A Robust Feedforward Model of the Olfactory System

Yilun Zhang and Tatyana Sharpee (2016)

Presented By:

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Problem Statement

Computational Problem	How olfactory system performs odor recognition?
Algorithm	Compressed Sensing
Biological Implementation	Feedforward binary neurons

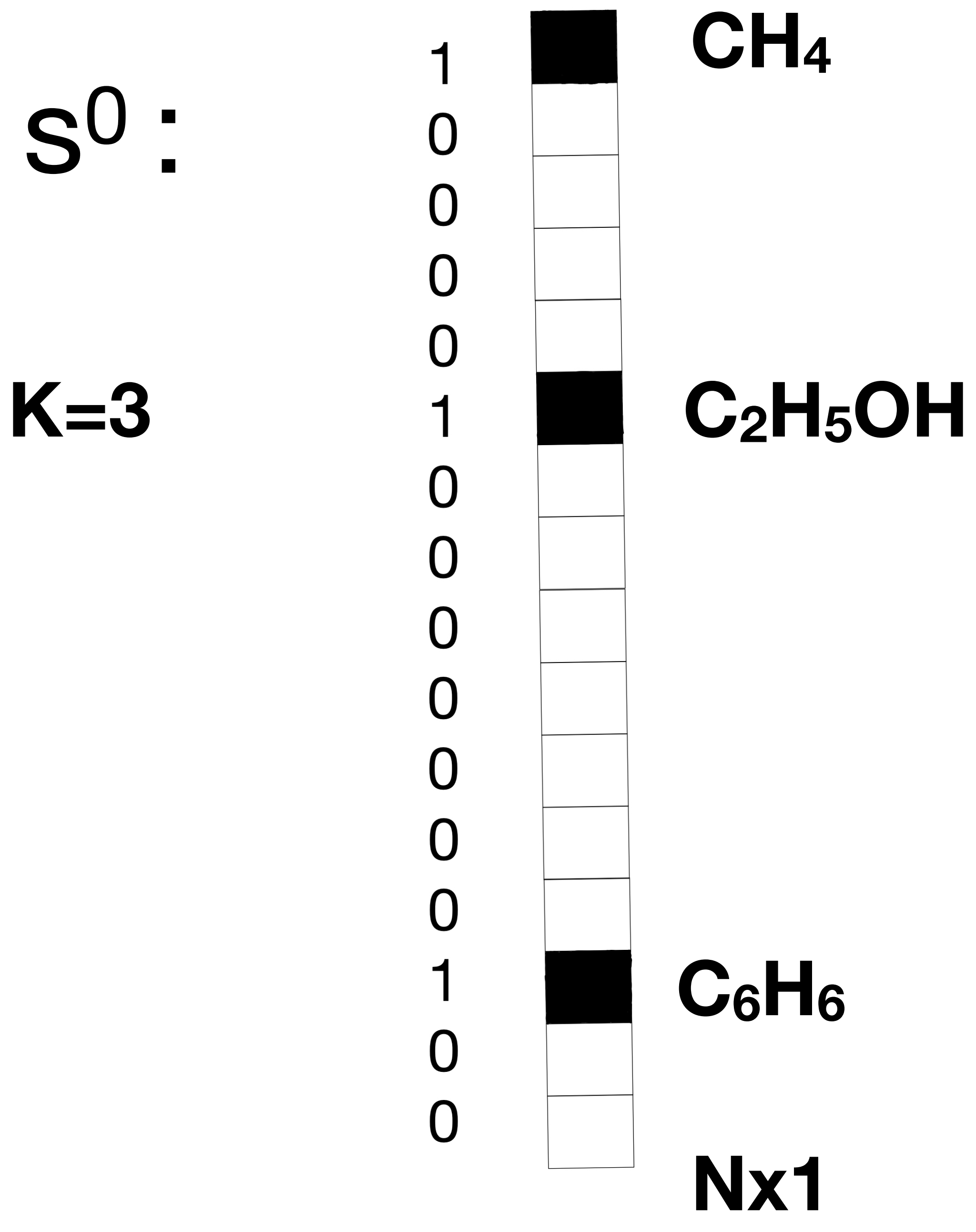
Achievements of the paper

- Presents a very **simple** model for odor recognition which can be solved exactly and analytically.
- Model is robust to noise. Removal of glomeruli still leads to recovery of odor identity
- Predictions (consistent with experiments): Response to odorants

	Glomeruli	Connectivity Rate (glomeruli->KC)
Drosophila	9%	6.5-12.5%
Locusts	50%	50%

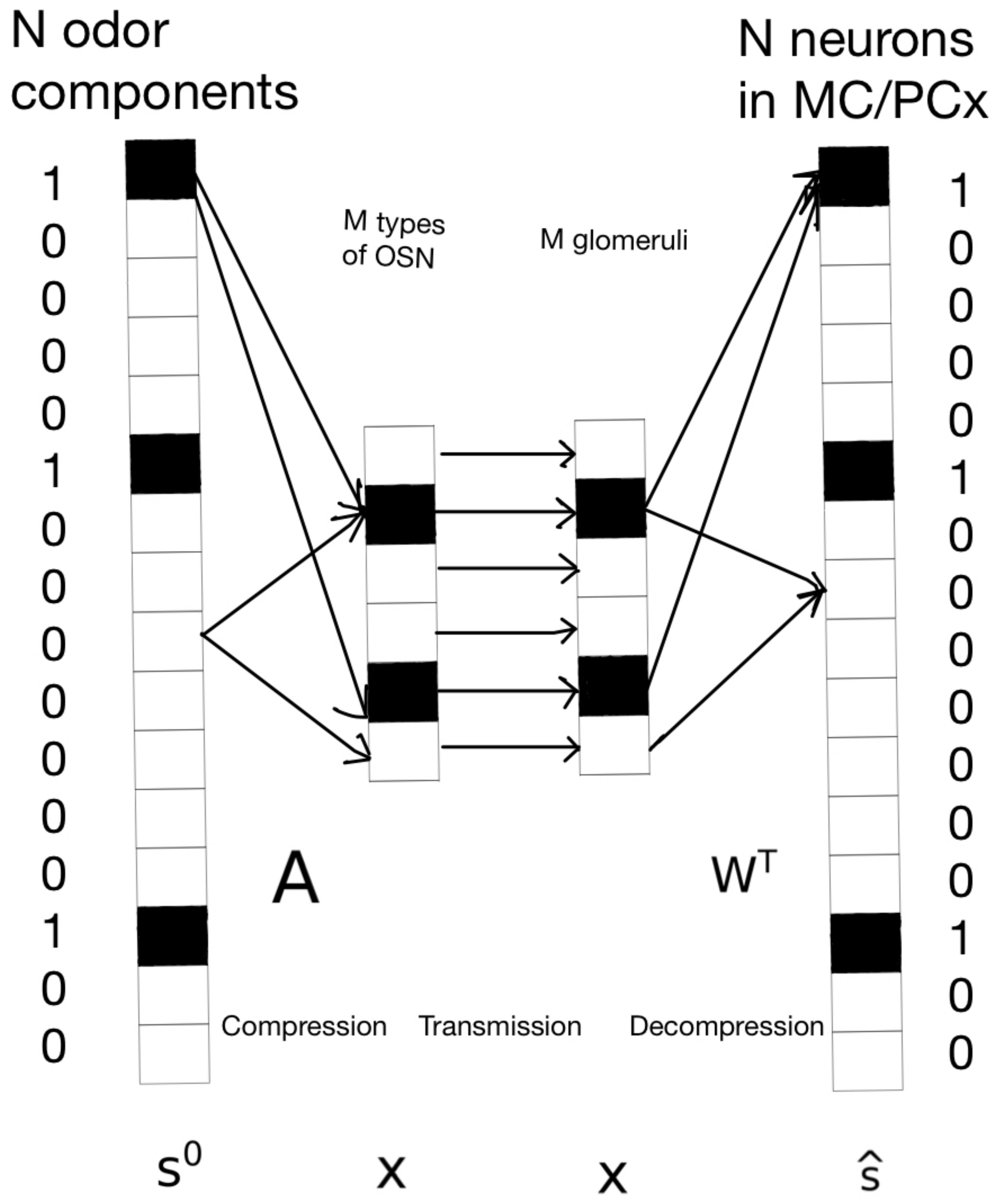
Nature of Olfactory Stimulus

- The olfactory universe consists of $N = 10^4$ volatile molecules
- Natural odors consists of hundreds of volatile molecules
- But only $K = 15$ (say) are important for perception
- Olfactory stimulus vector s^0 :



Highly(!) Simplified Model of Olfactory System

- Odor stimulus: s^0 (K sparse Nx1 vector)
- Recovered signal: $\hat{s}$
- Glomerular signal: x (Mx1 vector)
- Want: $\hat{s} = s^0$



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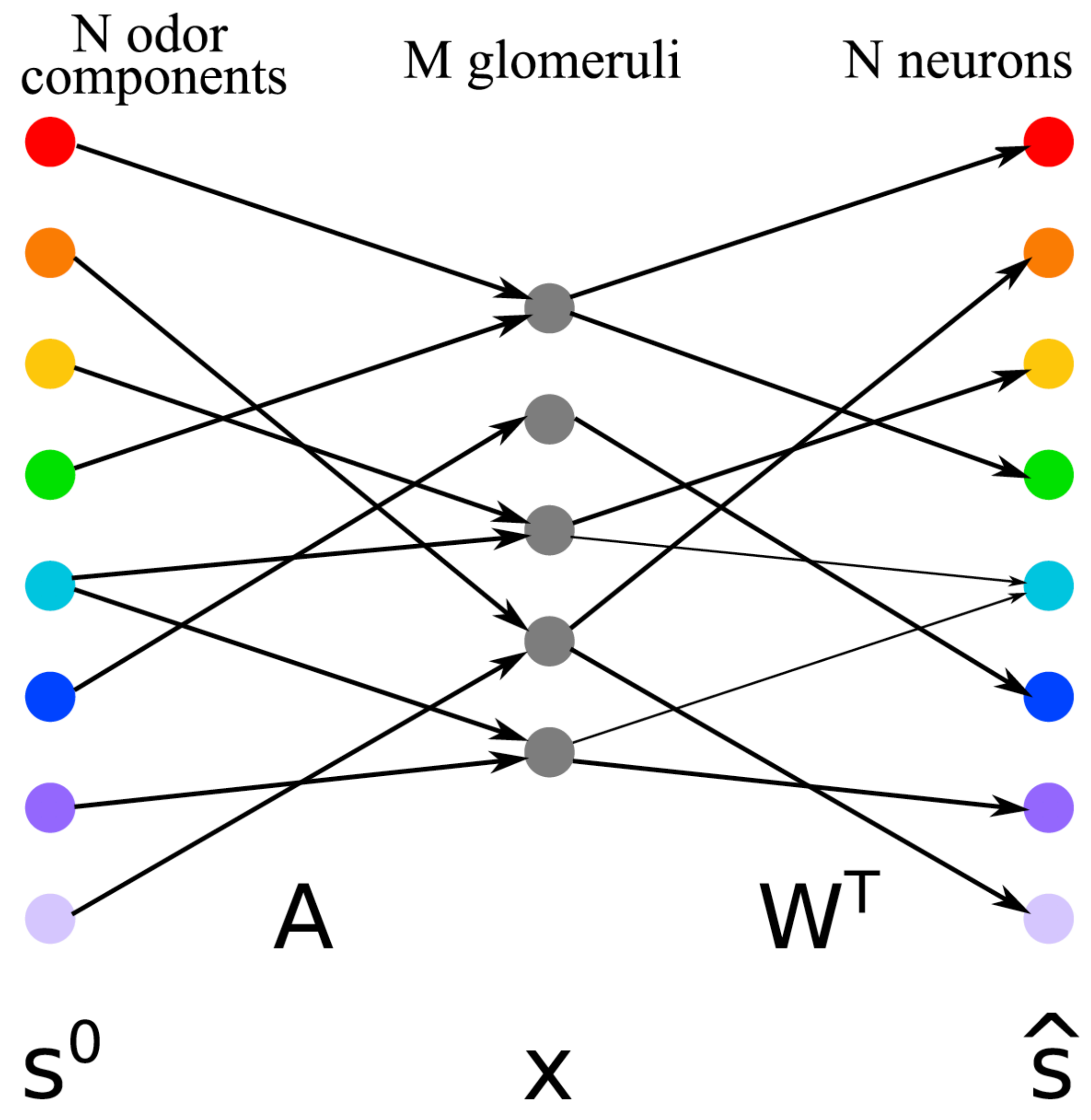
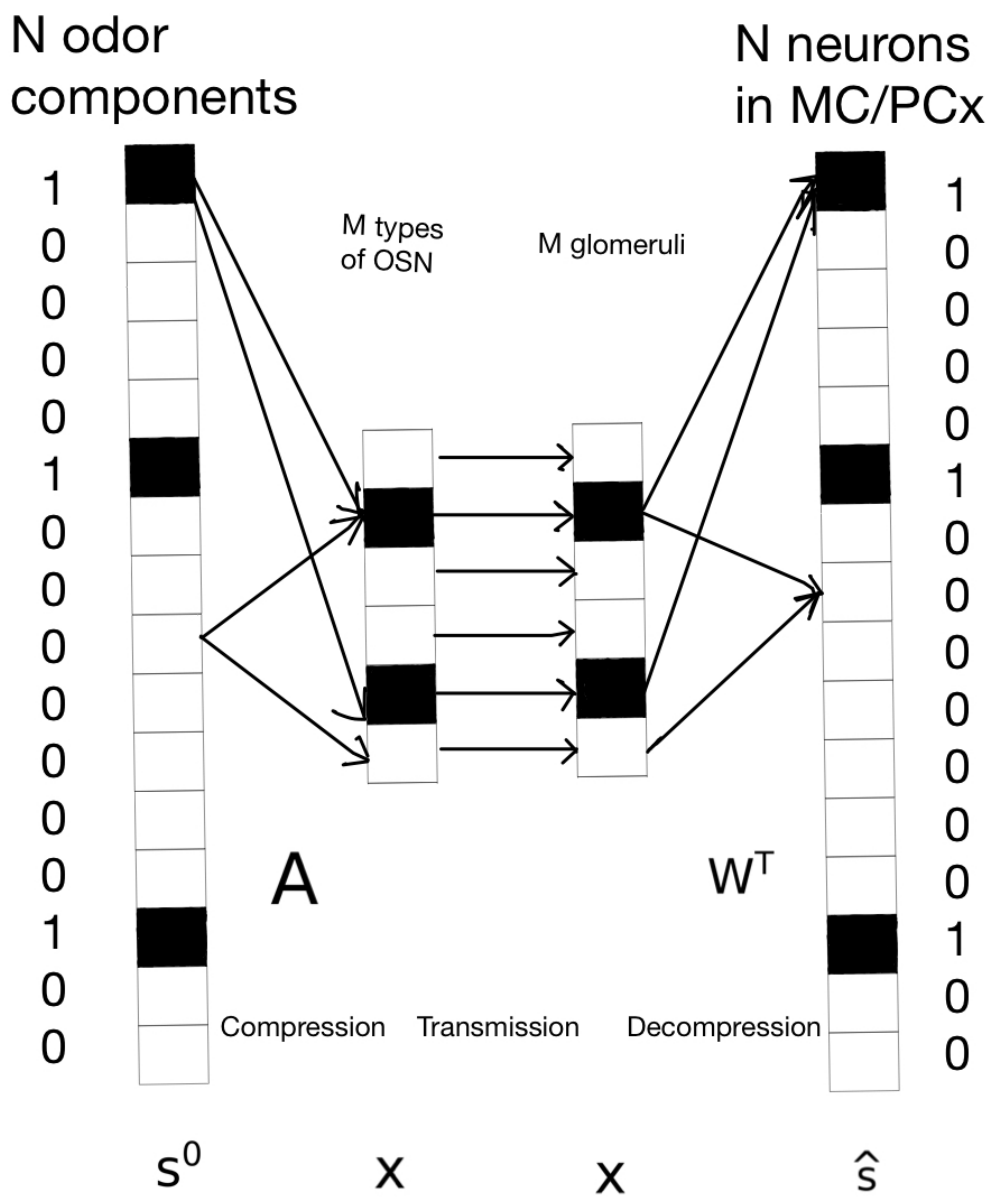




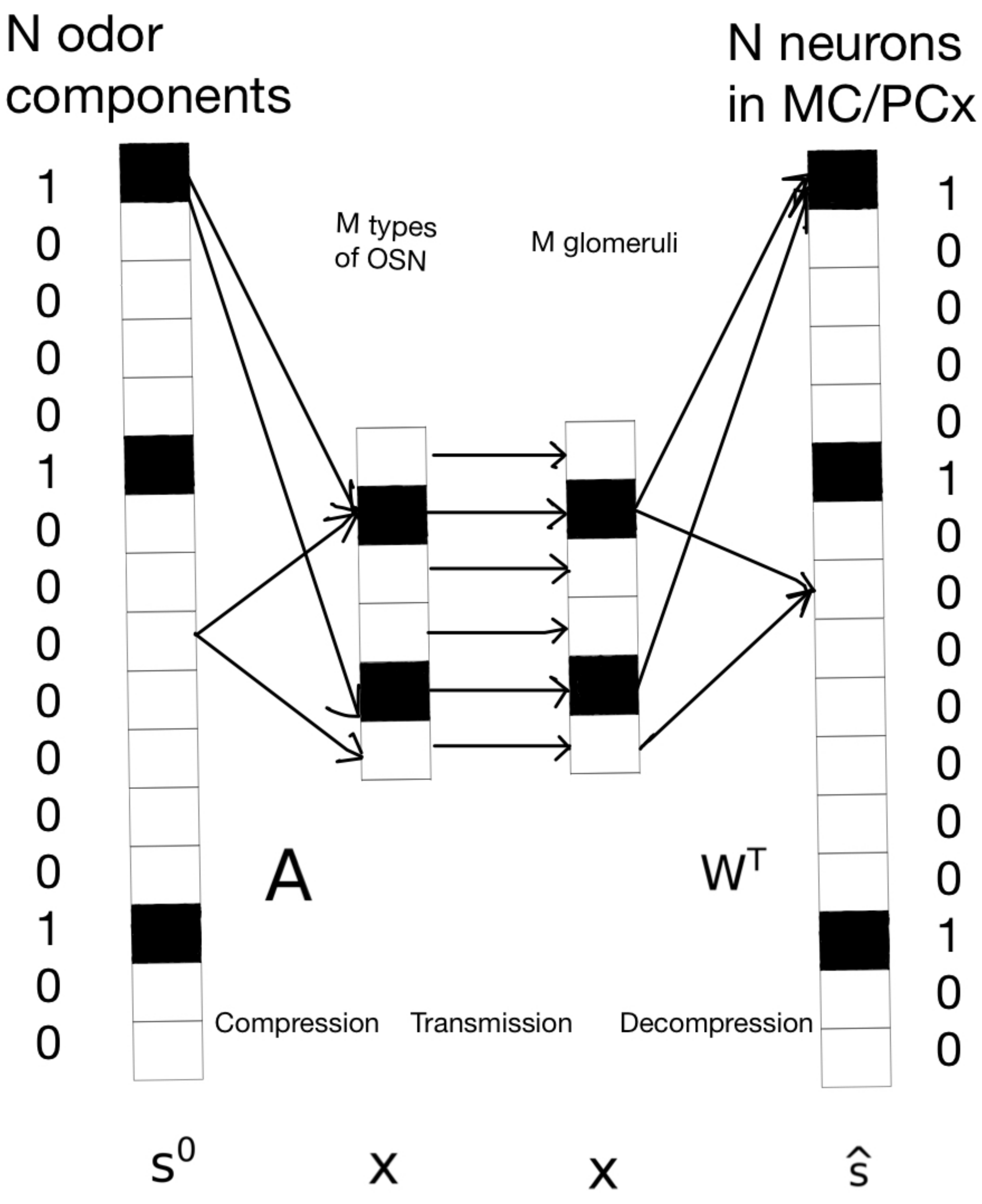
Non-linear Compressed Sensing

$$x = \mathcal{H}(As^0 - \theta_c)$$

$$\hat{s} = \mathcal{H}(W^T x - \theta_r)$$

K<M<<N

- All vectors and matrices are binary
- Elements of matrix A are 1 with probability p and 0 with probability 1-p
- θ_c and θ_r equal to 1 (as vectors)
- The elements are W are given by: $W_{ki} = A_{ki}/\sum_k A_{ki}$



Simple Example: N=3, K=1, M= 2

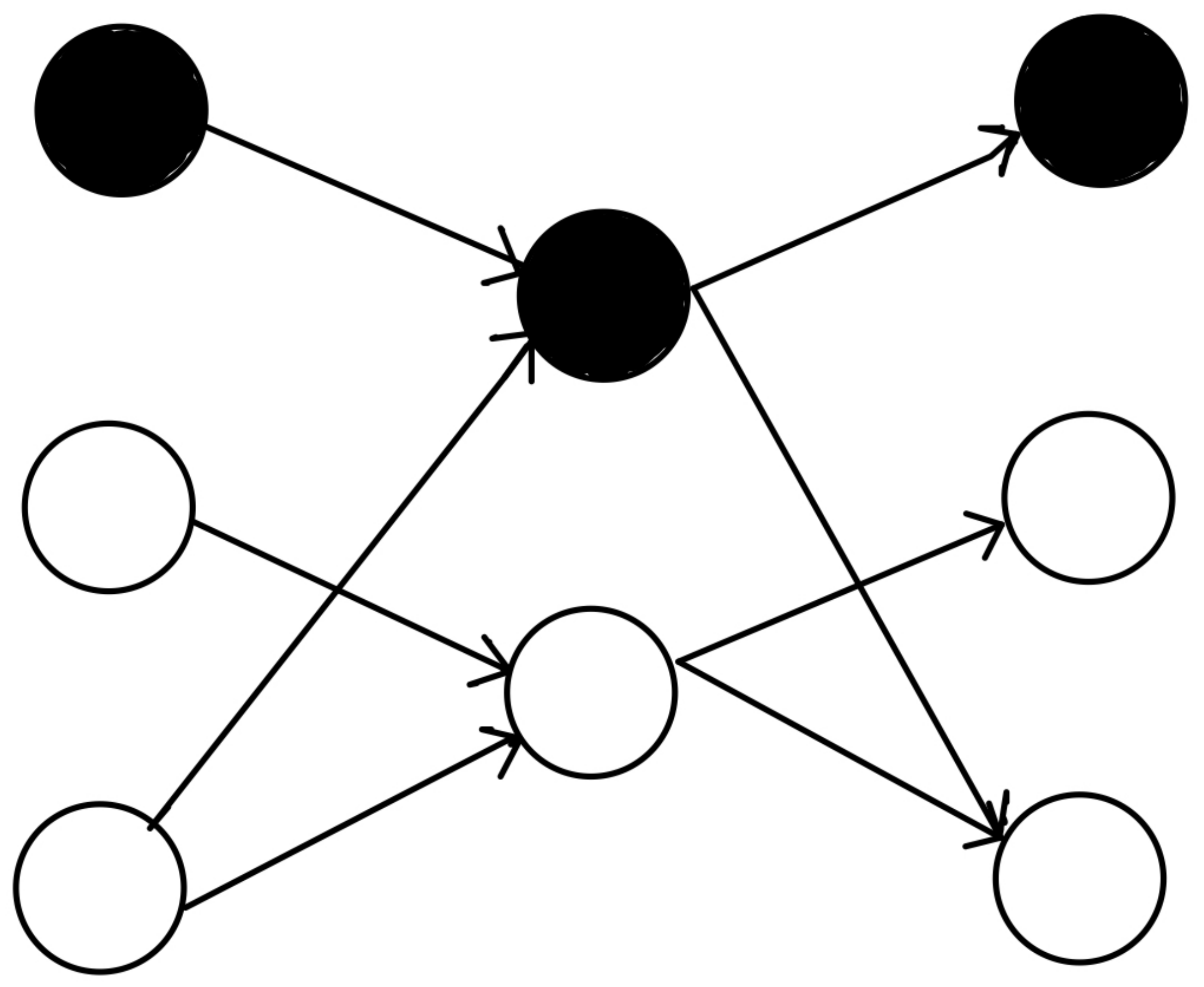
$$s^0 = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} \qquad A= \begin{pmatrix} 1 & 0 & 1 \\ 0 & 0 & 1 \end{pmatrix} \qquad W= \begin{pmatrix} 1 & 0 & 0.5 \\ 0 & 0 & 0.5 \end{pmatrix}$$

$$x = \mathcal{H}(As^0 - \theta_c) \qquad \hat{s} = \mathcal{H}(W^T x - \theta_r)$$

Intuition

- Compression stage implements OR operation. If **any** input to OSN(glomeruli) are active then the OSN(glomeruli) get activated.

- Decompression stage implements AND operation. Iff **all** input to neurons in MB/PCx are active then the neuron get activated.



Deducing p by maximizing mutual information

- Want: Maximum odor stimulus information reaches the brain
- Do: Maximize information transfer across the channel (mutual information)
- Result: $$p_m = \frac{1}{K+1}.$$
- Meaning: Sparser connections gives you greater odor acuity(?)

Figures

Figure 1b

$$\mathrm{SNR} = \frac{||s^0||_0}{< ||\hat{s}||_0 > - ||s^0||_0} = \frac{K}{(N-K)p_{\mathrm{false}}},$$

- SNR ratio decreases as sparsity increases
- For large K, low connectivity probability p leads to higher SNR

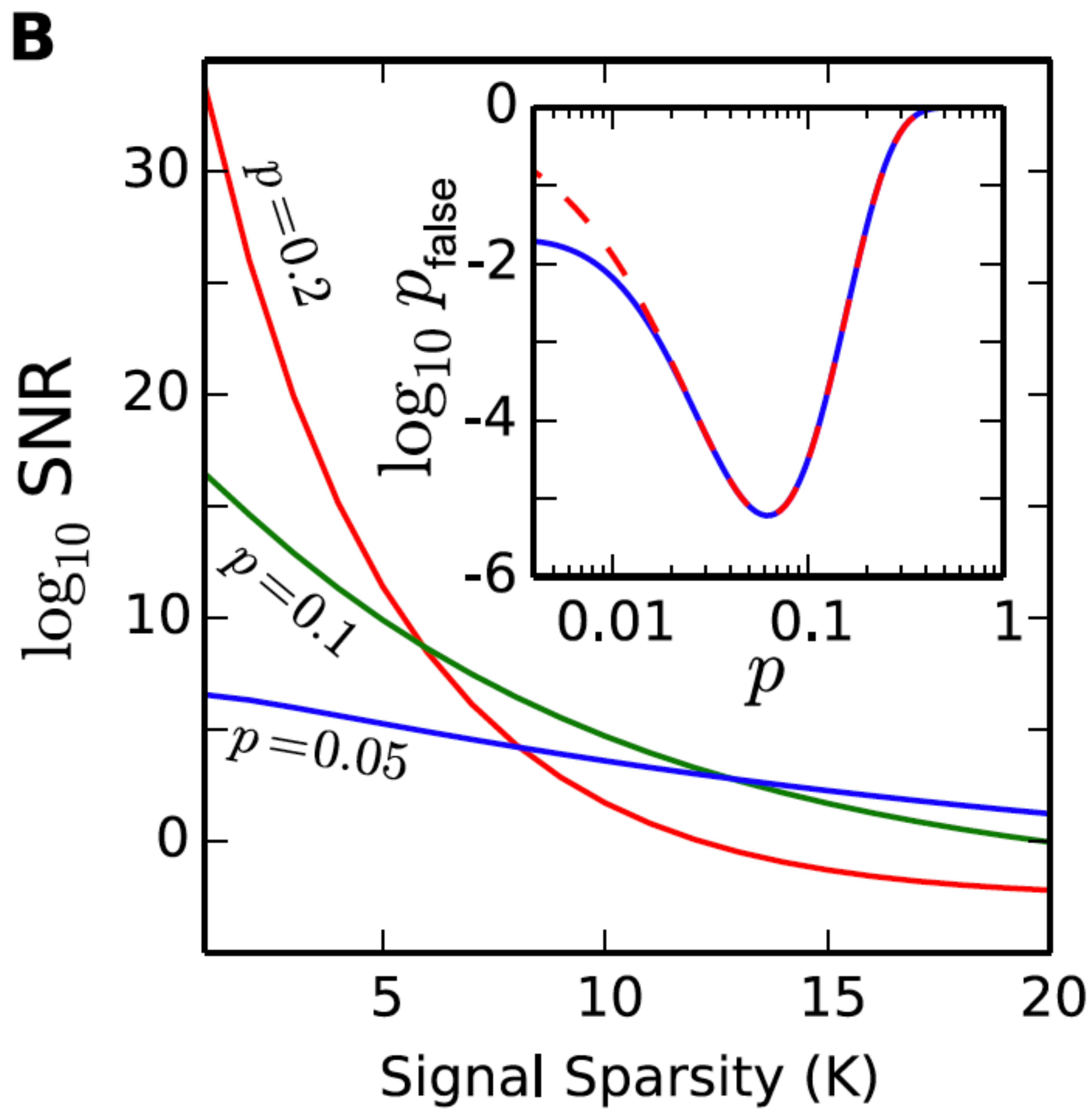


Figure 2a

- Increasing number of glomeruli for a given sparsity increases SNR

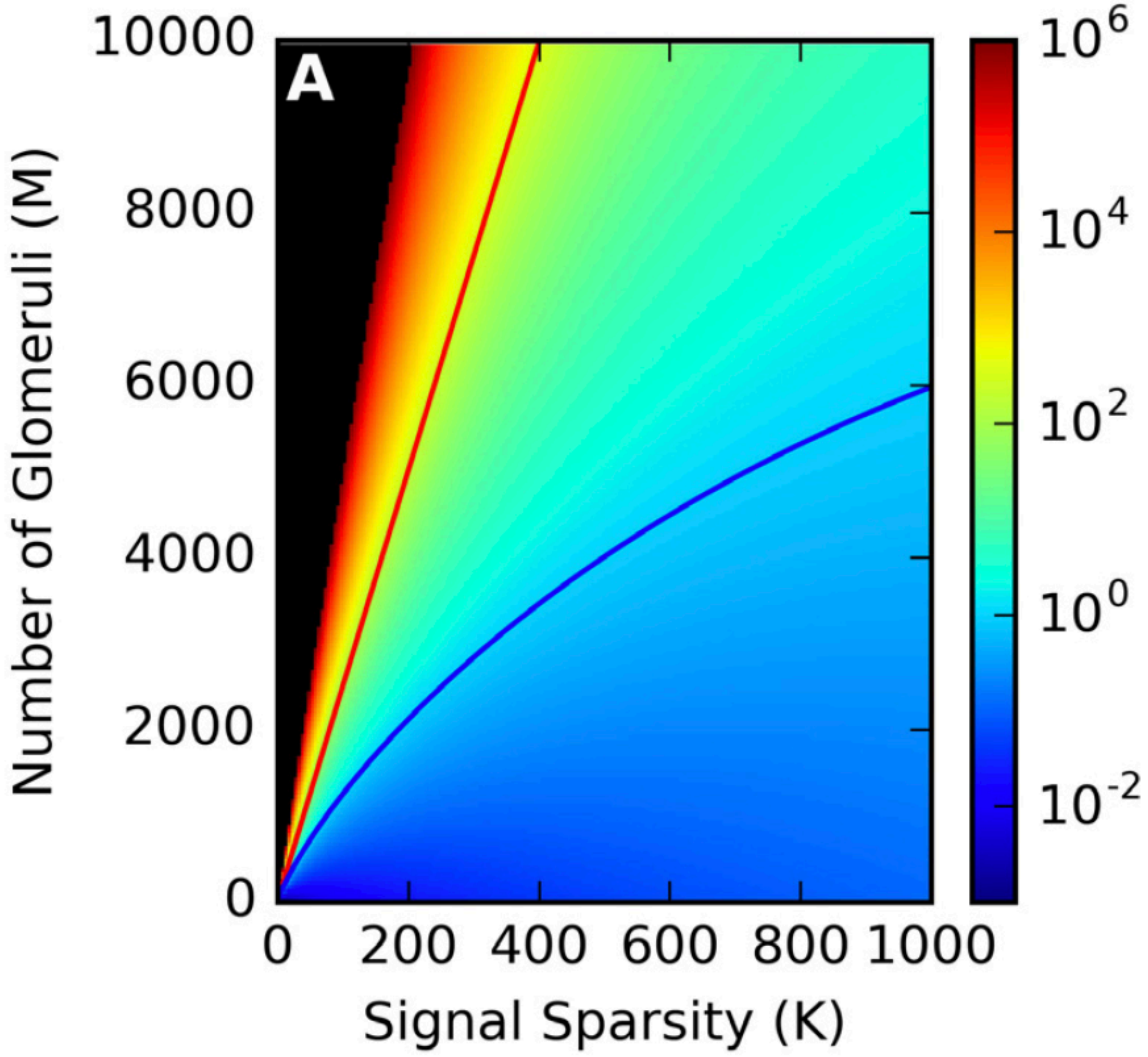


Figure 2b

- SNR increases exponentially with the number of glomeruli (types of OSNs)
- Decreasing sparsity(K) of the stimulus increases the SNR for given number of glomeruli

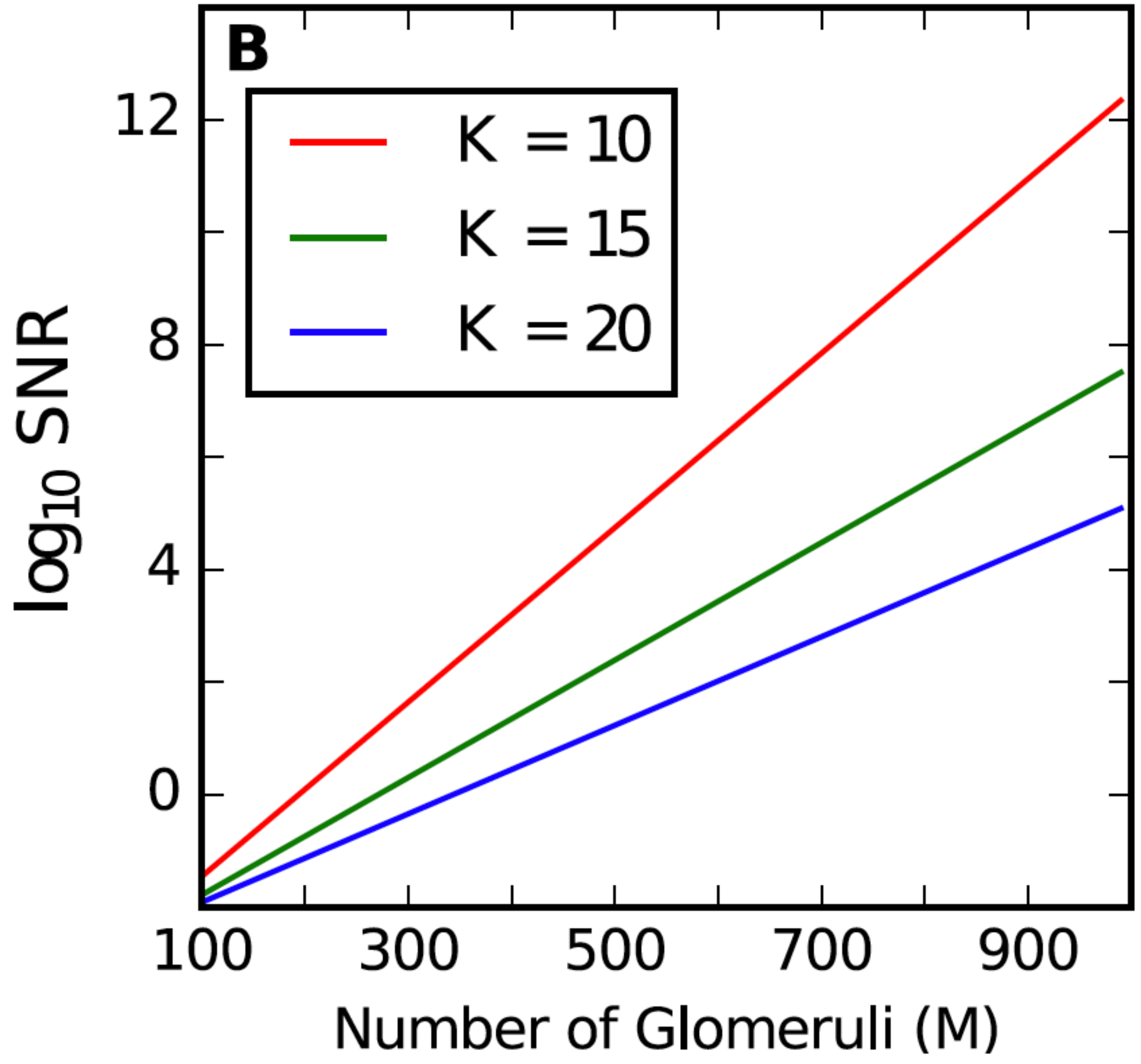


Figure 2c

- SNR ratio decreases as sparsity increases
- Higher M corresponds to higher SNR

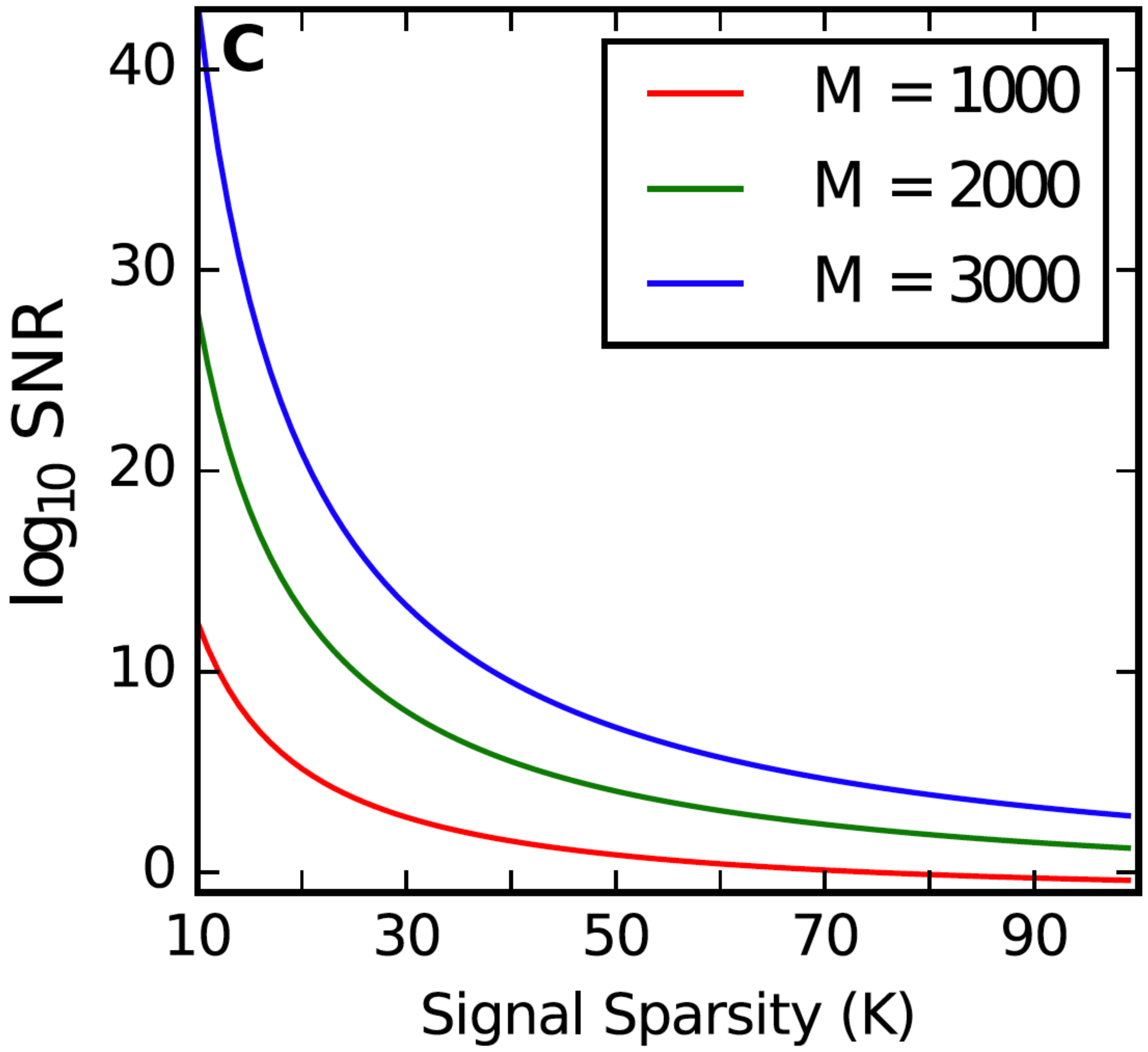


Figure 2d

- More glomeruli per sparsity K means more SNR
- Theoretical limit is the minimum number of glomeruli for reconstruction of signal

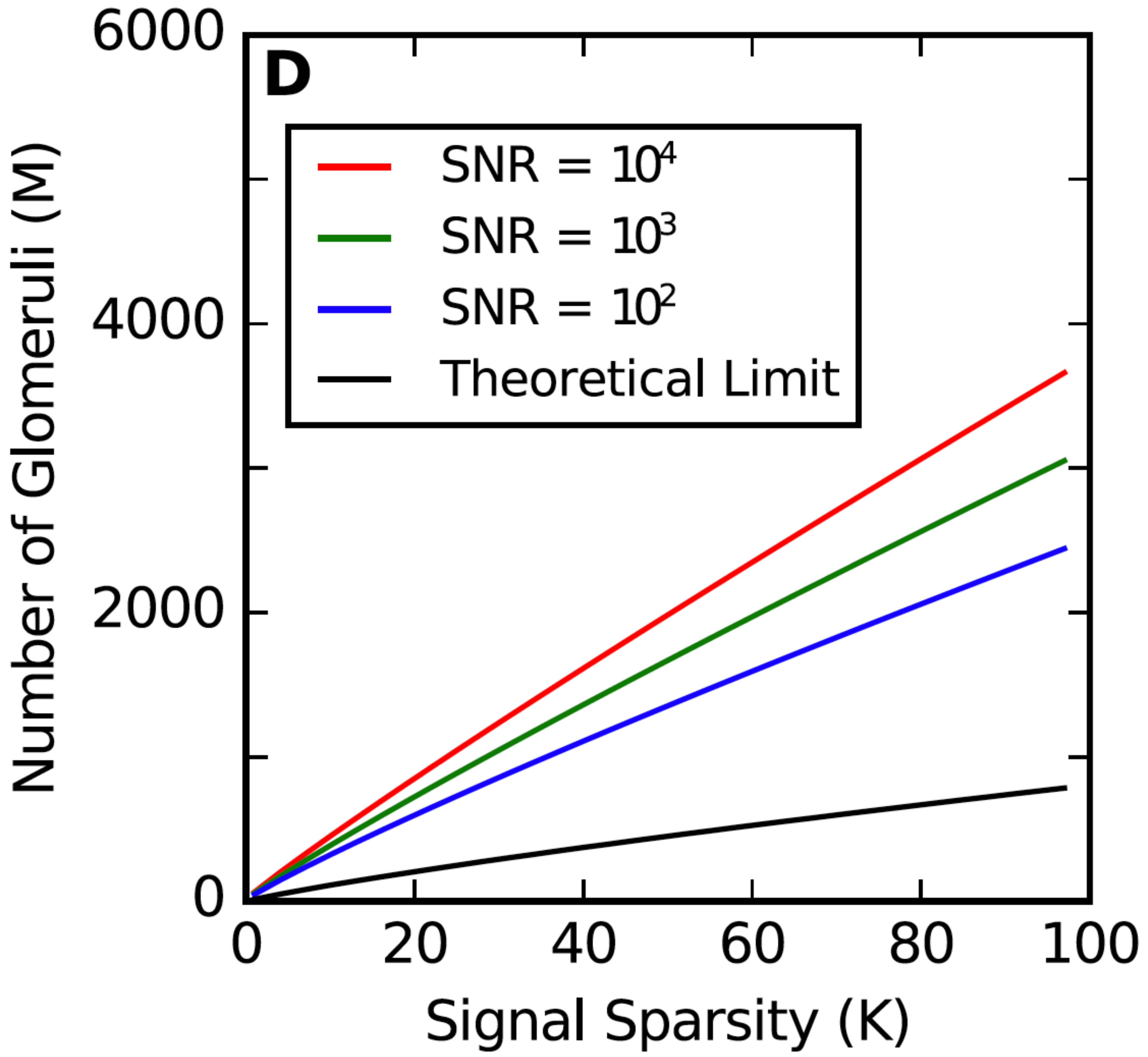


Figure 3a

$$\hat{s} = \mathcal{H}(W^T x - \theta_r)$$

- Decreasing θ_r means neurons in MB/PCx will be activated with smaller number of glomeruli
- Pattern completion in MB/PCx can still recover the signal

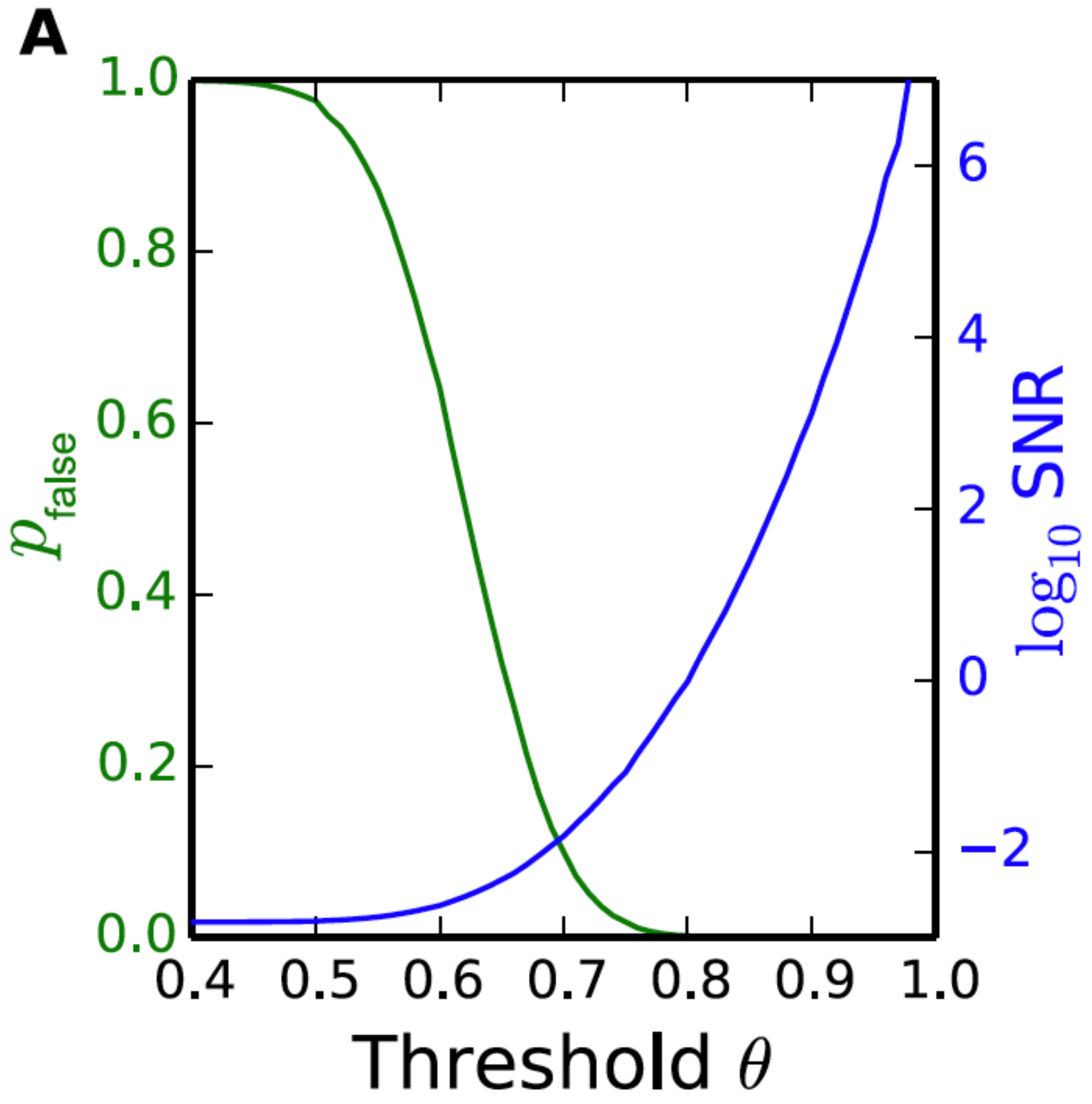


Figure 3b

- Lower threshold leads to corrupt output (poorer reconstruction)

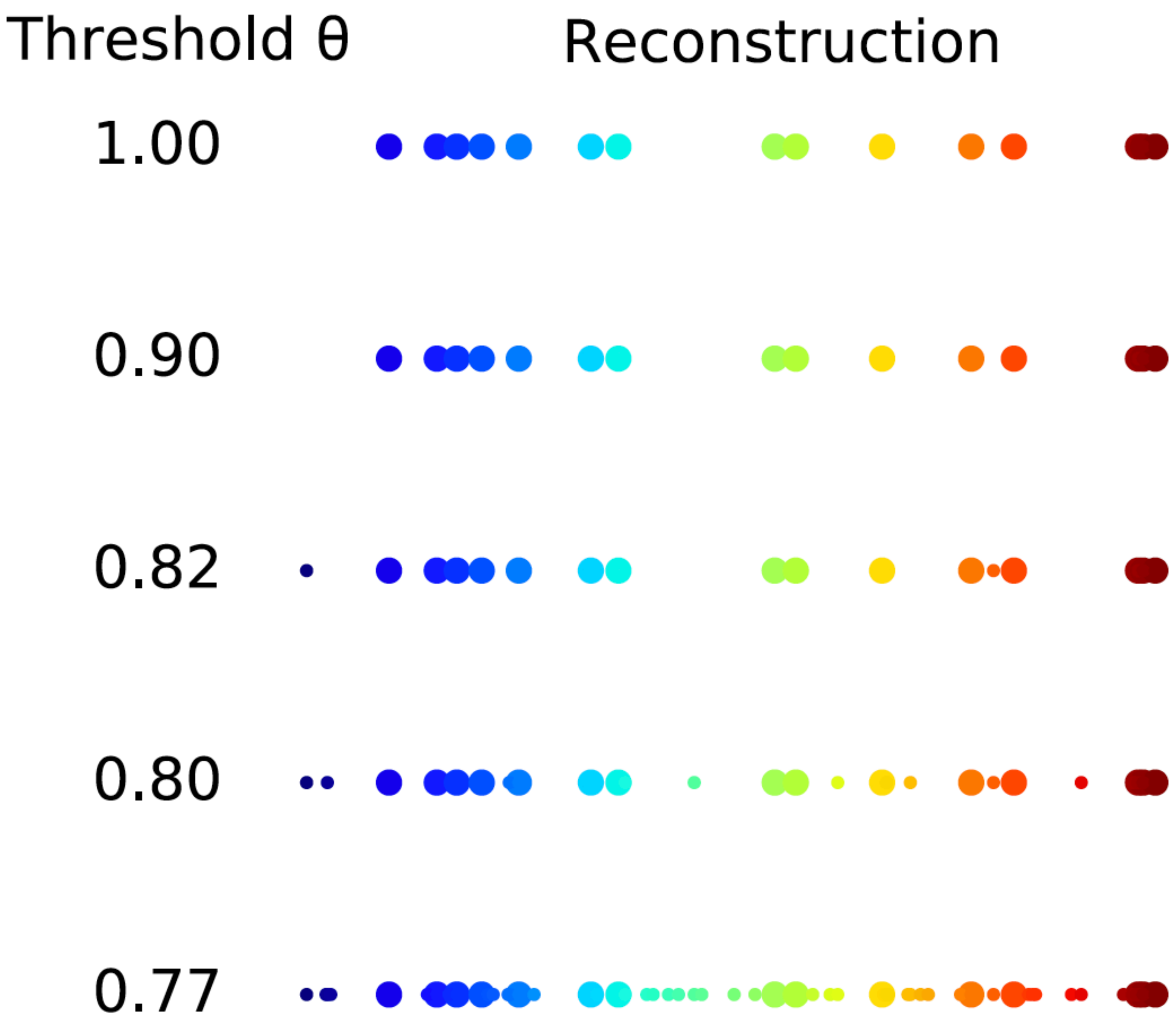
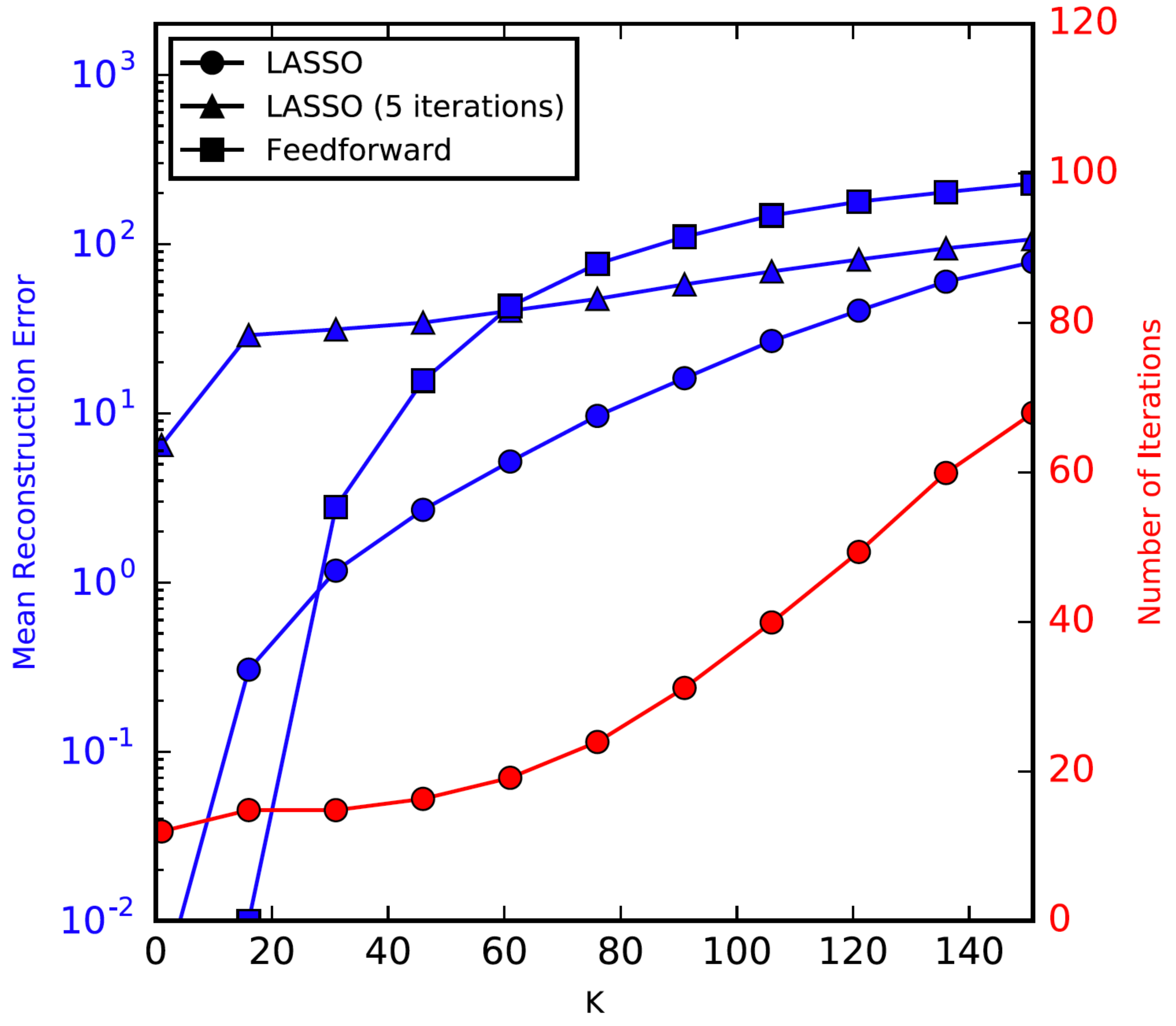


Figure 4

- Comparison with LASSO:

$$\min_{\hat{s}} \frac{1}{2M} ||A\hat{s} - x||_2^2 + \beta ||\hat{s}||_1$$

- LASSO performs better than neural network for sparsity K>30
- LASSO limited to 5 iterations performs worse than neural network for K<60
- For large K, LASSO outperforms neural network



Strengths and Weaknesses of the Paper

Strengths:

- Simple and easily interpretable model for odor recognition
- Predictions consistent with experiments

Weaknesses:

- Biological realism of the non-linearity is doubtful
- Role of different neural populations is unclear
- Makes very few predictions

Thank You!

Discussion Questions

- What behavioral factors determine sparsity K for an organism?
- What is the optimal value for SNR?