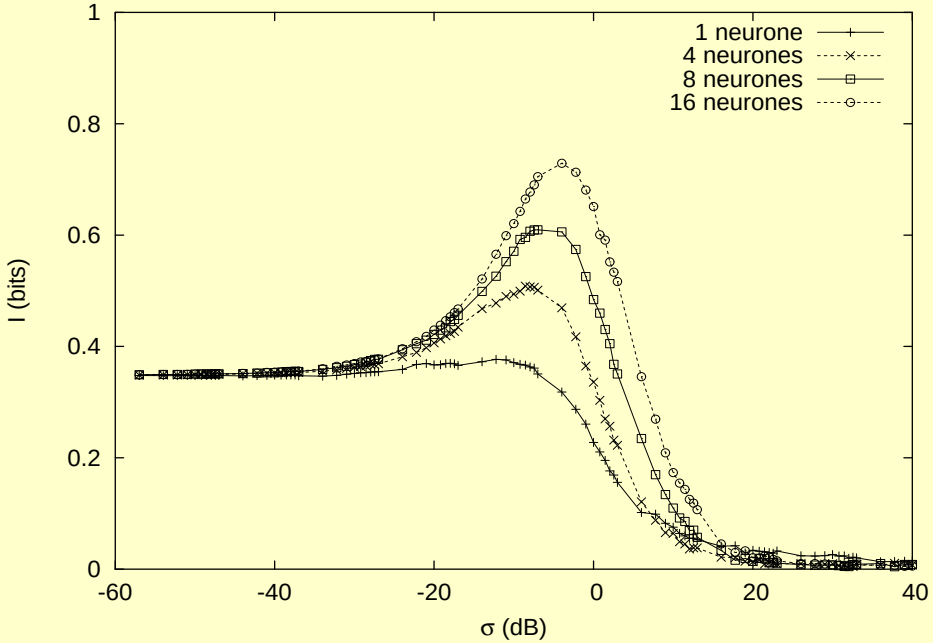
Information curves

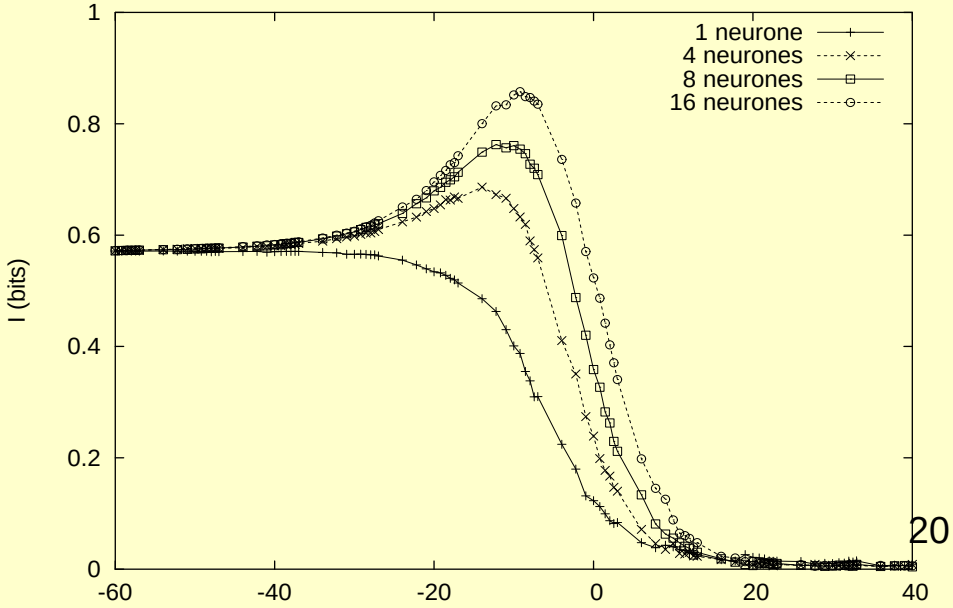


Information curves




Signal 6dB
Mutual information (bits)
Noise level (dB re base level)
1 fibre
2 fibres
4 fibres
8 fibres
16 fibres
20 fibres


I (bits)
σ (dB)
1 neurone
4 neurones
8 neurones
16 neurones


I (bits)
1 neurone
4 neurones
8 neurones
16 neurones

```
ERROR: invalidrestore
OFFENDING COMMAND: restore

STACK:

-savelevel-
-savelevel-
-dictionary-
```