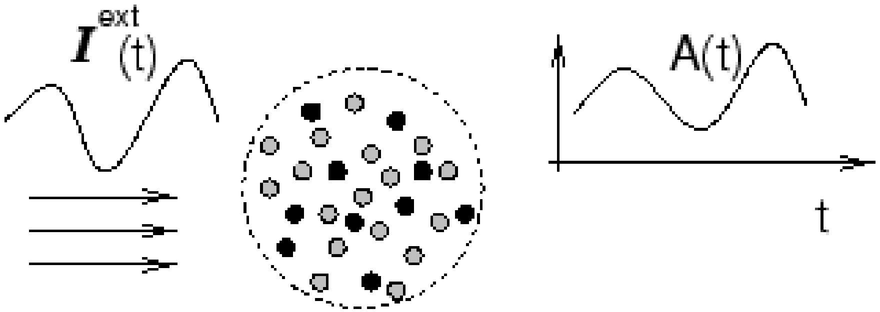
Neural Populations



In order to analyse the dynamics of recurrent spiking networks theoretically, one considers homogeneous populations of LIF- or SRM neurons.

For an external input $I^{ext}(t)$, one wants to know the population activity

$$A(t) = \lim_{\Delta t \to 0} \frac{1}{\Delta t} \frac{n_{act}(t;t+\Delta t)}{N} = \frac{1}{N} \sum_{j=1}^{N} \sum_{f} \delta(t - t_j^{(f)}).$$

Neural Populations

One can show:

$$A(t) = \int_{-\infty}^{t} P_I(t|\hat{t})A(\hat{t})d\hat{t},$$

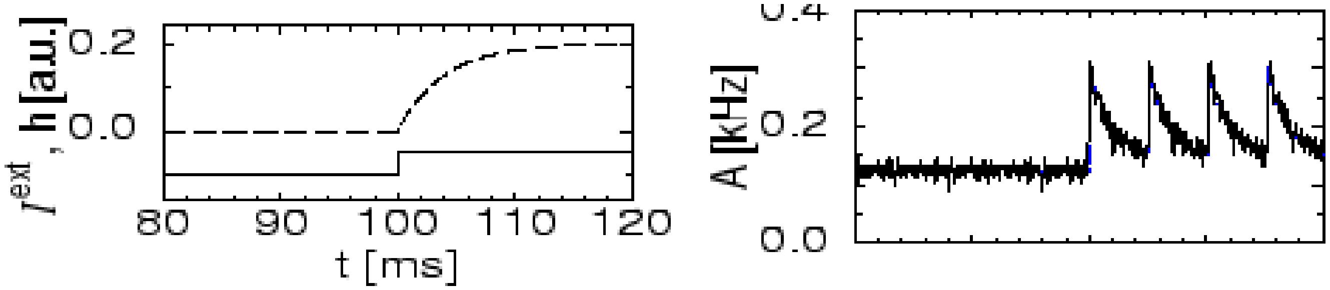
where $P_I(t|\hat{t})$ is the interval distribution of a neuron for input I given that the last action potential of the neuron was at time $\hat{t}$.

$P_I(t|\hat{t})$ depends on the external input, recurrent activity, and from the noise model.

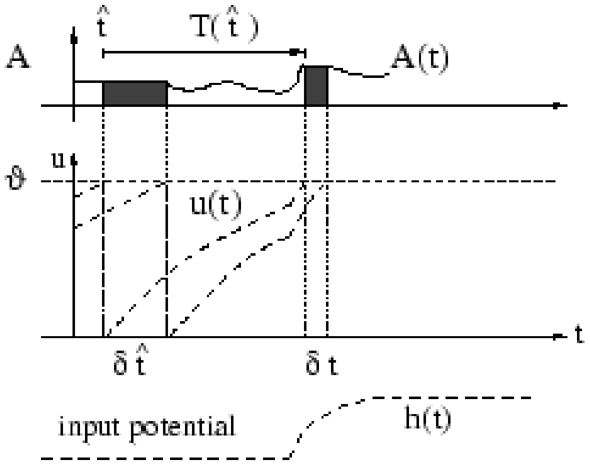
Transients in Neural Populations

For a given population of uncoupled (i.e., not connected) neurons, the response to a step input depends on the noise level

Low noise (I&F):

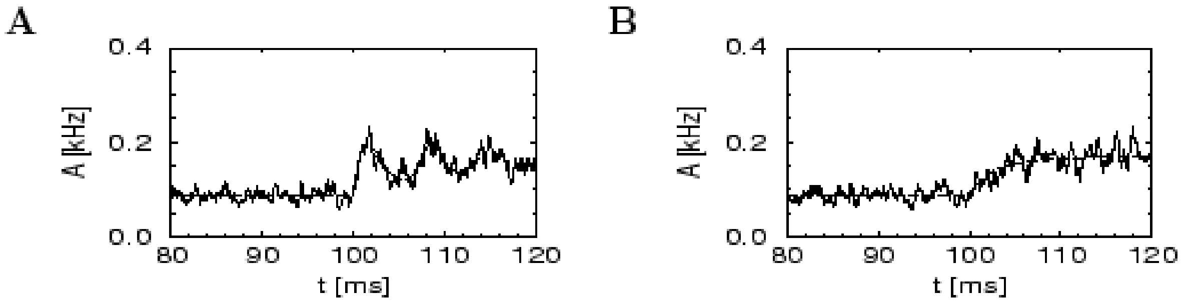


The first activity transient is proportional to the *temporal change* of the membrane potential $h(t) = \int_0^\infty \kappa_0(s) I^{ext}(t-s)$.



Transients in Neural Populations

More noise (A) and high noise (B):



For high noise, the response is proportional to the membrane potential.

(The noise model used here was white noise on the input current.)

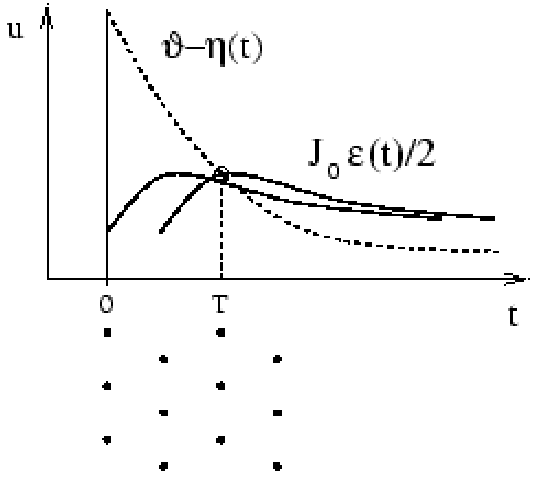
Oscillations in Neural Populations

Coupled neural populations tend to oscillate. Wheter oscillations occur depends on the synaptic delay and on the noise level.

Asynchronous Regime: Neurons are firing asynchronous. This regime is only stable for high noise levels.

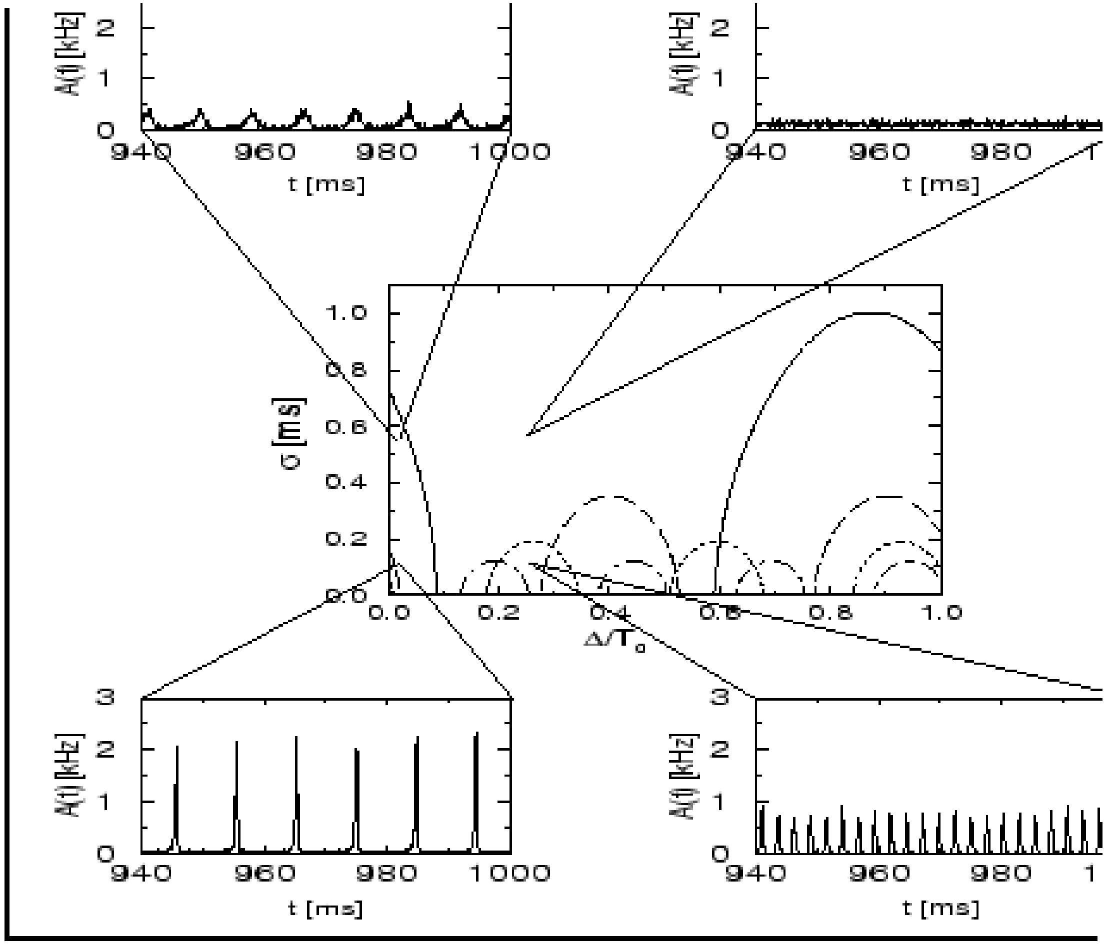
Locking: All neurons are firing together. Can be a stable state without noise.

Cluster states: Neurons divide into subgroups which fire synchronous. Neurons in each group fire synchronous and trigger the spikes of other groups.



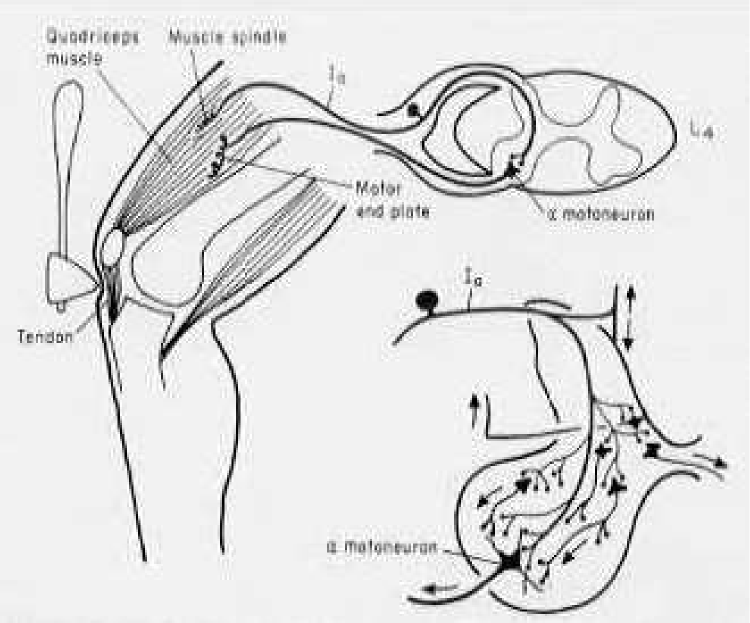
Oscillations in Neural Populations

Stability diagram:



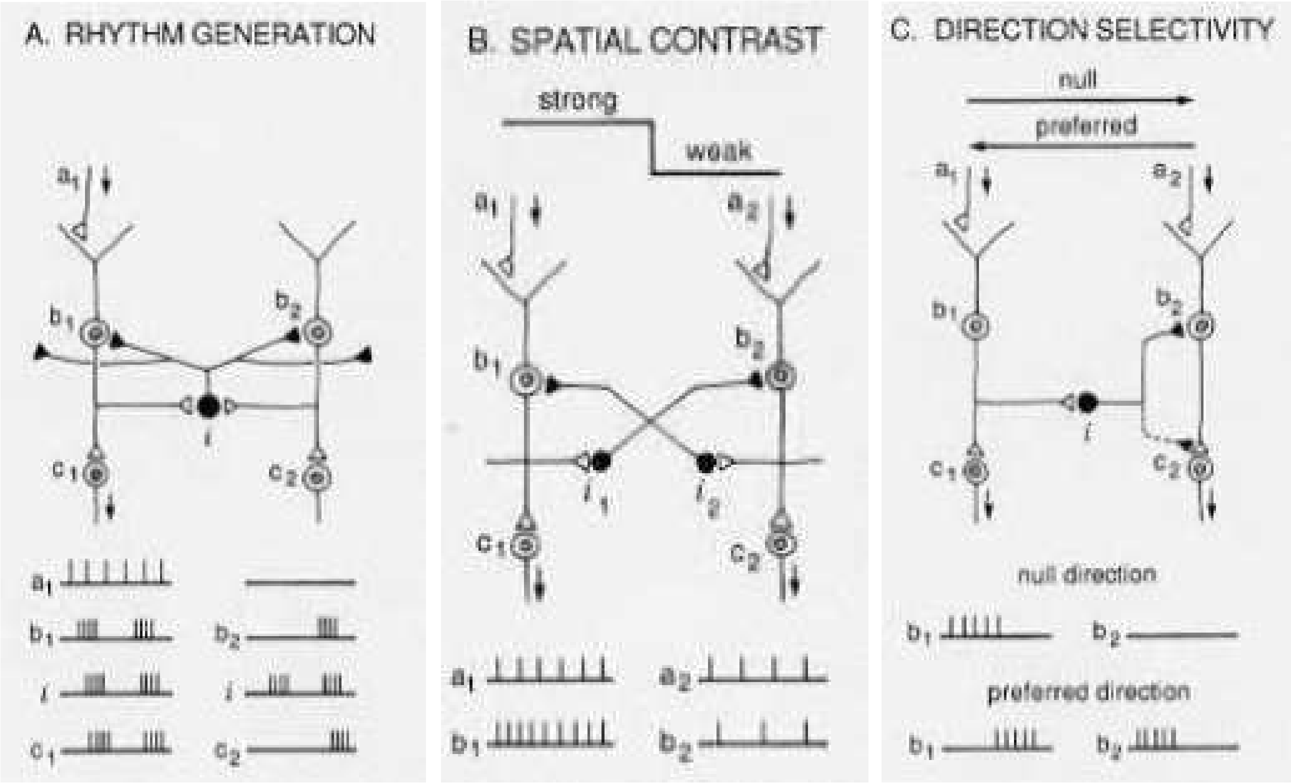
Δ is the synaptic delay, T_0 is the average inter spike interval, σ is the noise level.

Neural Circuits



- One of the simplest circuits is the circuit for the knee-reflex.
- An excitatory neuron (I_a) projects to a motoneuron.
- If the muscle is strongly streched, it is contracted due to the motoneuron.
- Reciprocal inhibition: I_a inhibits also the antagonist via an inhibitory neuron.

Simple Neural Circuits

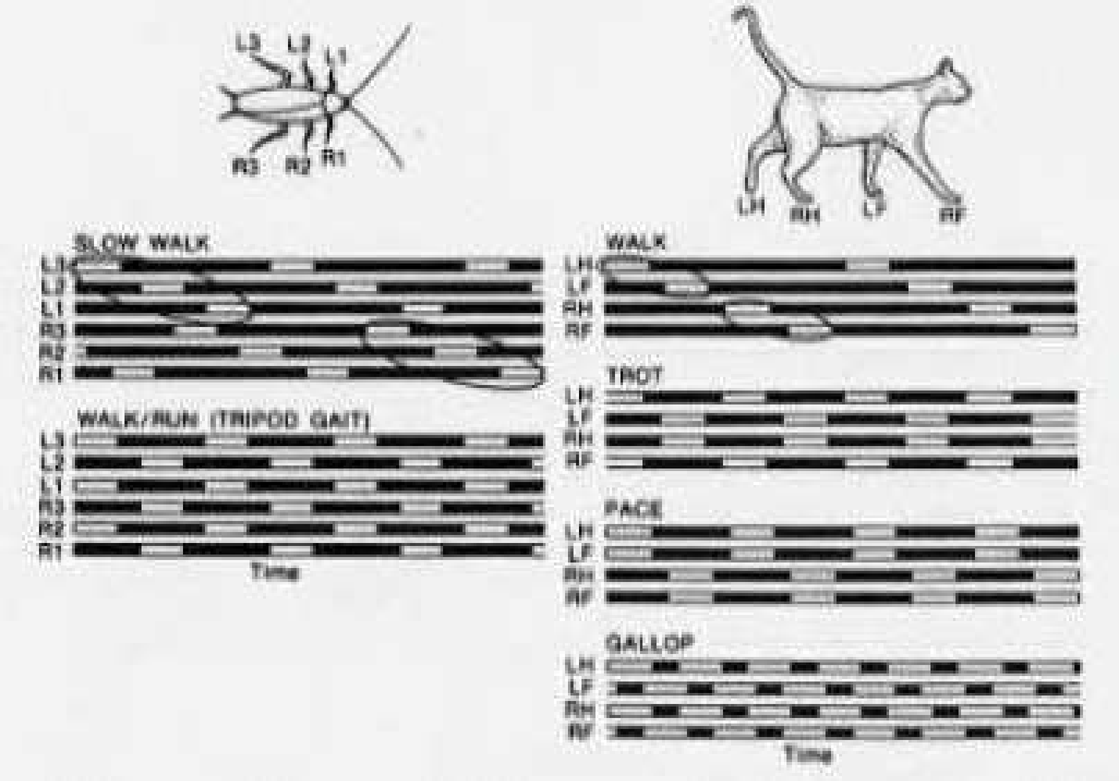


A Oscillator

B Contrast-Enhancement

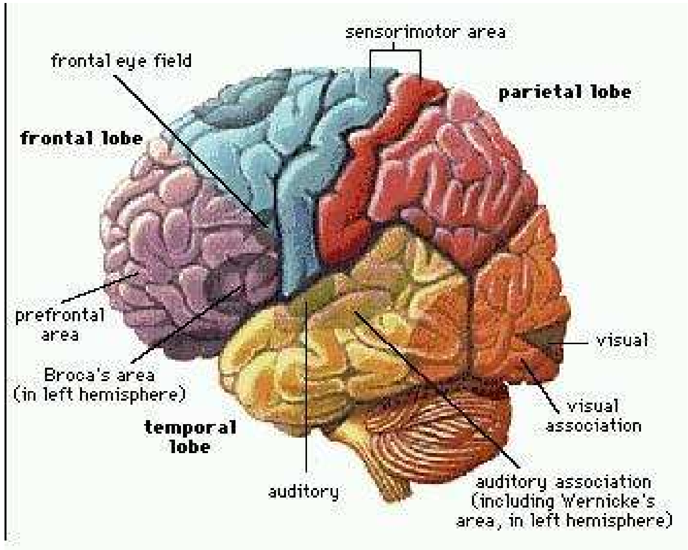
C Direction-Selectivity

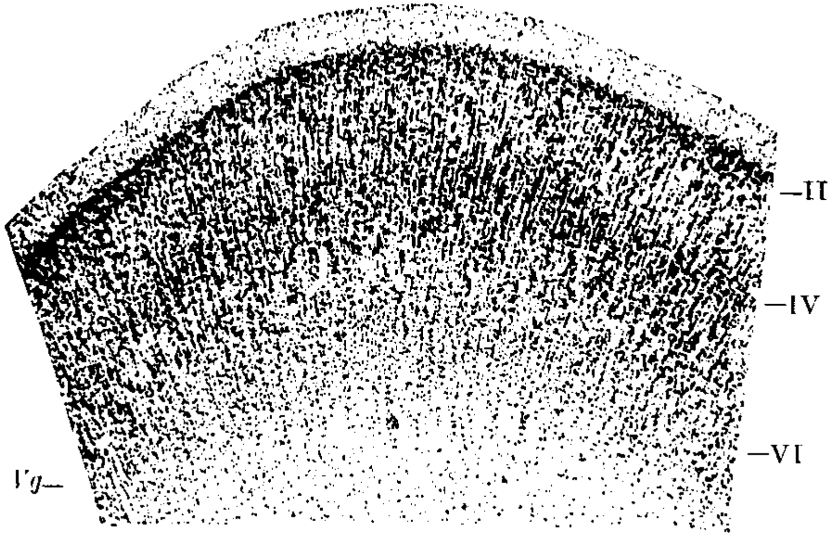
Central Pattern Generators (CPGs)



- CPG’s are coupled oscillators
- They coordinate complex walking patterns (e.g., animal gaits)
- CPG’s for gaits are in the spinal cord.
- Simple commands from the CNS can evoke complex motion patterns.

Cortical Circuits

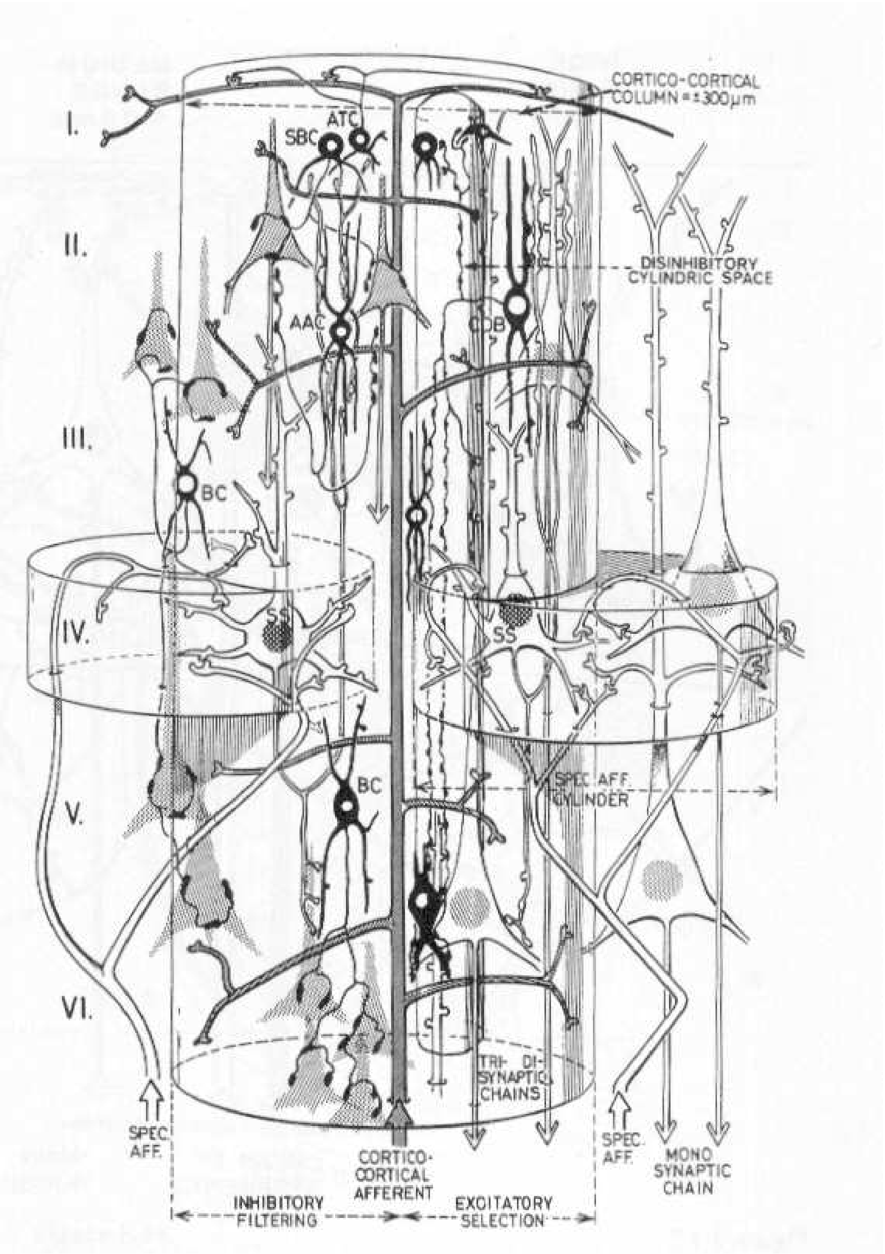




The cortex

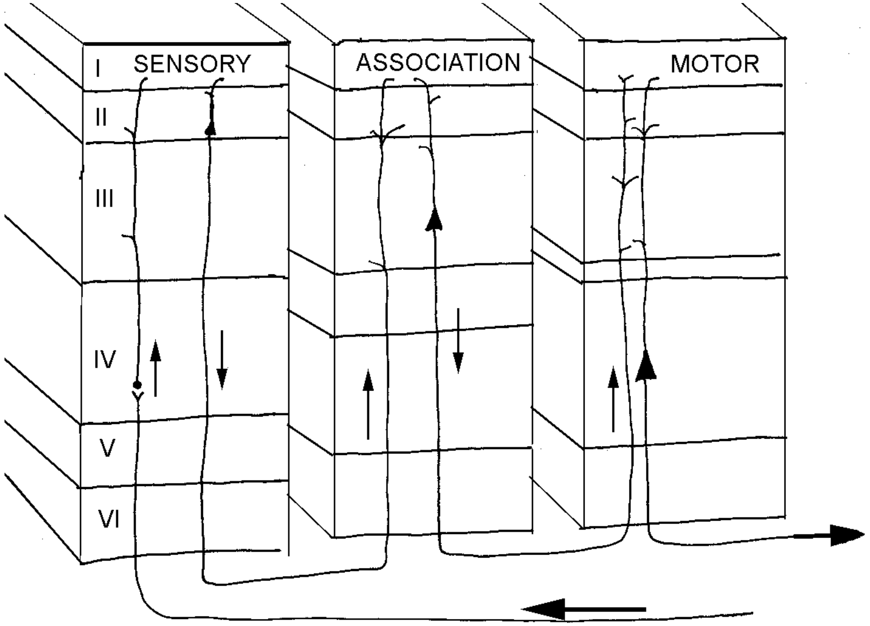
- extracts important signals from the input,
- compares them to stored patterns,
- decides which actions to take.

Cortical Circuits



Draft of the cortical column

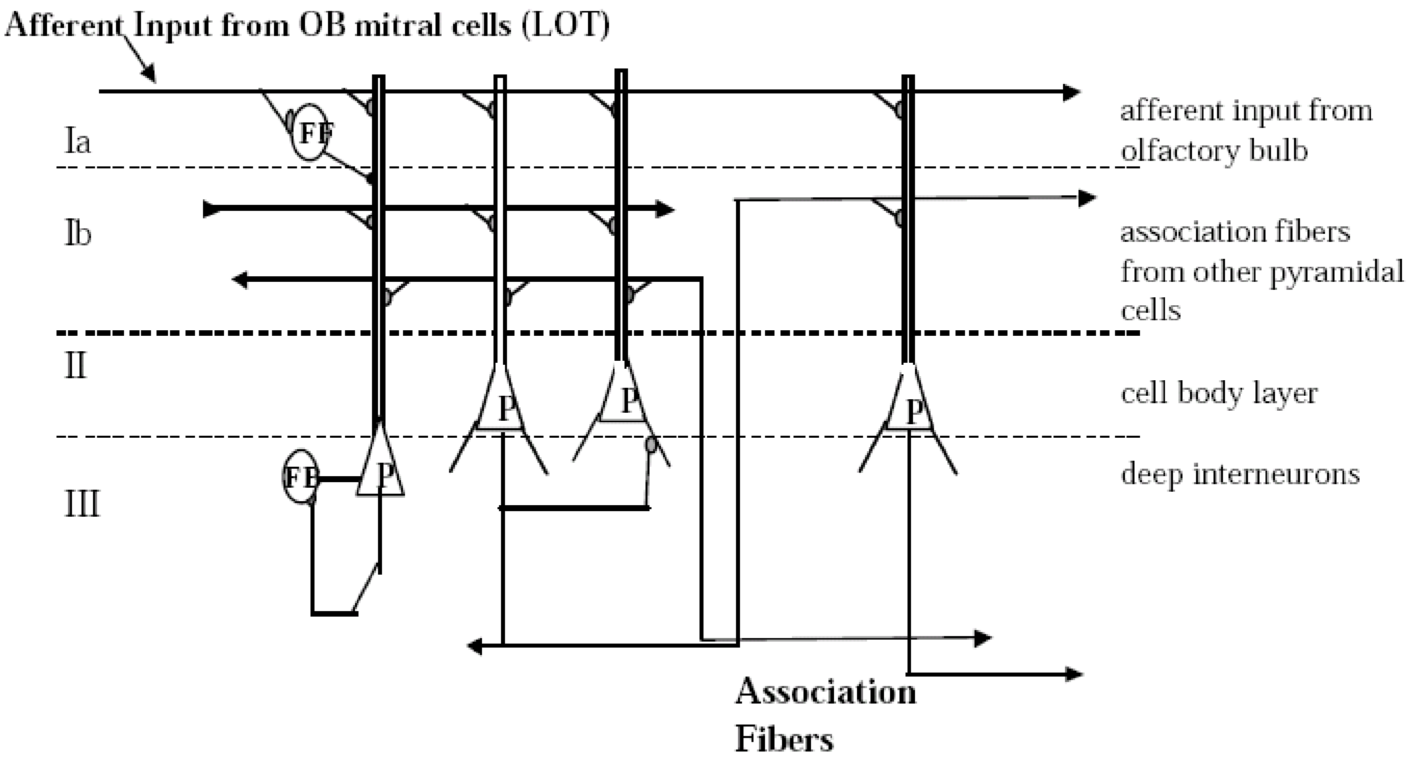
Cortical Circuits



Properties of the cortex:

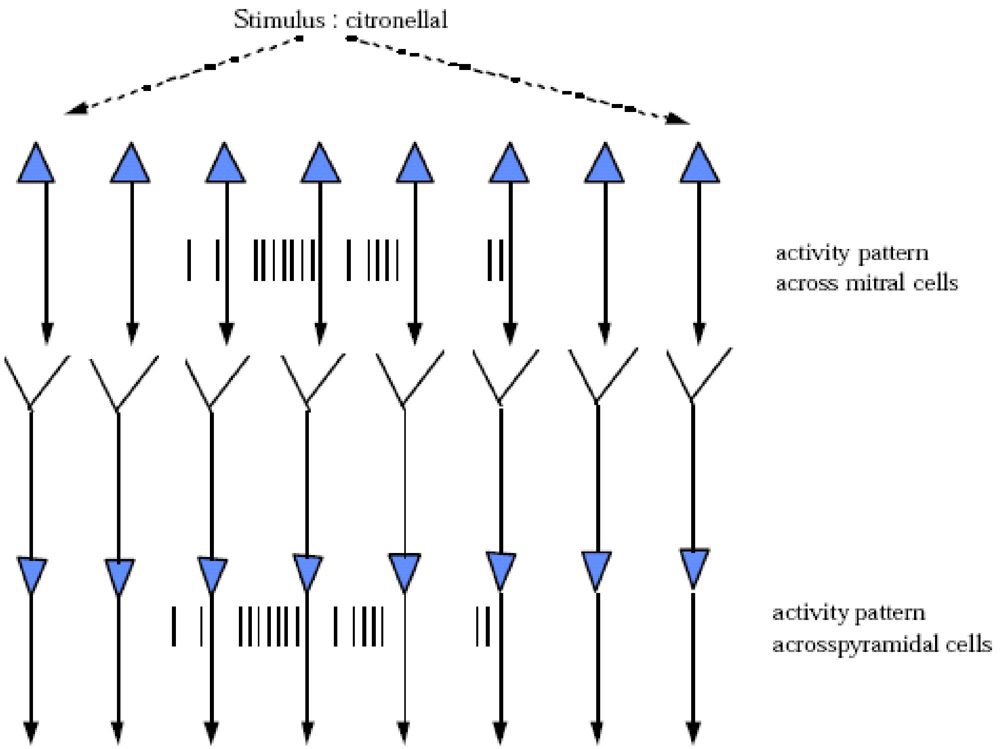
- Divided into 6 (with some exceptions) layers parallel to the surface.
- Important excitatory cells (ca. 85% of the cells in cortex): Pyramidal cells, Spiny Stellate (local interneurons)
- Local connectivity is mainly vertical (columnar architecture).

Example: Piriform Cortex



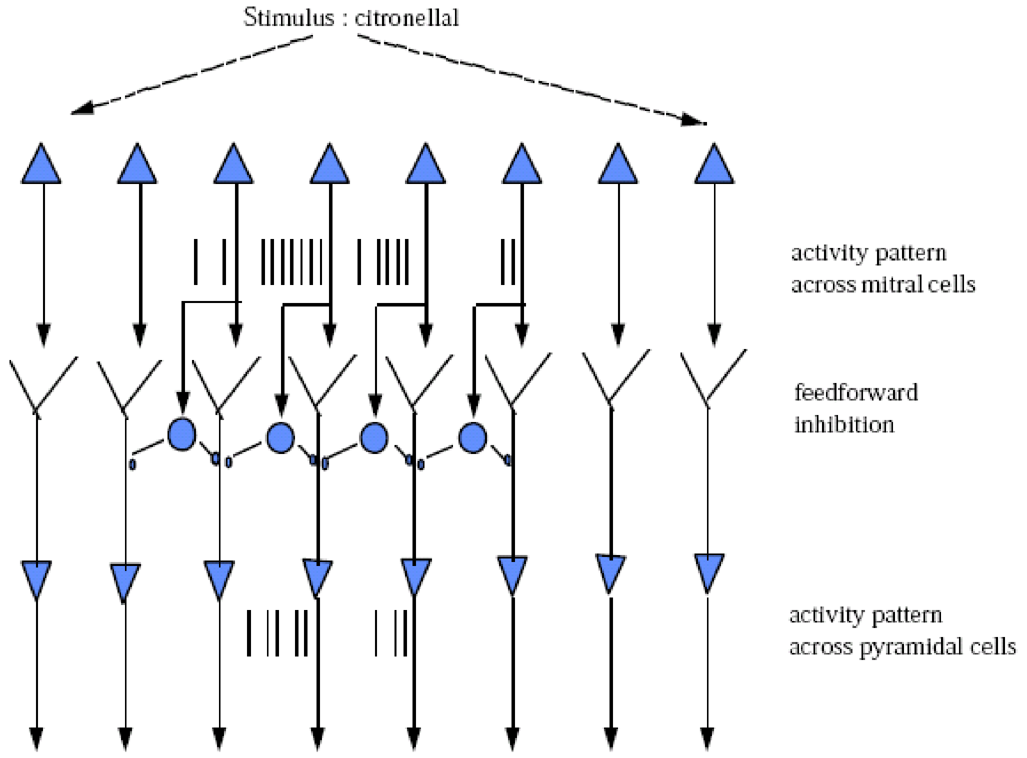
The olfactory cortex has only one layer with cell bodies.

Excit. feedforward



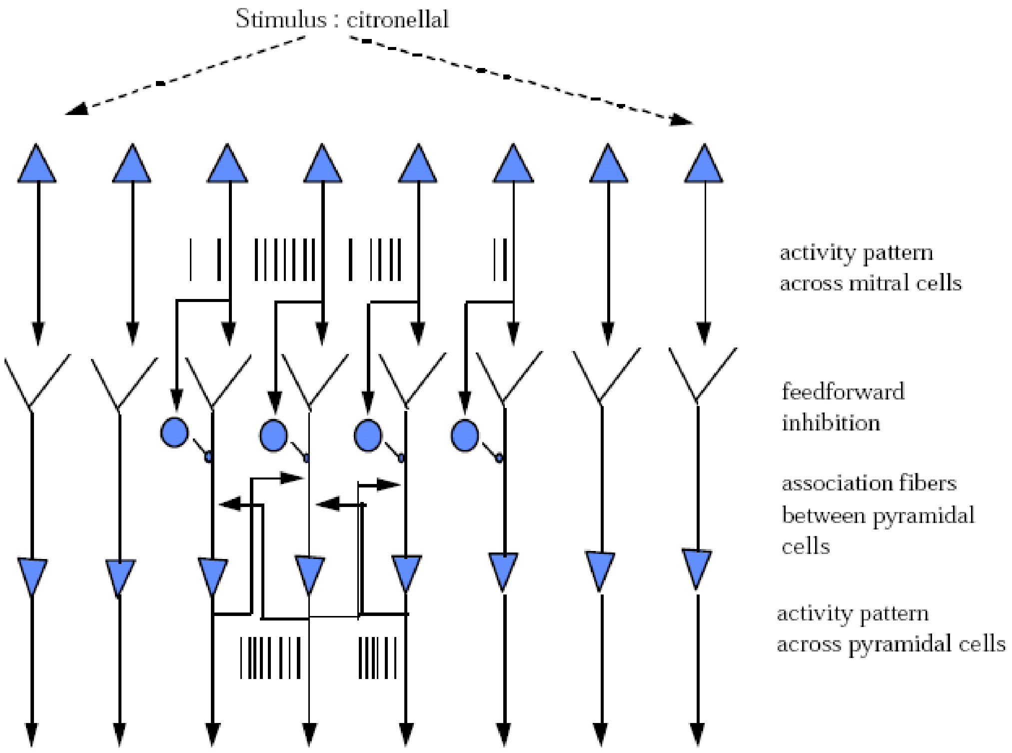
- In the olfactory bulb, odors are coded in the spike timings of so-called mitral cells.
- Afferent inputs from the olfactory bulb project to pyramidal cells.

Feedforward Inhibition



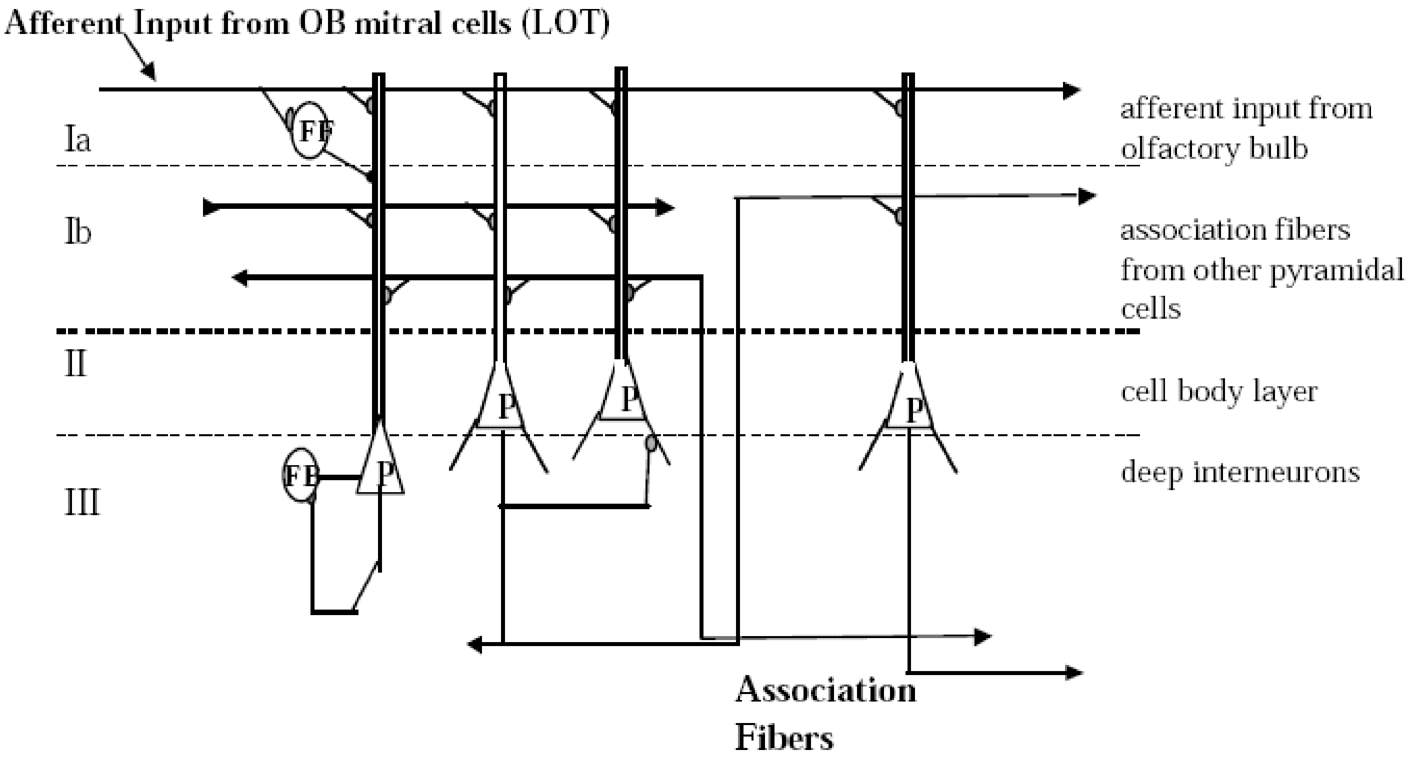
- Local interneurons generate local inhibition.
- This leads to an attenuation of weak stimuli (contrast enhancement).
- When a group of pyramidal neurons mutally inhibiting each other, this can lead to a "winner-take-all" circuit.

Excit. Lateral Connections



- Pyramidal neurons excite other pyramidal neurons via “association fibers”.
- Associations can be learned via Hebbian type learning in these fibers.
- Memory

Feedback Inhibition



- A second layer of inhibitory neurons limits the activity of the pyramidal neurons.
- This is called feedback-inhibition.
- Important because of the positive feedback of pyramidal neurons (instability).