Graphs, codes and the cortex

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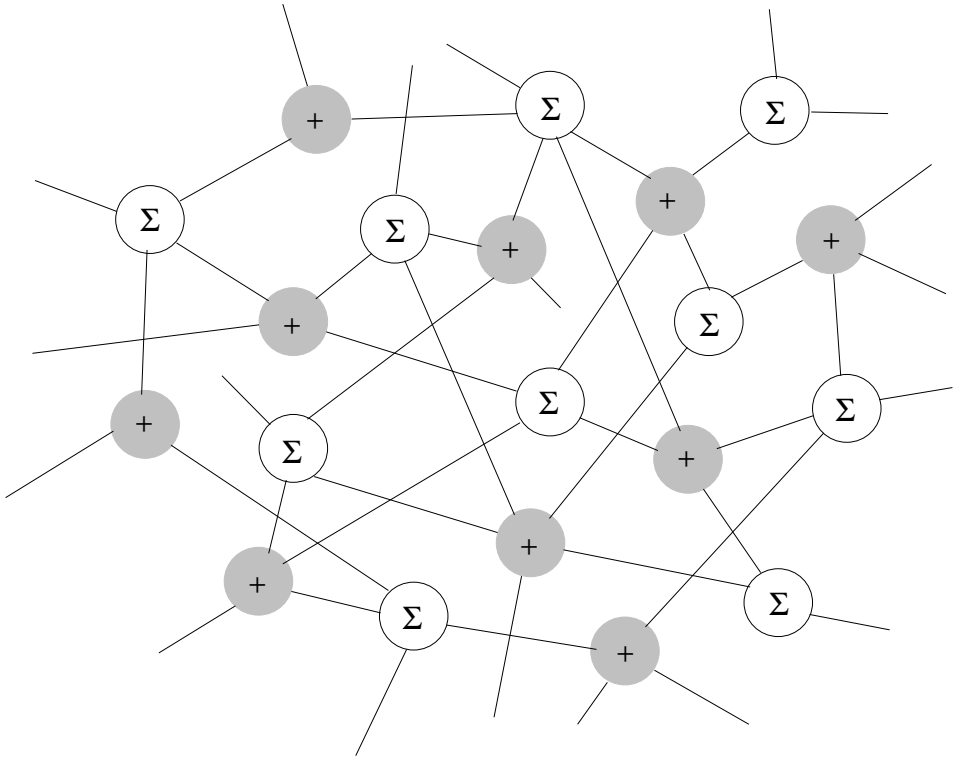
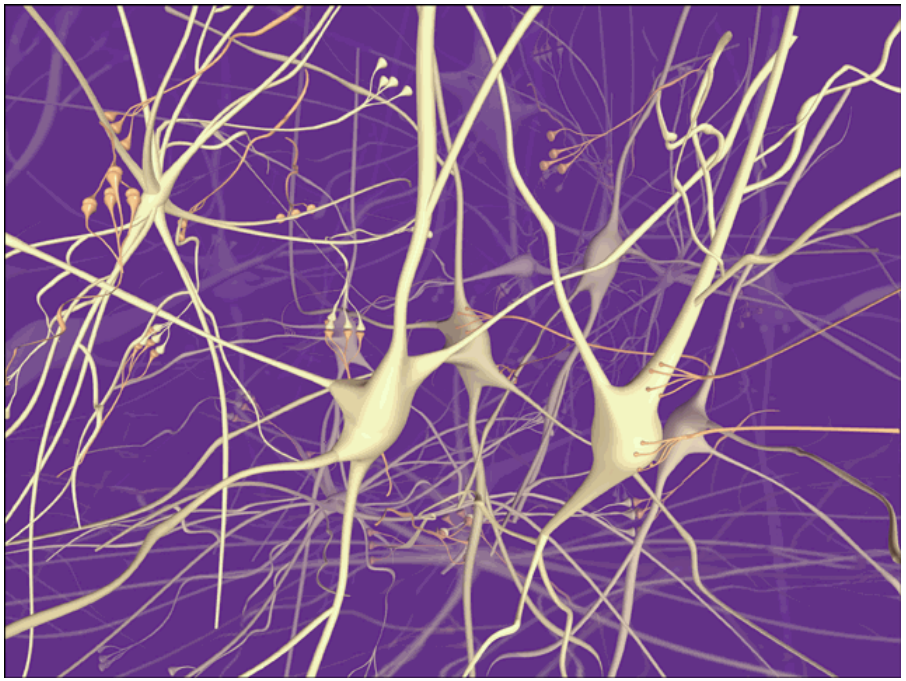
The neocortex behaves like a distributed decoder!

Which one?

LDPC decoder



Cortical decoder



+ : parity processor

Σ : variable processor

"If you want to understand life, don't think about vibrant, throbbing gels and oozes, think about information technology."
(Richard Dawkins, *The blind watchmaker*, 1986, Norton, p. 112)

The neocortex behaves like a distributed decoder!

Binary signalization: (0 or 1) ⟷ (Neuron inactive or firing)

(inhibitory signals are only for control)

Astronomic number of combinations

Fixed point decoding ⟷ Non confused, single thought

Large minimum distances ⟷ Easily separable thoughts

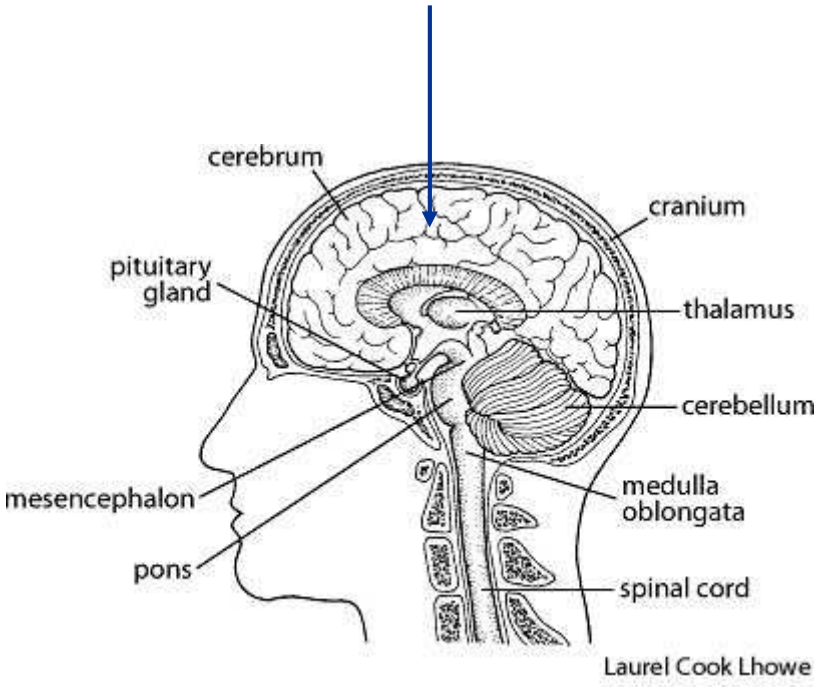
Resilience

Linearity ⟷ Nonlinearity

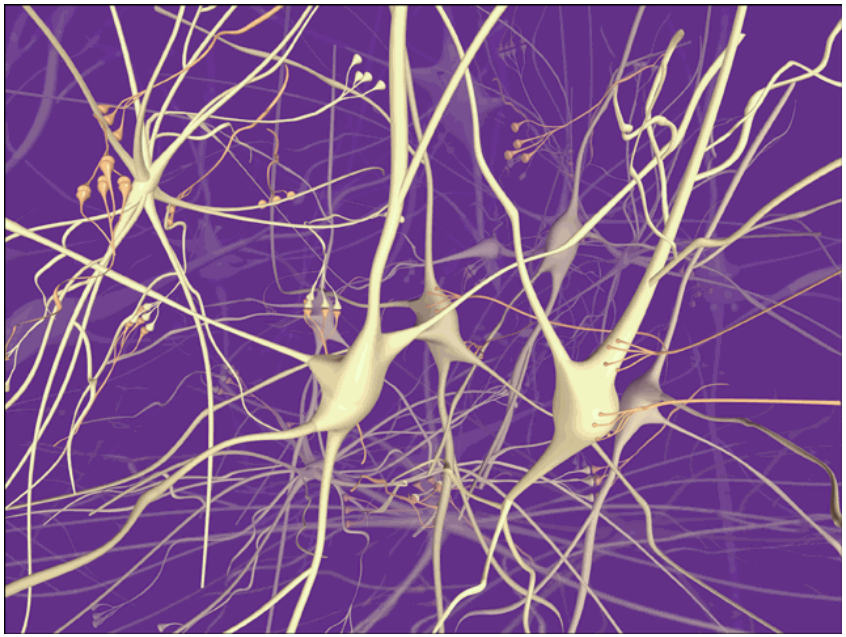
Importance of cycles

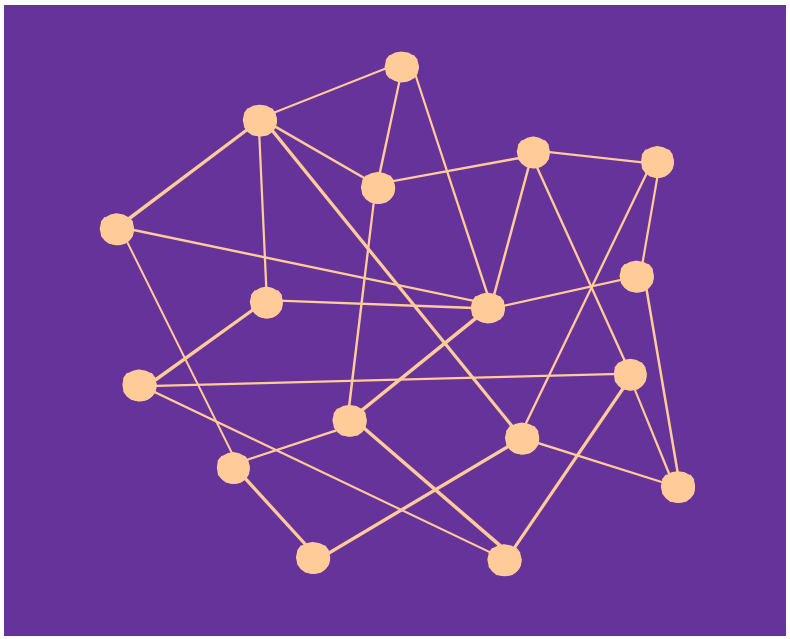
Importance of correlation

Contrary to ancestral sensory and motor feed-forward circuits, the neocortex can be essentially regarded as a very recurrent (loopy) graph



What is the code?

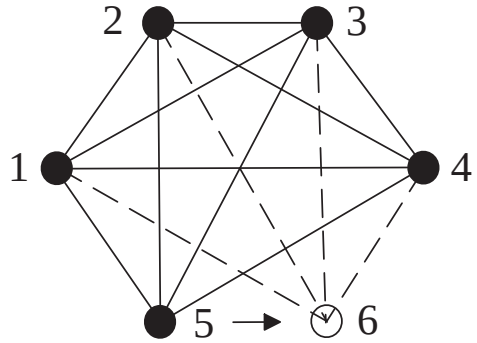




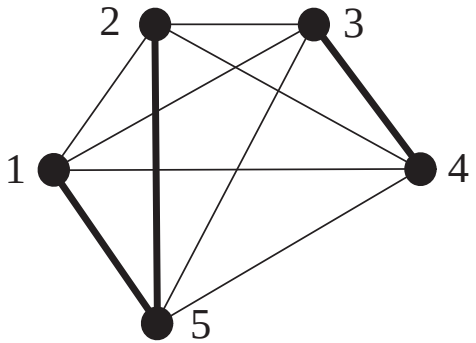
A graphical code !

What is the code?

The fundamental brick: the clique



(a)



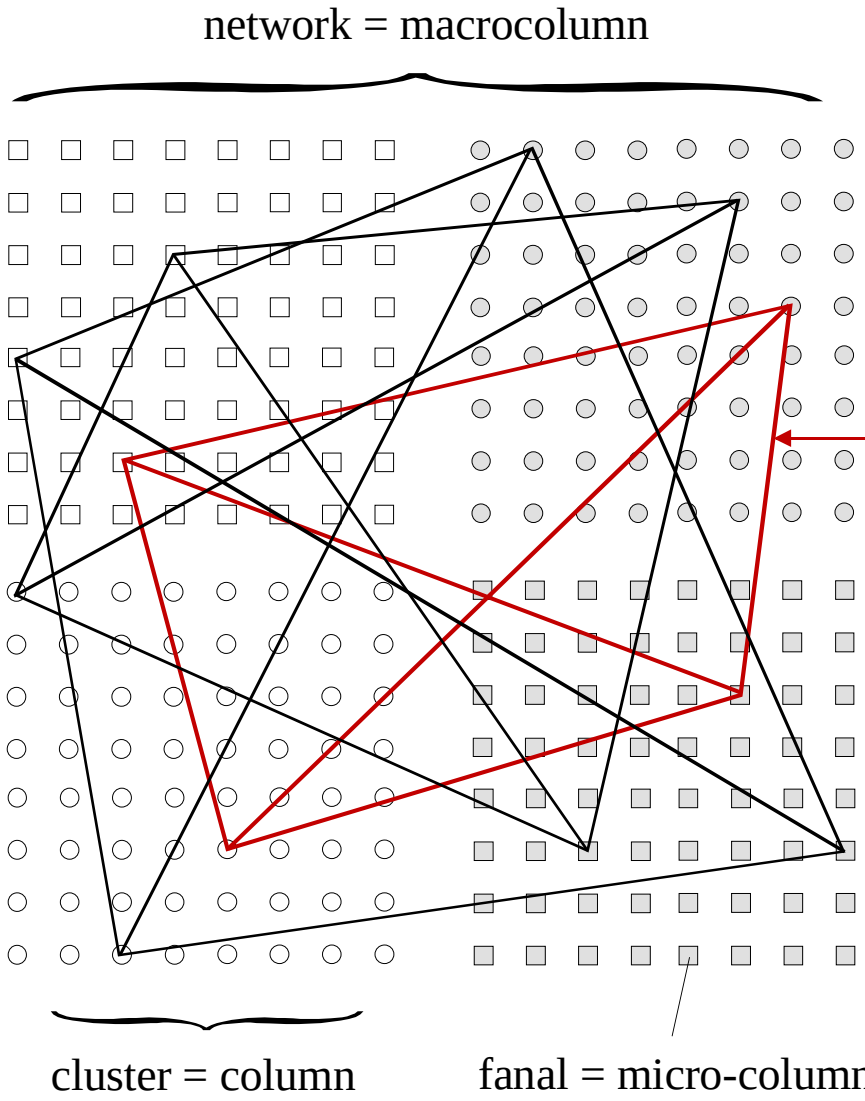
(b)

c vertices: $d_{\min} = 2(c-1)$ $R = \dfrac{\left\lfloor \frac{c+1}{2} \right\rfloor}{\frac{c(c-1)}{2}} = \dfrac{1}{c-1}$ (for c even)

$$F = Rd_{\min} = 2$$

V. Gripon and C. Berrou, "Sparse neural networks with large learning diversity", *IEEE trans. on Neural Networks*, vol. 22, n° 7, pp. 1087-1096, July 2011

In order to control the cliques, the graph is structured



l fanals per column,

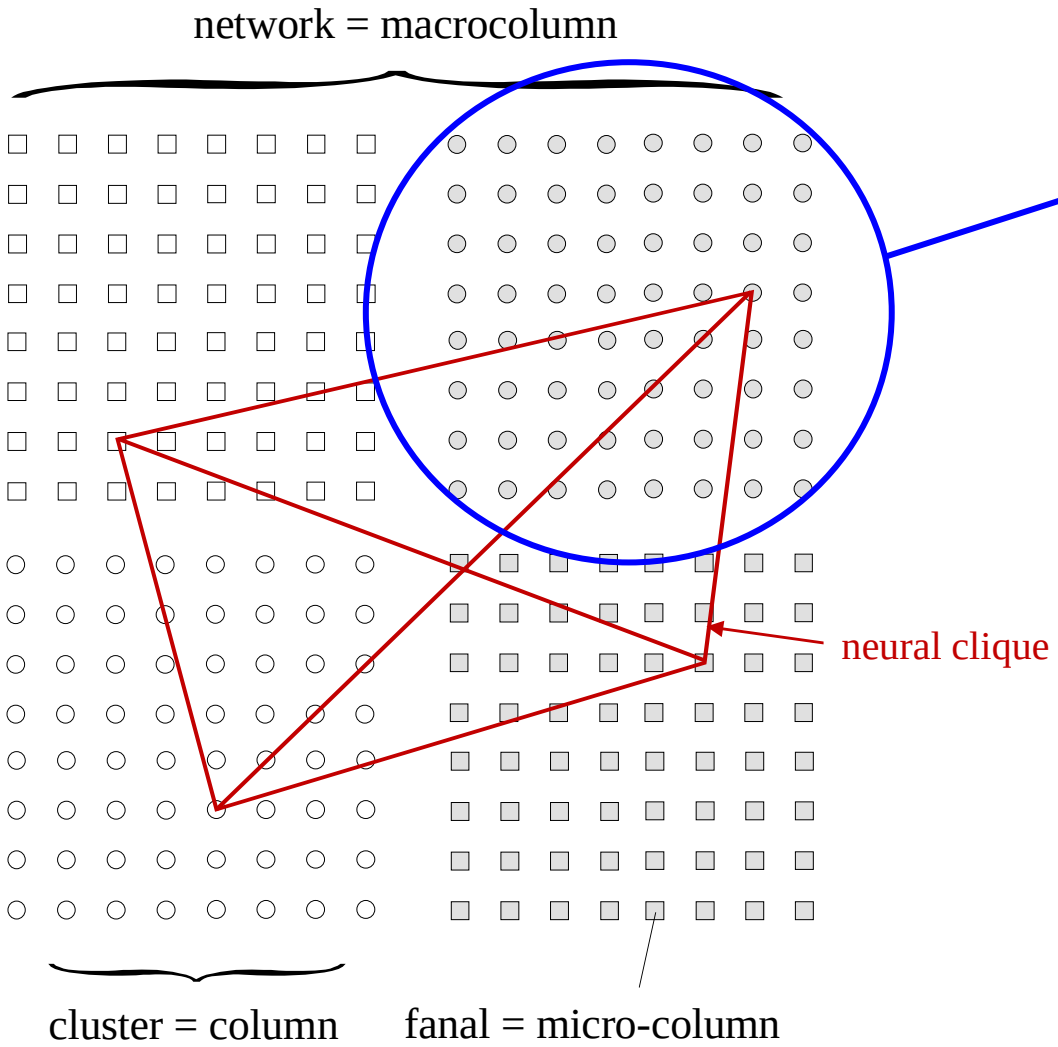
M messages

$\Rightarrow$ density d

$$d = 1 - \left(1 - \frac{1}{l^2}\right)^M$$

$$\approx \frac{M}{l^2} \text{ if } M << l^2$$

Concatenation of simple codes (comparable to LPDC codes)



a constant-weight code(*) with length l and weight $w = 1$

$k = \log_2(l)$ bits $\Rightarrow$

$R = \log_2(l)/l$

$d_{min} = 2$ only but easy to decode according to the *winner-take-all* (WTA) rule (max function)

(*) F. J. MacWilliams and N. J. A. Sloane, *The theory of error-correcting codes*, pp. 526-527, North-Holland, 1979.

Application to associative memory

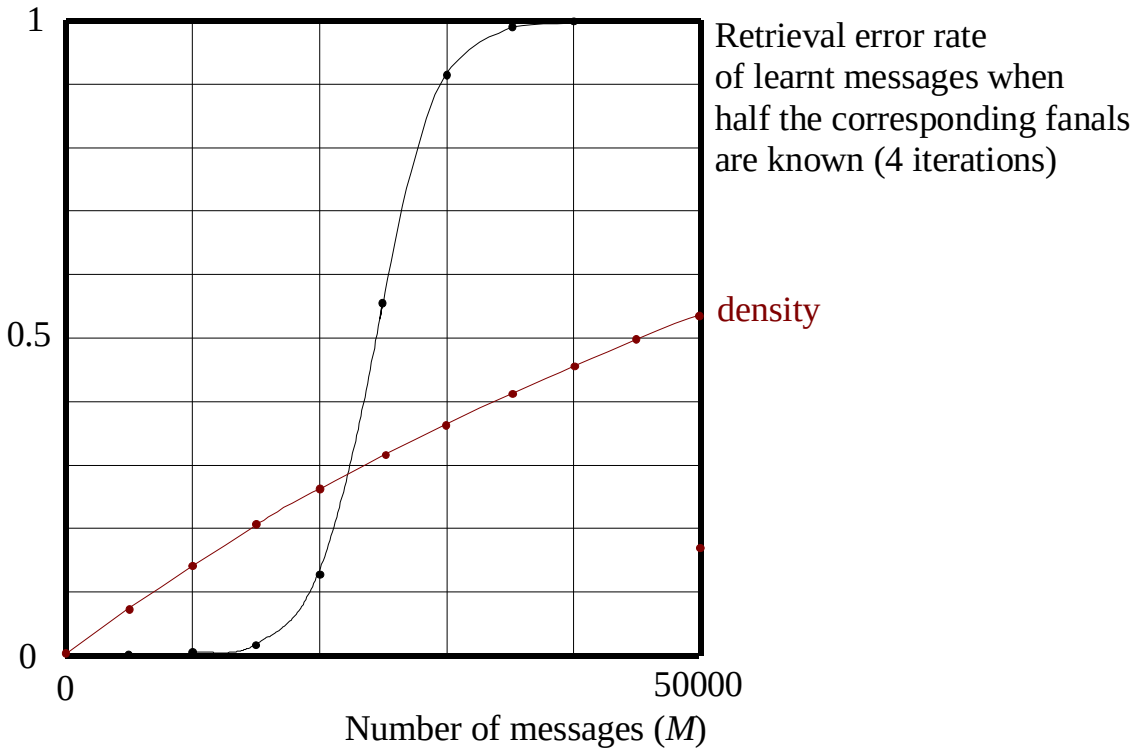
Gains compared to Hopfield networks (with the same amount of memory used):

diversity : 250

capacity : 20

efficiency : 20

(52% instead of 2.6%)



c = 8 clusters, l = 256 fanals

Messages of $8.\log_2(256) = 64$ bits

Application to go/no-go classification

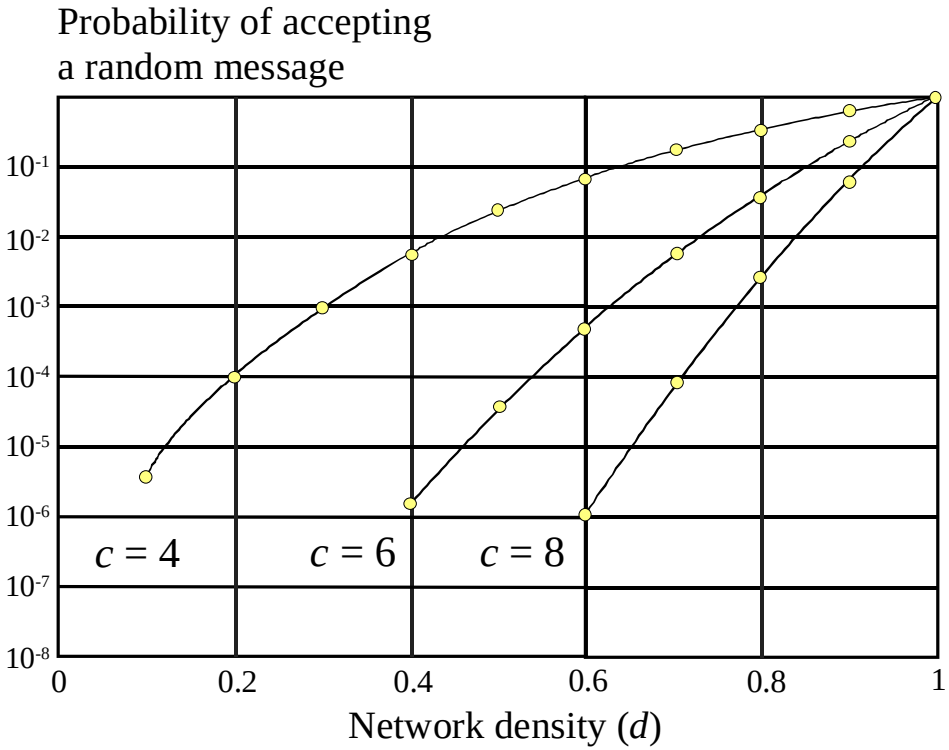
Gains compared to Hopfield networks (with the same amount of memory used and $c = 4$):

diversity : 1071

capacity : 52

efficiency : 52

(137% instead of 2.6%)

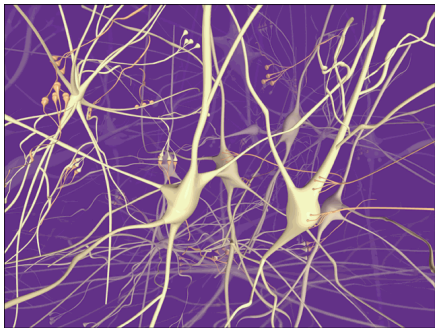


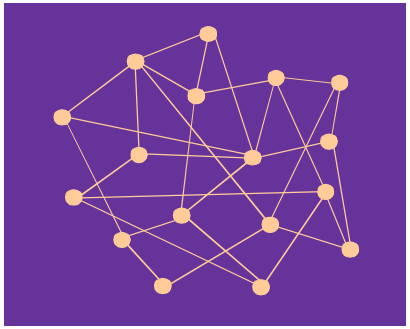
$c = 4$, 6 or 8 clusters, $l = 512$ fanals

Messages of $c.\log_2(512) = 9c$ bits

An innovative neural theory

• neurons (more precisely microcolumns) are fundamentally nodes in a graph

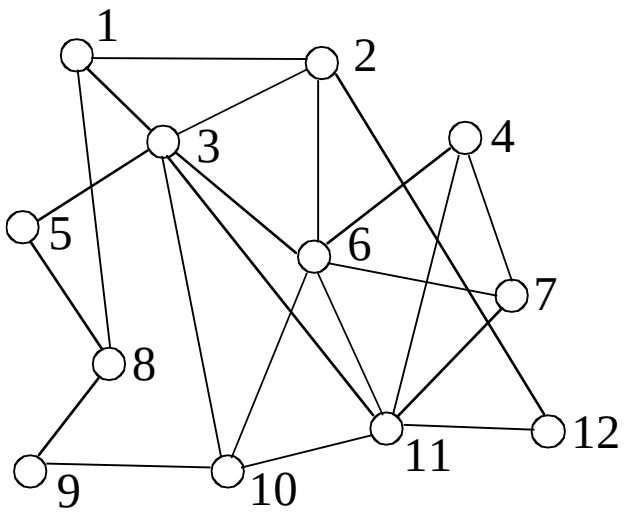




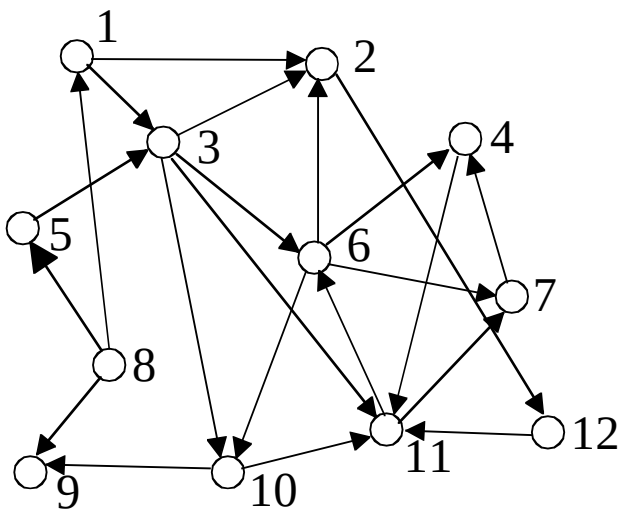
• information is borne by binary connections

• plasticity, firing frequency, thresholds and inhibitory signals are additional degrees of freedom for control (attention, vigilance, relevance, short term memory)

To store sequences instead of atemporal messages:
replace cliques with tournaments

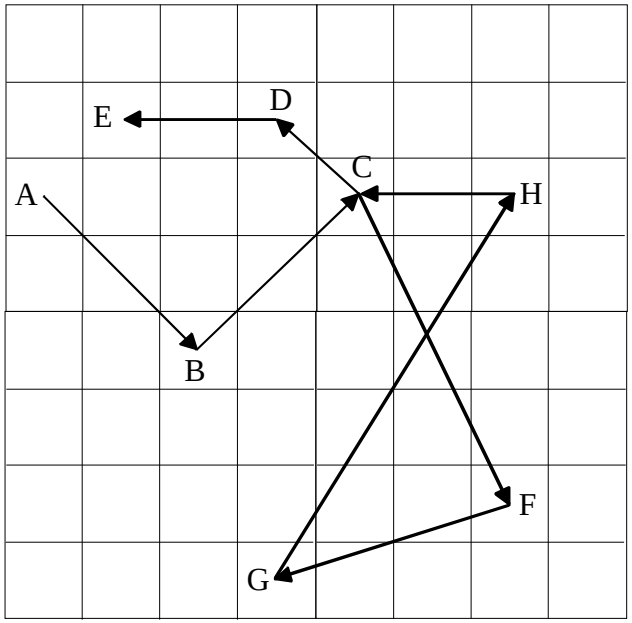


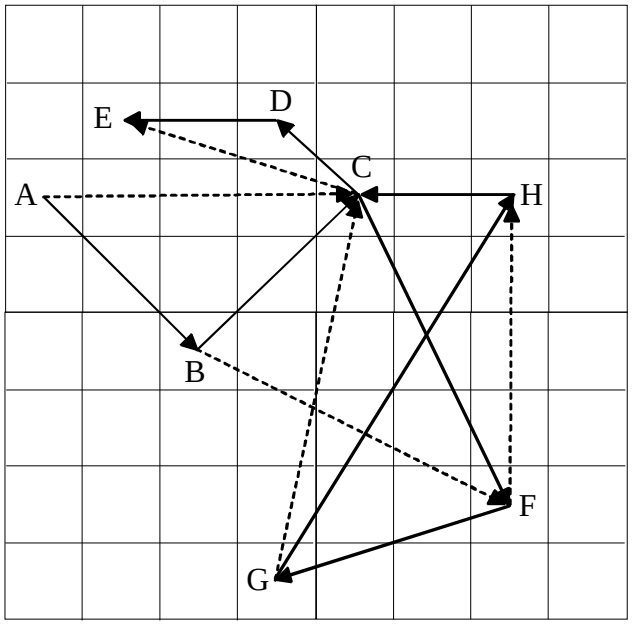
(a)



(b)

How to avoid ambiguousness in a journey with only graphical tools?

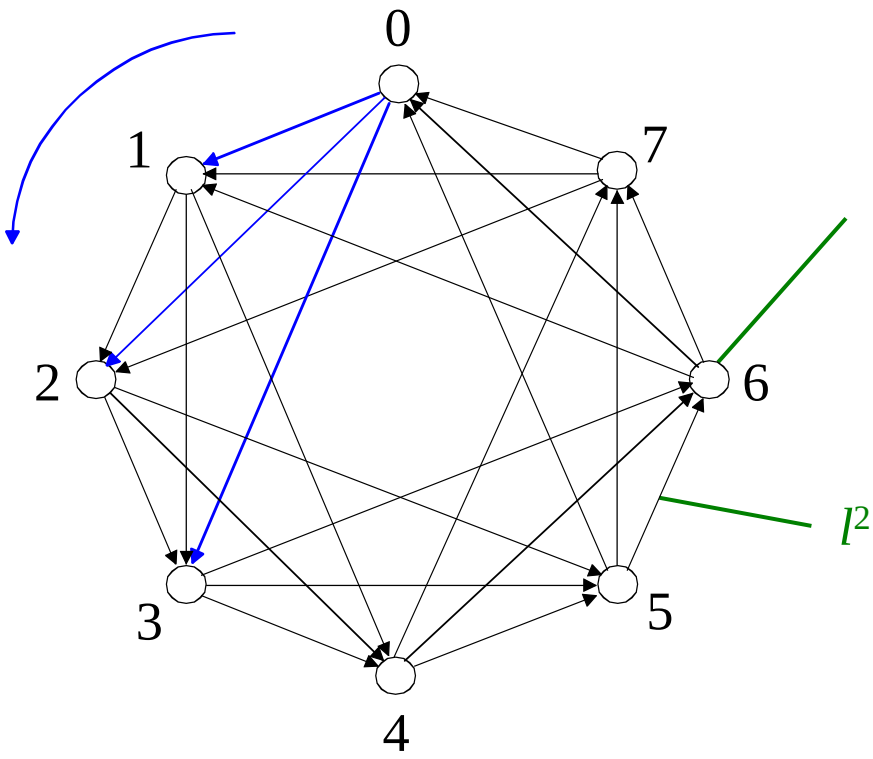




use multilevel aiming

(time overlapping)

So, to store sequences instead of atemporal messages:
replace cliques with tournaments



1 cluster = l fanals

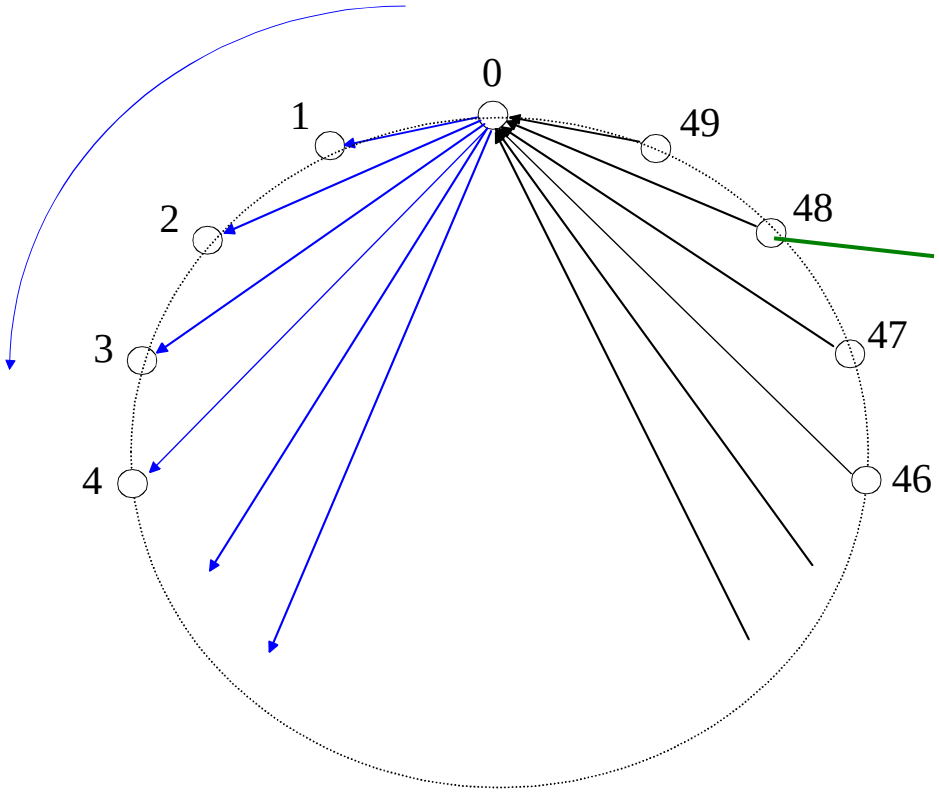
l^2 possible connections

(not yet published)

For instance, learning pieces of music

time overlapping

= 20



50 clusters

1 cluster = 256 fanals

(16 pitches x 16 lengths)

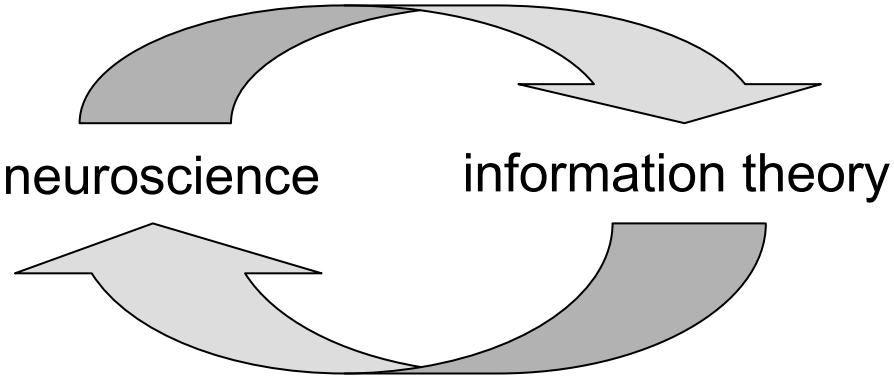
This network of 12800 fanals is able to learn 1800 pieces of music, each having 1000 notes and to retrieve each of them from the first 20 notes, with a failure rate of 10^{-2}.

That is a plausible explanation of the way the neocortex, **which is a graphical machine**, performs its sequential operations!

Current studies

- Introducing soft-input decoding in order to recognize noisy or blurred messages
- Considering variable-length messages
- Devising networks of networks
- Introducing cognitive concepts (attention, relevance, …)
- …

Conclusion



a very promising cross-fertilization

Our objectives

- **Implementing electronic machines having the ability to learn a lot of information and to produce new one by association, fusion, crossbreeding and deduction,**
- **Contributing to the understanding of the biological long and short term memories,**
- **Find applications to telecommunications**