

# Storing messages with multipartite neural cliques

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## Abstract

We extend recently introduced associative memories based on cliques to multipartite cliques. We propose a variant of the classic retrieving rule. We study their relative performance for retrieving partially erased and corrupted messages. We provide both analytical and simulation results showing improvements of capacity.

**Index terms**— associative memory, error correcting code, cliques, multipartite cliques, neural networks

## I Introduction

## II Networks of neural cliques

### 1 Learning messages

### 2 Retrieving messages

#### a The "winner takes all" rule

#### b The " $a$ winners take all" rule

less biologically plausible rule

same algorithmic complexity

## III Retrieval performance

### 1 Retrieving partially erased messages

#### a Analytical result

number of neurons per cluster  $l$

number of clusters  $c$

number of erased clusters  $c_e$

number of messages :  $m$

number of activities per cluster :  $a$

density :  $d$

edge :  $(i, j)$

probability for  $i$  and  $j$  to be active in their respective clusters for one message :  $\frac{a}{l}$

probability of the edge not being added in the network for one message :  $1 - \left(\frac{a}{l}\right)^2$

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

gap with density in simulations : under 1 percent

probability for a vertex  $v$  to achieve the maximum score, that is to mean  $a(c - c_e)$  :  $d^{a(c-c_e)}$

probability for a vertex  $v$  not to achieve the maximum :  $1 - d^{a(c-c_e)}$

probability for none of the vertices of one erased cluster, excepting the correct ones, to

achieve the maximum :  $(1 - d^{a(c-c_e)})^{l-a}$

probability for none of the vertices in any erased cluster, excepting the correct ones, to achieve the maximum in their respective cluster :  $(1 - d^{a(c-c_e)})^{c_e(l-a)}$

Whence error rate is :

$$P_{err} = 1 - \left(1 - d^{a(c-c_e)}\right)^{c_e(l-a)}$$

## b Simulations

Improves the retrieval rate for multiple iterations and/or corrupted messages.

The simulations agree with the analytical results for density and error rate.

For one iteration (for erasures, not for errors), winner takes all is the same as  $a$ -winners take all.

For multiple iterations  $a$ -winners take all is a significant improvement.

" $a$ -winners take all" better than "winner takes all" with errors instead of erasures, even for one iteration.

For errors : only better than only 1 activity per cluster if multiple iterations of the  $a$ -winners take all rule. For one iteration, it is less efficient.

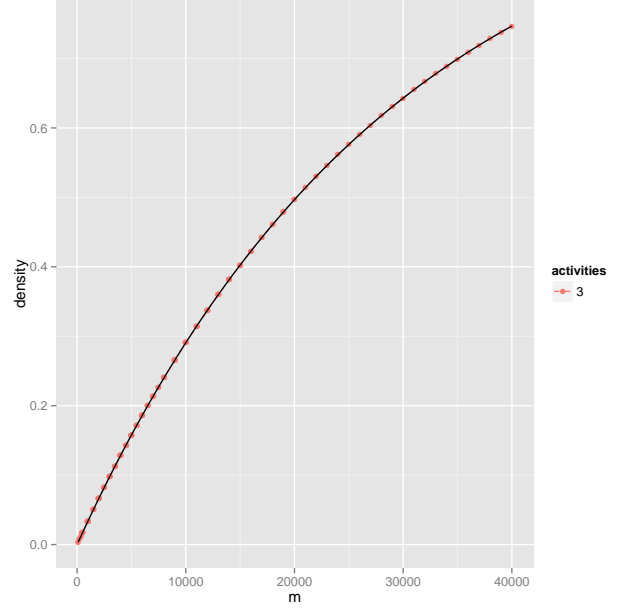


Figure 1: Theoretical and empirical densities

a

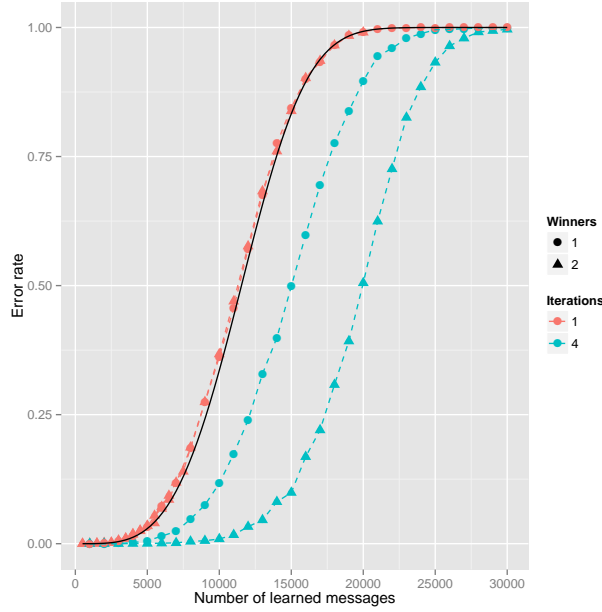


Figure 2: 2 activities per cluster, 4 clusters, 512 neurons per cluster, two erasures, each point is the mean of 5 networks with 1000 sampled messages, analytical result in continuous black

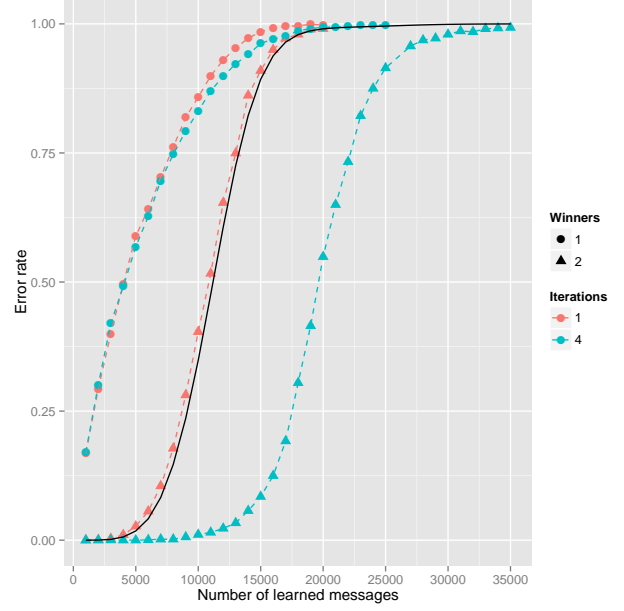


Figure 3: 2 activities per cluster, 4 clusters, 512 neurons per cluster, one erroneous cluster, each point is the mean of 5 networks with 1000 sampled messages, analytical result in continuous black

## 2 Retrieving corrupted messages

Spéculations en Français :

Peut-être un intérêt pour cluster based associative memories build from unreliable storage : si une arête porte moins d'info, on peut peut-être en supprimer plus (mais rajout ?!)

Marche mieux pour des bruits importants

$$P(n_{v_c} = n_0) = \binom{ac_k}{n_0} (1 - \psi)^{n_0} \psi^{ac_k - n_0}$$

$$P_+ = \psi(1 - d) + (1 - \psi)d$$

$$P(n_v = x) = \binom{ac_k}{x} P_+^x (1 - P_+)^{ac_k - x}$$

Sans tenir compte du choix au hasard si plus sont activés.

a priori for noise on edges :

a

$$P(\text{no other vertex activated in this cluster}) = \sum_{n=1}^{ac_k} \left[ \sum_{k=1}^a \binom{a}{k} P(n_{v_c} = n)^k P(n_{v_c} > n)^{a-k} \right] \left[ \sum_{x=0}^{n-1} P(n_v = x) \right]^{l-a}$$

$$P(\text{no other vertex activated in any cluster}) = \left( \sum_{n=1}^{ac_k} \left[ \sum_{k=1}^a \binom{a}{k} P(n_{v_c} = n)^k P(n_{v_c} > n)^{a-k} \right] \left[ \sum_{x=0}^{n-1} P(n_v = x) \right]^{l-a} \right)^{c_e}$$

Formula for errors insted of erasures :

gc : good (à remplacer par right) neuron in correct cluster

ge : good neuron in erroneous cluster

abe : bad activated neuron in erroneous cluster

be : others bad (à remplacer par wrong ou incorrect etc.) neurons in erroneous cluster

bc : bad neuron in correct cluster

$$P(n_{gc} = (c - c_e - 1) + \gamma + x) = \binom{c_e}{x} d^x (1 - d)^{c_e - x}$$

$$P(n_{ge} = (c - c_e) + x) = \binom{c_e - 1}{x} d^x (1 - d)^{c_e - 1 - x}$$

$$P(n_{abe} = \gamma + x) = \binom{c - 1}{x} d^x (1 - d)^{c - 1 - x}$$

$$P(n_{be} = x) = P(n_{bc} = x) = \binom{c - 1}{x} d^x (1 - d)^{c - 1 - x}$$

$$P_{retrieve} = \left[ \sum_{n=1}^{c-1+\gamma} P(n_{gc} = n) \left[ \sum_{x=0}^{n-1} P(n_{bc} = x) \right]^{l-1} \right]^{c-c_e} \\ \times \left[ \sum_{n=1}^{c-1+\gamma} P(n_{ge} = n) \left[ \sum_{x=0}^{n-1} P(n_{bc} = x) \right]^{l-2} \left[ \sum_{x=0}^{n-1} P(n_{abc} = x) \right] \right]^{c_e}$$

generalisation to multiple activities per cluster

:

$$P(n_{gc} = a(c - c_e - 1) + \gamma + x) = \binom{ac_e}{x} d^x (1 - d)^{ac_e - x}$$

$$P(n_{ge} = a(c - c_e) + x) = \binom{a(c_e - 1)}{x} d^x (1 - d)^{a(c_e - 1) - x}$$

$$P(n_{abe} = \gamma + x) = \binom{a(c - 1)}{x} d^x (1 - d)^{a(c - 1) - x}$$

$$P(n_{be} = x) = P(n_{bc} = x) = \binom{a(c - 1)}{x} d^x (1 - d)^{a(c - 1) - x}$$

$$P_{retrieve} = \left[ \sum_{n=1}^{a(c-1)+\gamma} \left[ \sum_{k=1}^a \binom{a}{k} P(n_{gc} = n)^k P(n_{gc} > n)^{a-k} \right] P(n_{bc} < n)^{l-a} \right]^{c-c_e} \\ \times \left[ \sum_{n=1}^{a(c-1)+\gamma} \left[ \sum_{k=1}^a \binom{a}{k} P(n_{ge} = n)^k P(n_{ge} > n)^{a-k} \right] P(n_{bc} < n)^{l-2a} P(n_{abc} < n)^a \right]^{c_e} \\ P_{err} = 1 - P_{retrieve}$$

## IV Conclusion

## References

[LPGRG14] François Leduc-Primeau, Vincent Gripon, Michael Rabbat, and Warren Gross. Cluster-based associative memories built from unreliable storage. In *ICASSP*, May 2014. To appear.