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When neural networks meet error-correction coding: new perspectives in associative memories

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« Pure mental information »

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9x8 = 72

Maître Corbeau, sur un arbre perché,…

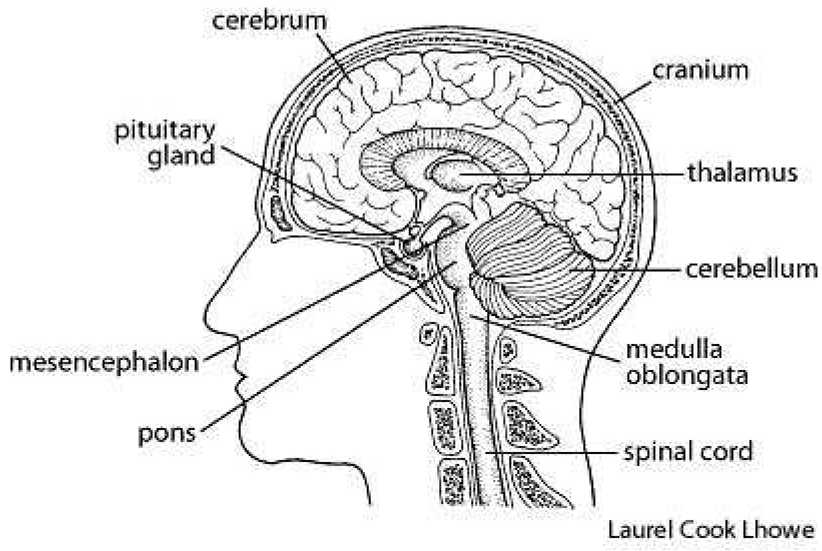
$$H = -\sum_{i=1}^{n} p_i \log_2(p_i)$$

Communication model

Nervous information

Mental information

Exuberant physical world → Source coding → Channel coding → Parsimonious and robust mental world

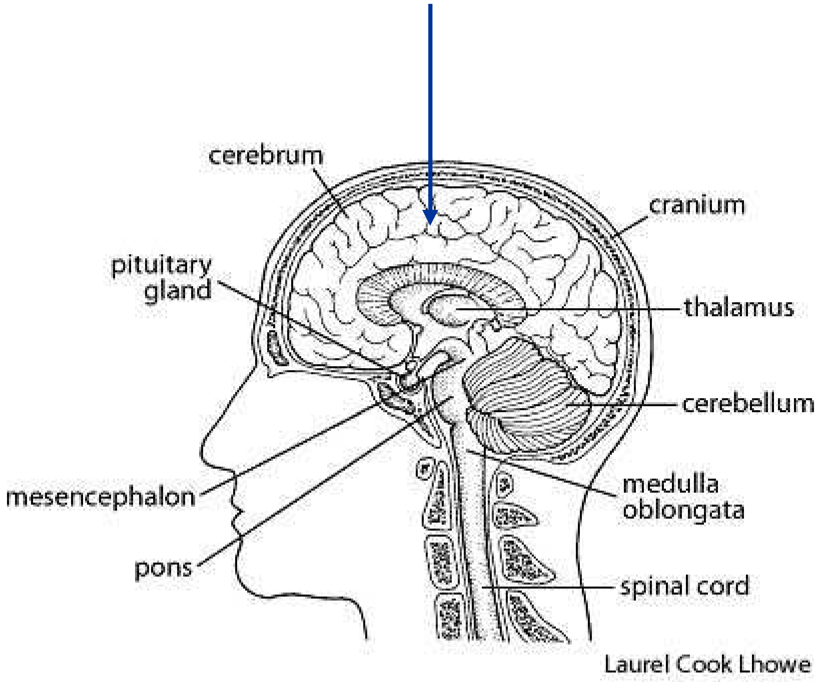


Mental information is robust and durable, therefore must be redundant.

$\mathcal{H}1$

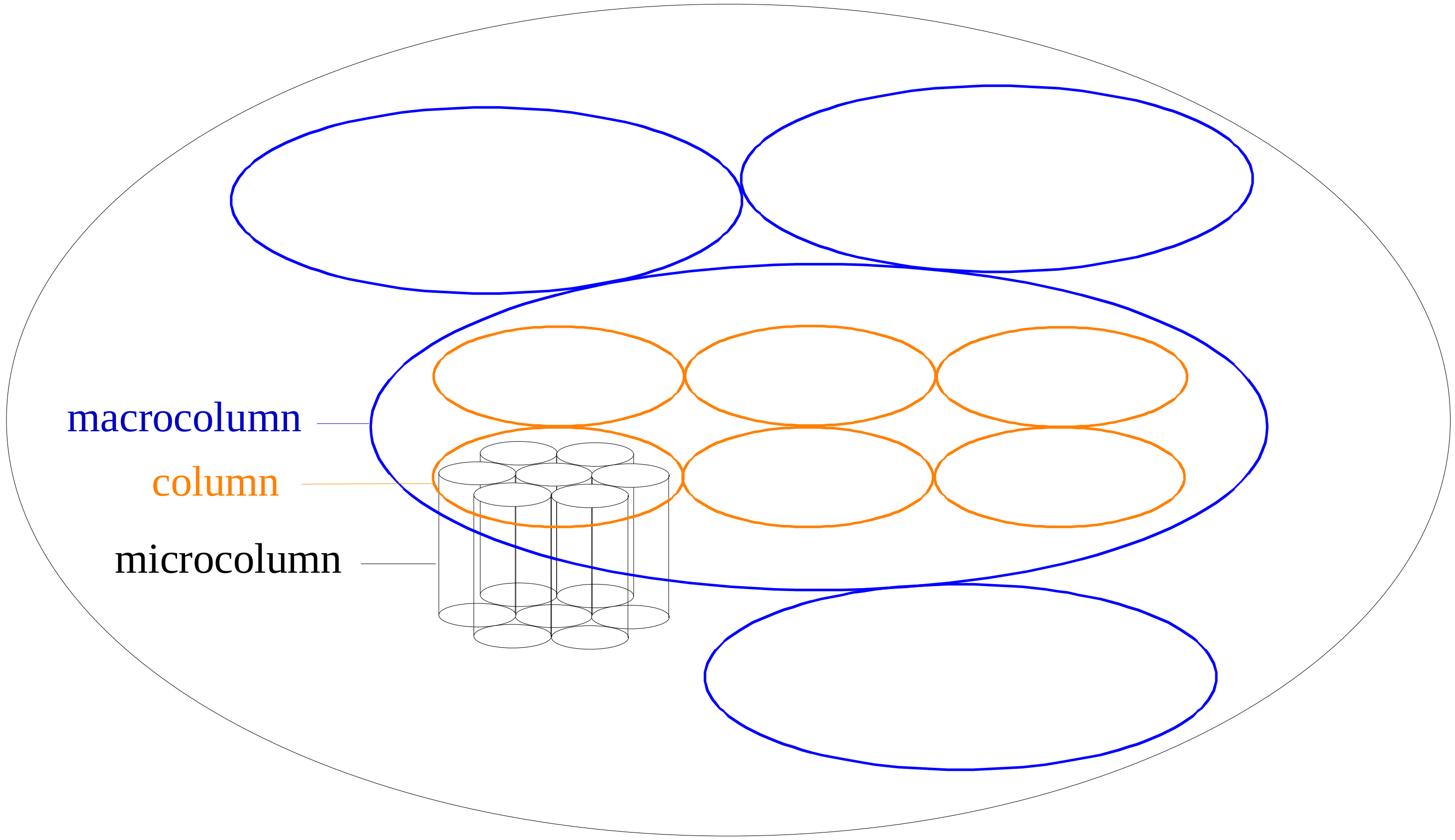
Contrary to ancestral sensory and motor feed-forward circuits, the neocortex can be essentially regarded as a very recurrent organized graph

$\mathcal{H}2$



The self-repeating unit (node) in the graph is the so-called microcolumn (~ 100 neurons)

Functional area of the cerebral cortex



The neocortex behaves like a distributed decoder!

$\mathcal{H}3$

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

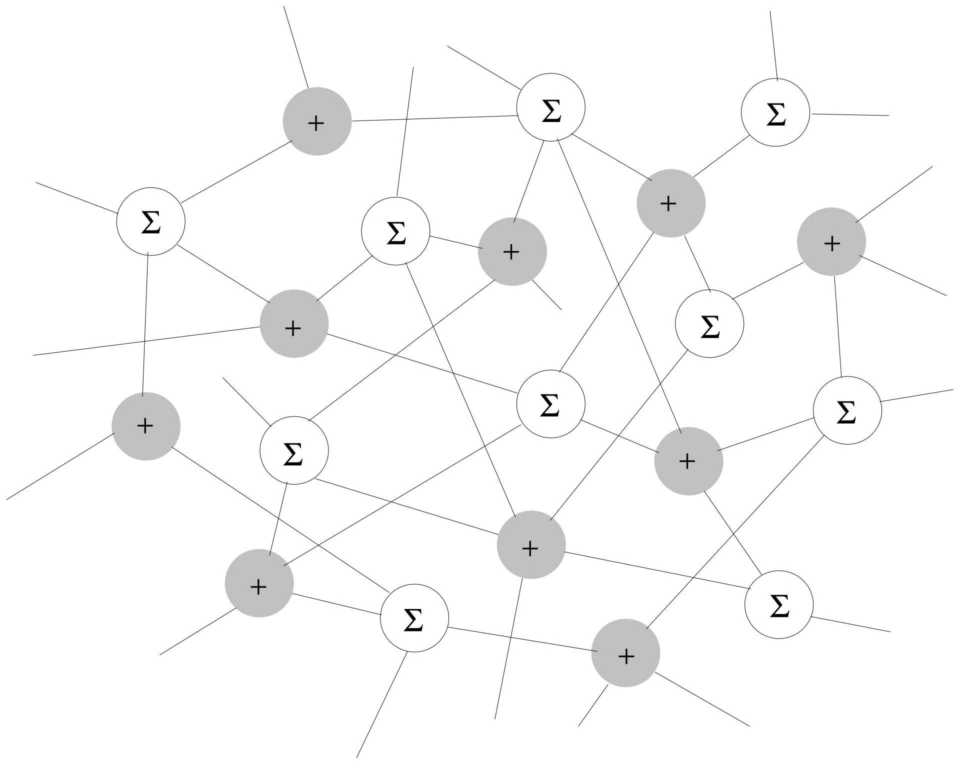
Linearity ⟷ Nonlinearity

Importance of cycles

Importance of correlation

The neocortex behaves like a distributed decoder!
Which one?

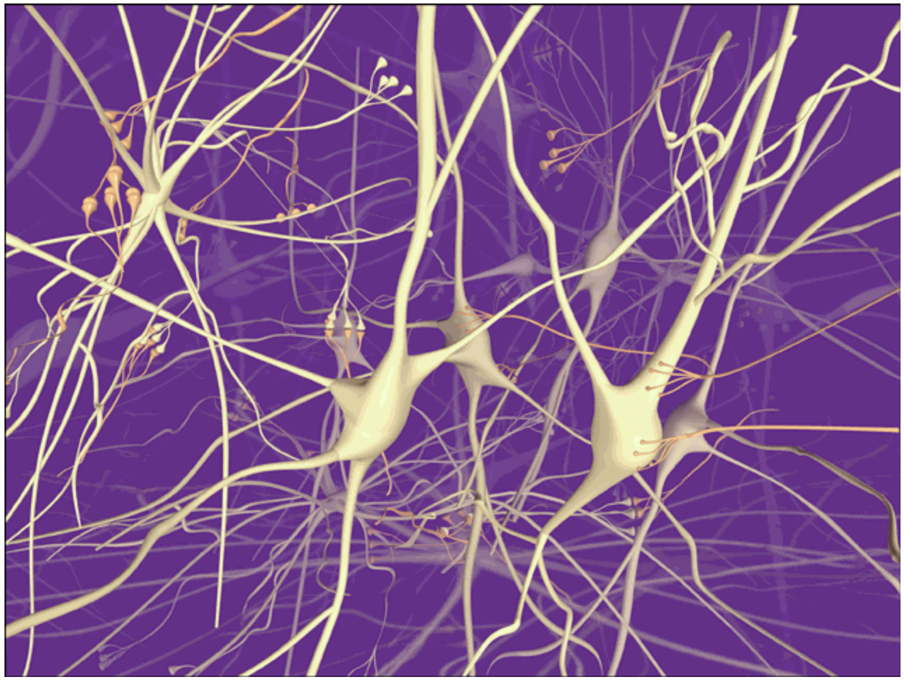
LDPC decoder



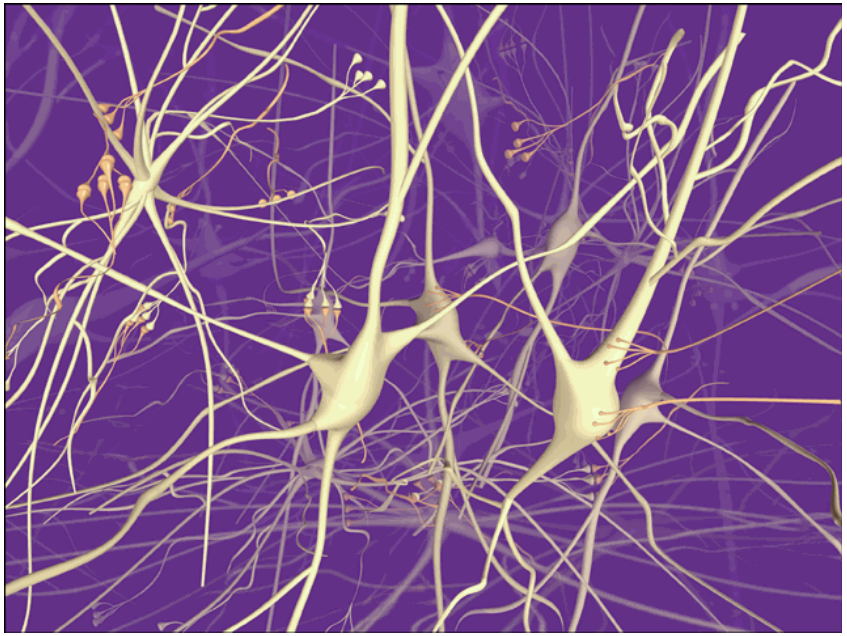
+ : parity processor

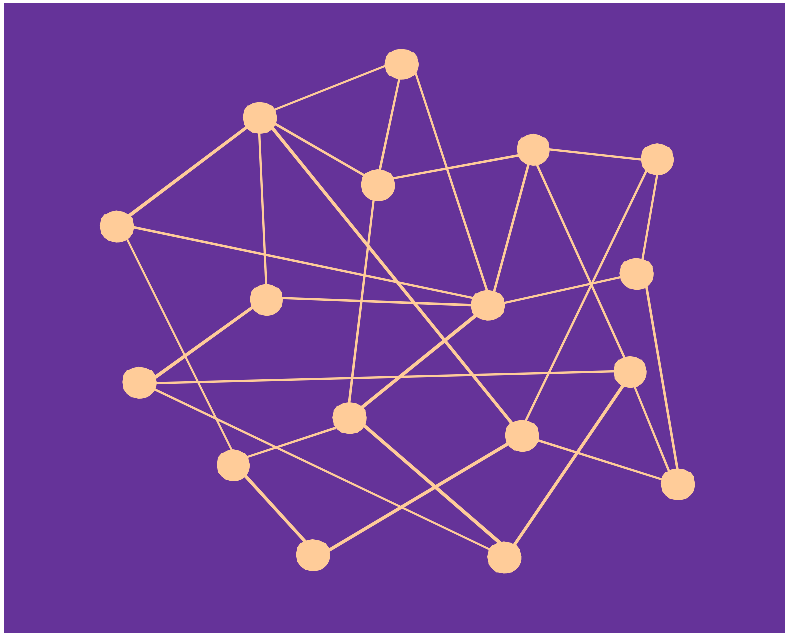
Σ : variable processor

Cortical decoder



What is the code?

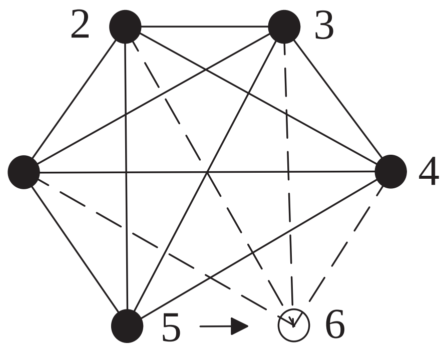




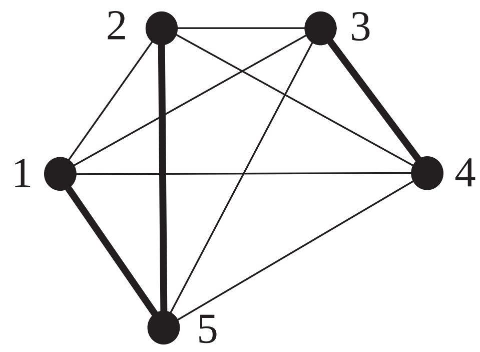
A redundant, distributed, graphical code !

What is the clique code?

The fundamental brick: the clique



(a)



(b)

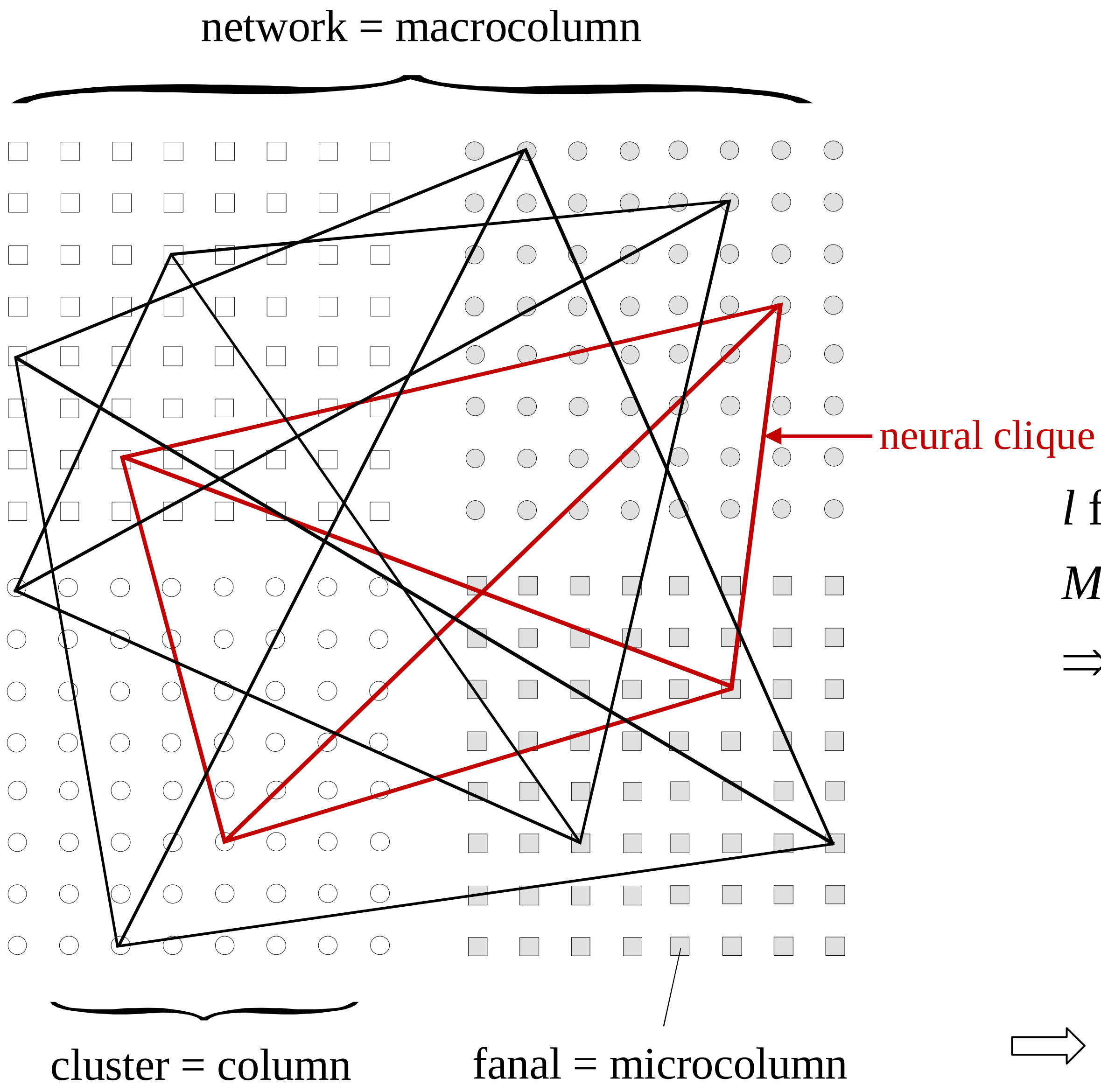
c vertices: $d_{\min} = 2(c-1)$ $R = \dfrac{\left\lfloor \dfrac{c+1}{2} \right\rfloor}{\dfrac{c(c-1)}{2}} = \dfrac{1}{c-1}$ (for c even)

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

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

V. Gripon, V. Skachek, W. J. Gross and M. Rabbat, "Random clique codes", *ISTC'12*, Gothenburg, Sweden, 2012

In order to control the cliques, the graph is structured (as biologists have brought it to the fore!)



l fanals per column,

M messages:

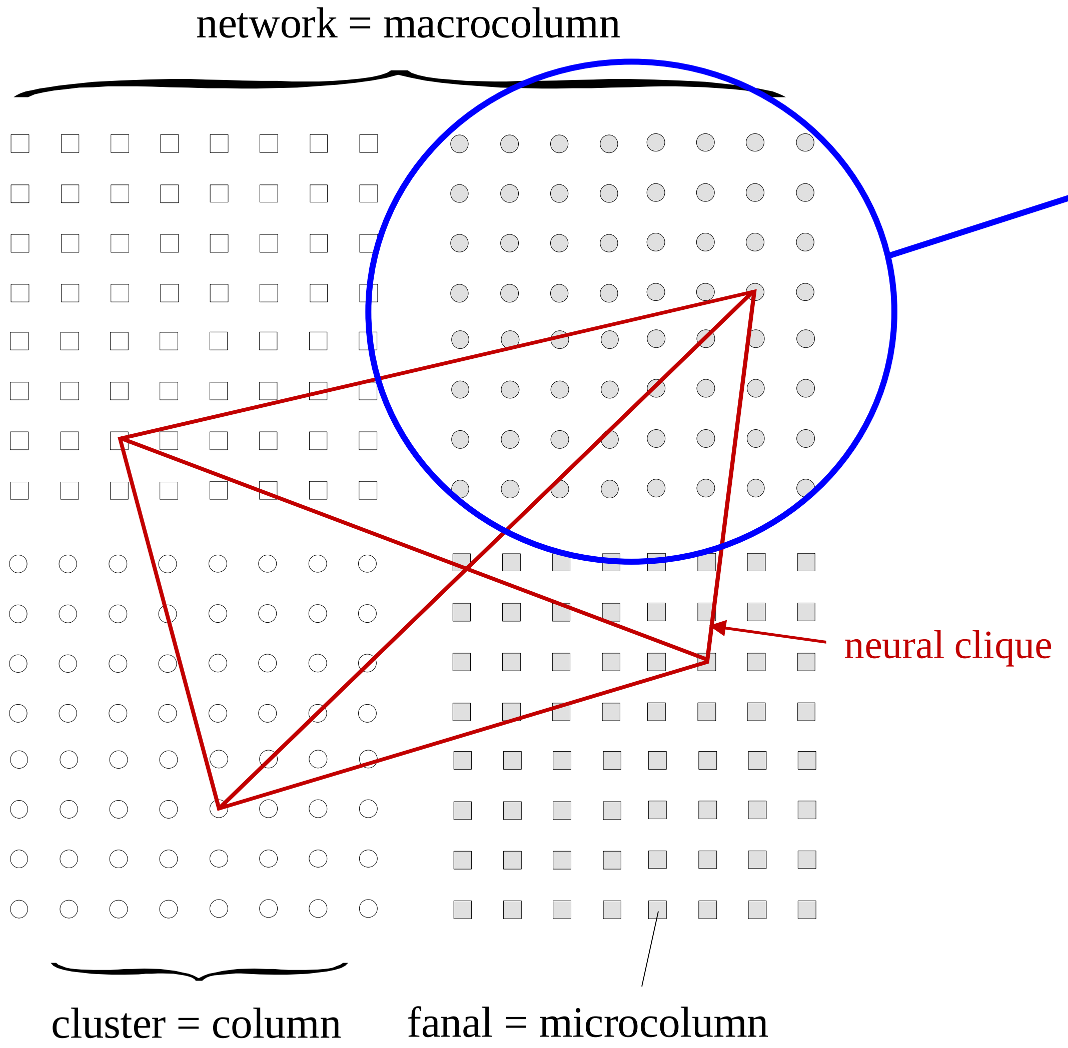
$\Rightarrow$ density d:

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

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

$$\Rightarrow \quad M \approx dl^2$$

Concatenation of simple and thrifty 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

$c = 8$ clusters, $l = 256$ fanals

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

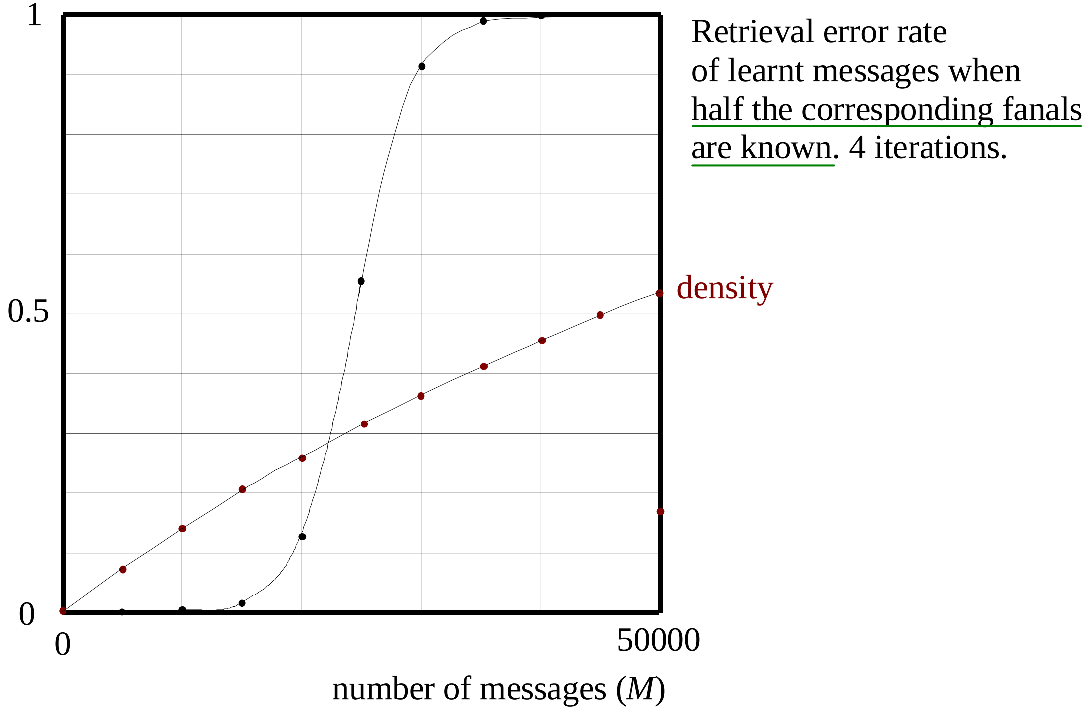
Gains compared to Hopfield networks (with the same amount of memory used):

diversity: 250

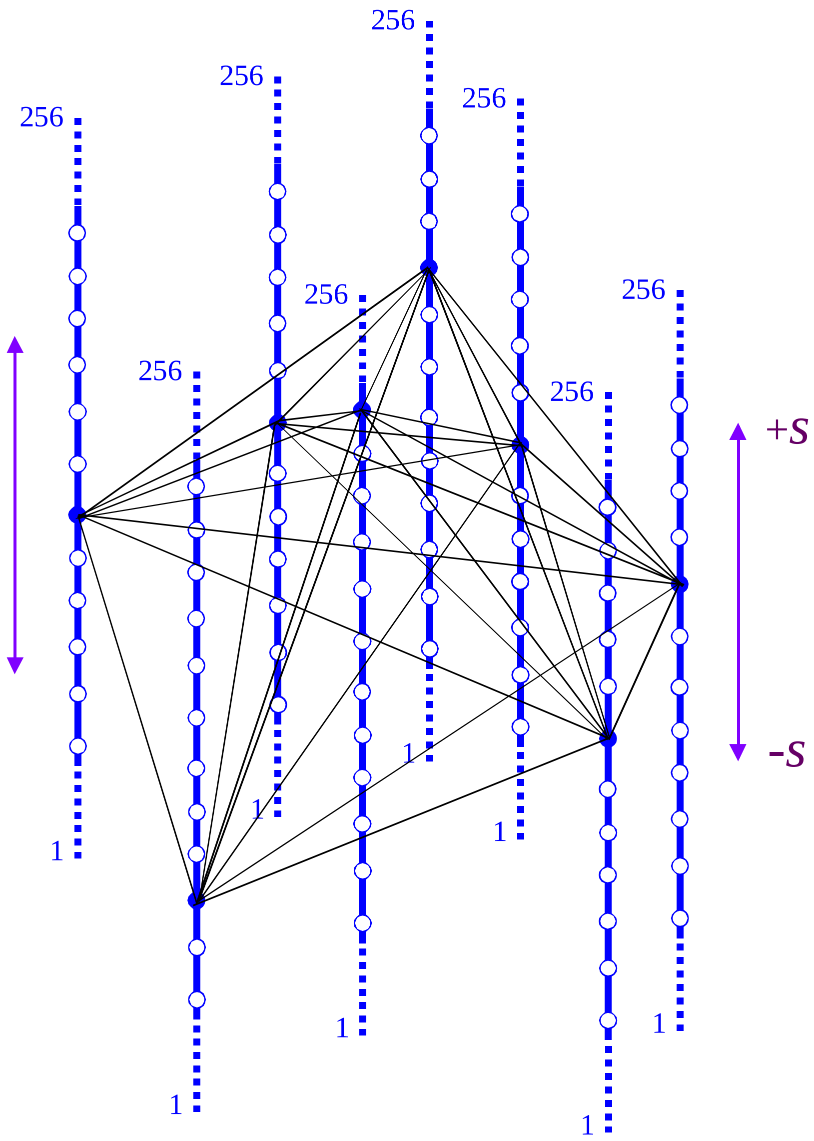
capacity: 20

efficiency: 20

(52% instead of 2.6%)



Associative memory with blurred stimuli



c = 8 clusters, l = 256 fanals

Messages of $8 \text{x} \log_2(256) = 64$ bits

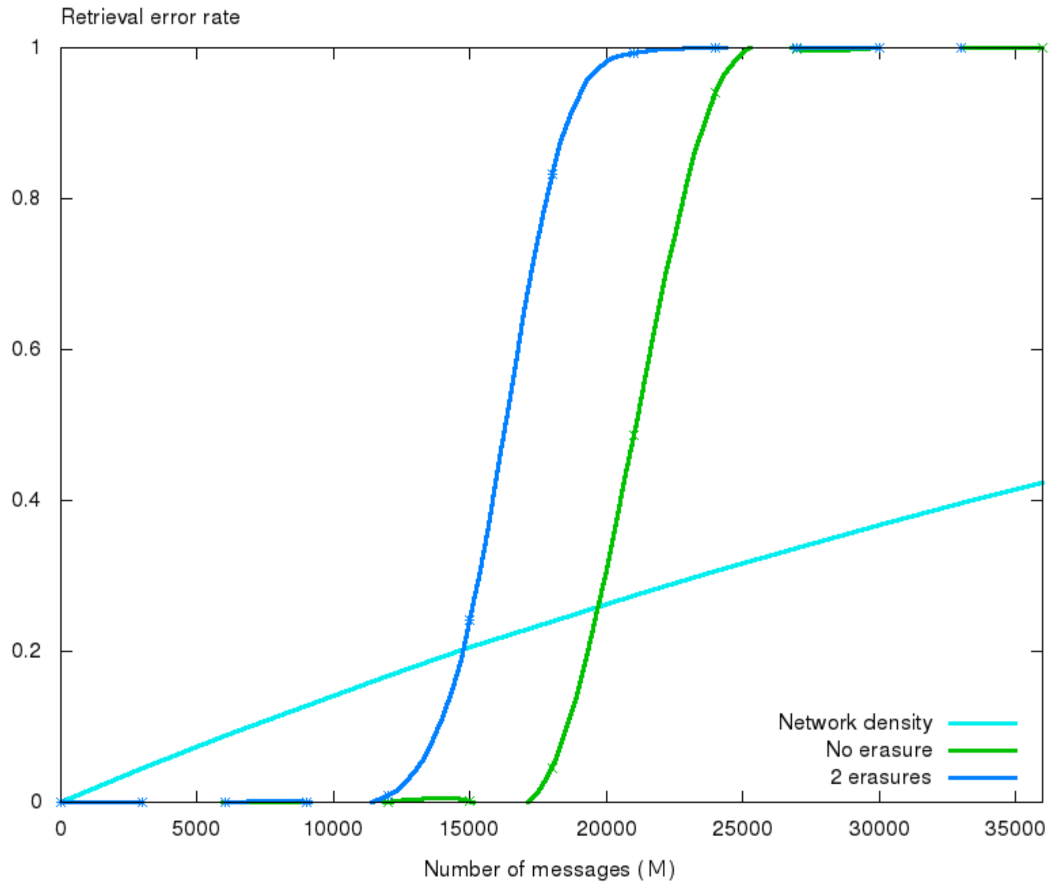
Fanals are approximately known, in a certain vicinity [-*s*,+*s*].

Associative memory with blurred stimuli

c = 8 clusters, l = 256 fanals

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

s = 5

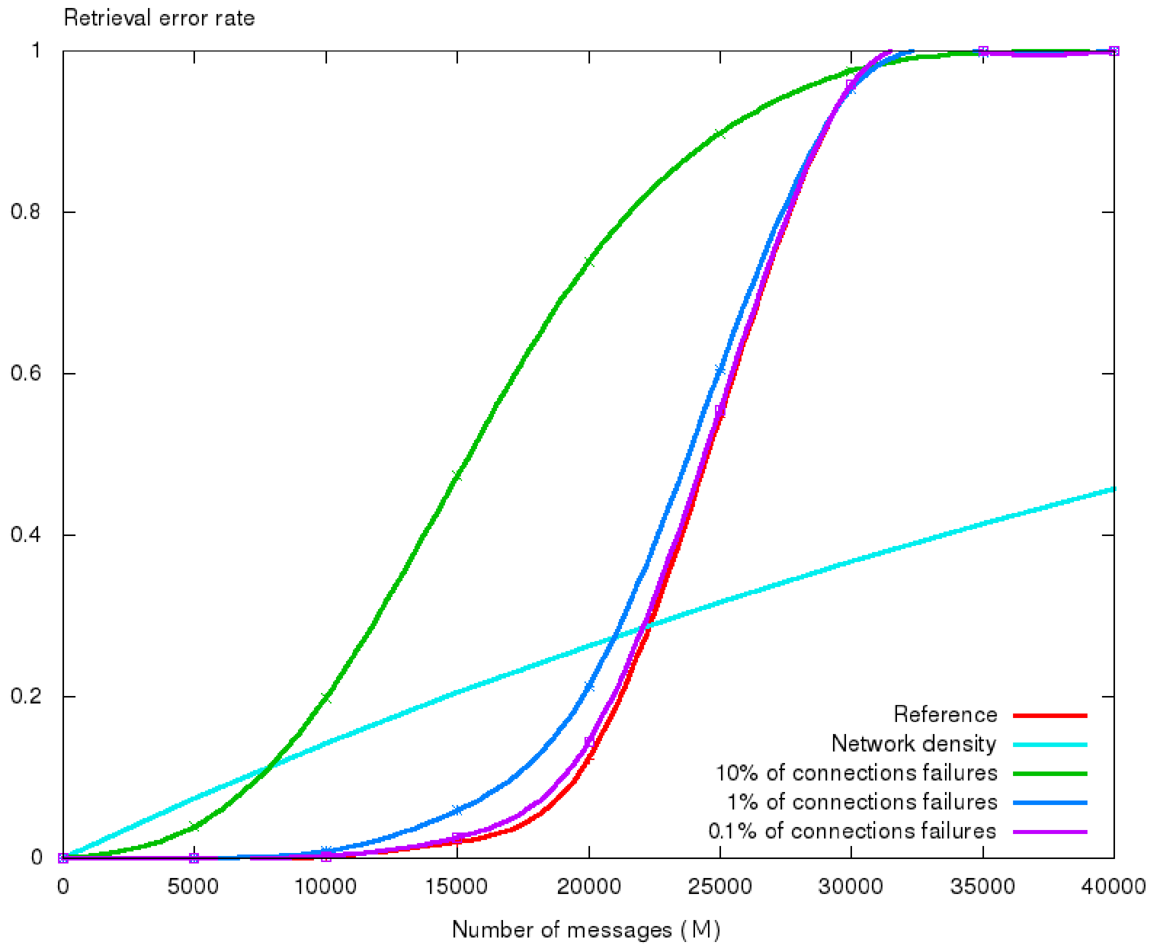


4 iterations

Robust associative memory

c = 8 clusters, l = 256 fanals

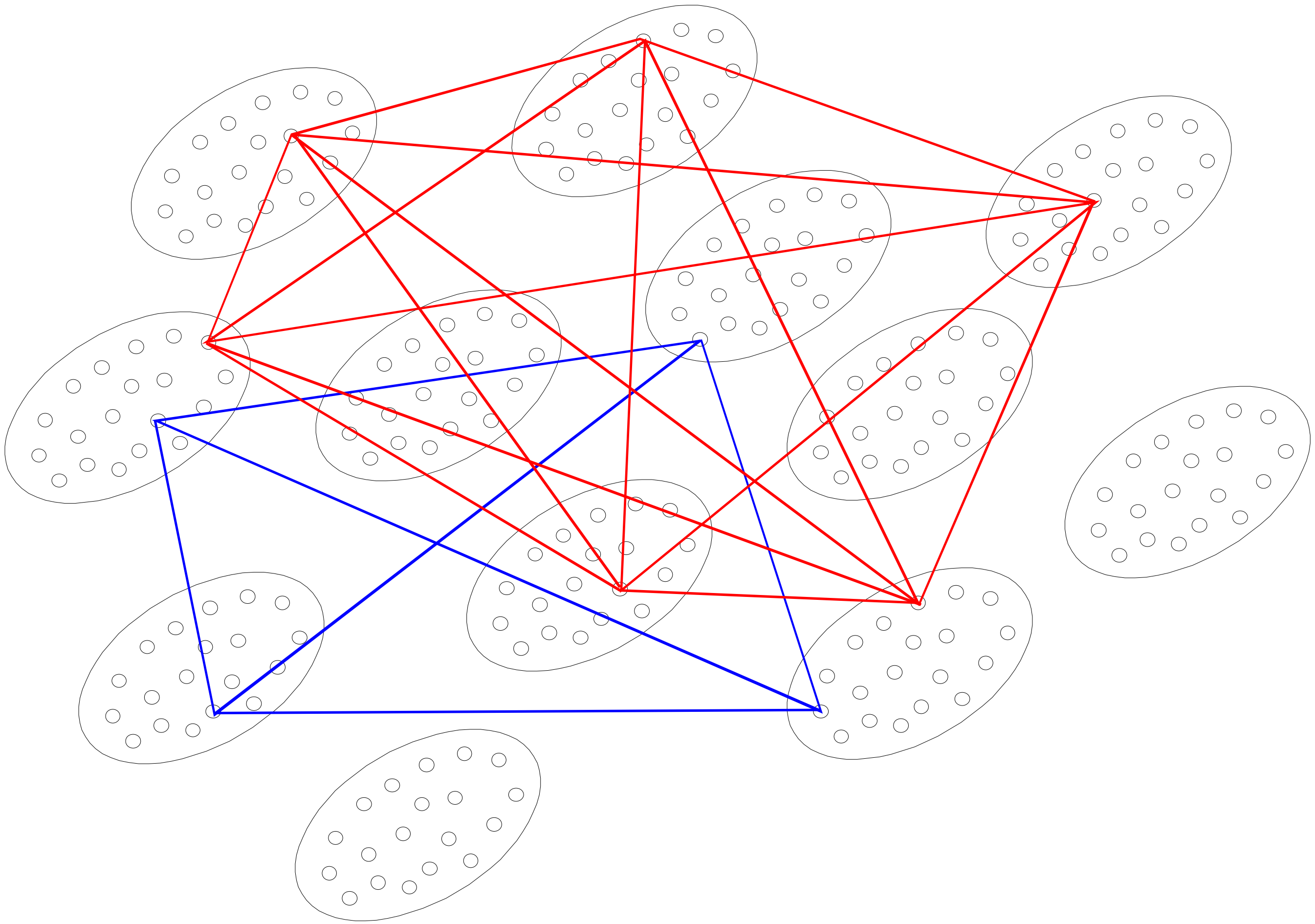
Messages of 8x$\log_2(256)$ = 64 bits



Connections are randomly erased during the recovery process.

4 iterations

Sparse messages

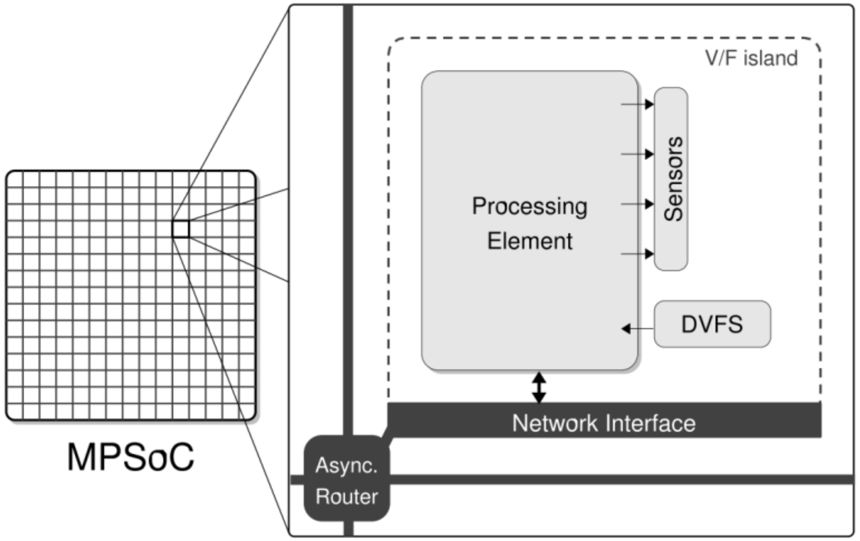


M proportional to n^2

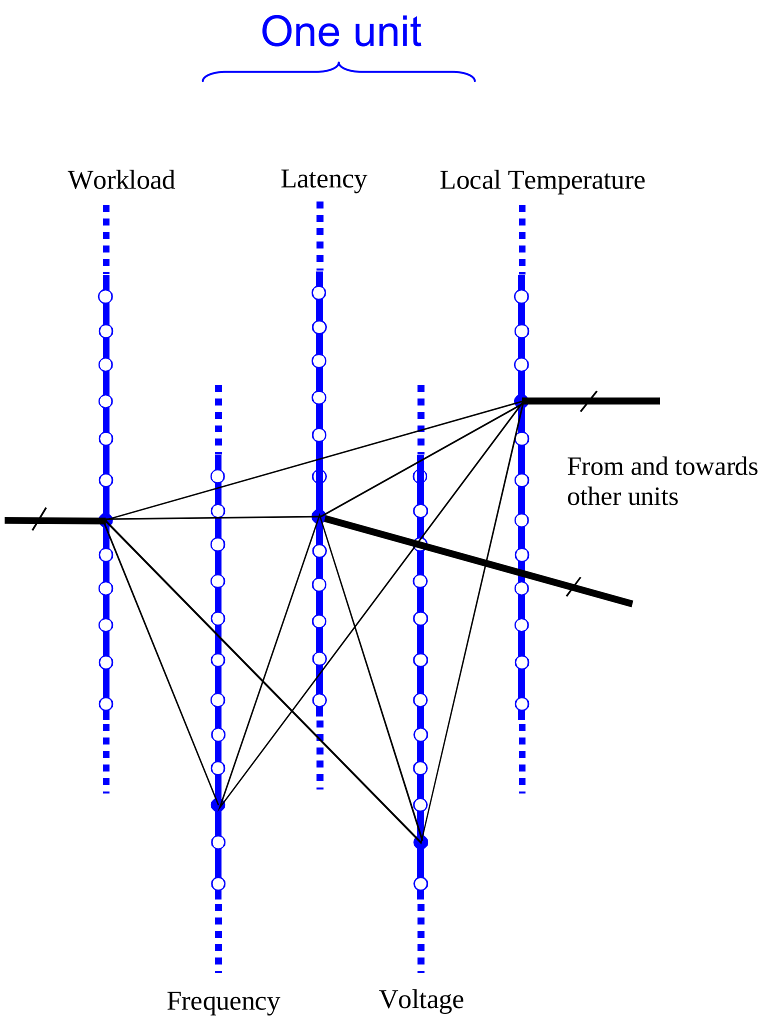
B. Kamary Aliabadi, C. Berrou, V. Gripon and X. Jiang, "Storing sparse messages in networks of neural cliques", submitted, 2012

Application to dynamic power management in MPSoCs

In collaboration with CEA-LETI

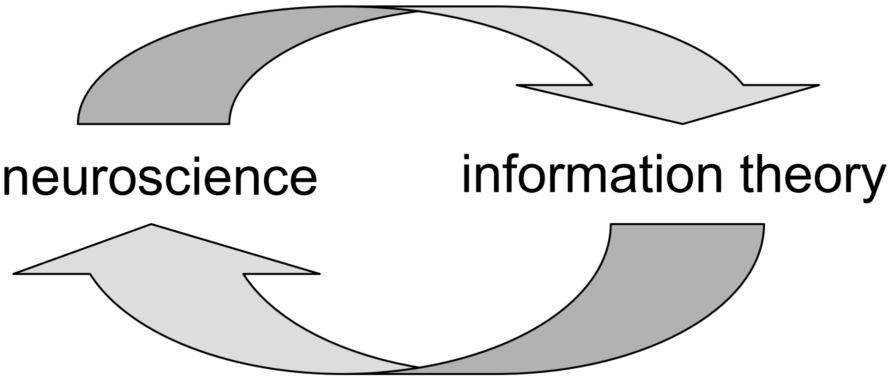


Application to dynamic power management in MPSoCs



Storing and retrieving a prefixed DVFS configuration
from any WLT combination, at the global scale

Conclusion



a very promising cross-fertilization

Our objectives

- **Implementing cognitive machines based on the properties of associative memories**
- **Contributing to the understanding of the biological long and short term memories,**
- **Find applications in electronics and telecommunications.**