

# Recap

- Dynamic rule
  - Asynchronous updates
  - Synchronous updates

# Practice: **Asynchronous** updating using the dynamic rule

$$\mathbf{m}_1 = \begin{pmatrix} 1 \\ 1 \\ -1 \\ -1 \end{pmatrix} \quad \mathbf{m}_2 = \begin{pmatrix} -1 \\ 1 \\ -1 \\ 1 \end{pmatrix} \quad \mathbf{x}_1 = \begin{pmatrix} 0 \\ 1 \\ -1 \\ 0 \end{pmatrix} \quad \mathbf{x}_2 = \begin{pmatrix} 1 \\ 1 \\ 0 \\ 0 \end{pmatrix}$$

$$w(i,j) = \sum_{k=1}^L a(i)a(j)$$

Learning rule

$$a(i) = \operatorname{sgn} \left( \sum_{j=1}^N w(i,j)a(j) \right)$$

Dynamic rule

# Practice: **Synchronous** updating using the dynamic rule

$$\mathbf{m}_1 = \begin{pmatrix} 1 \\ 1 \\ -1 \\ -1 \end{pmatrix} \quad \mathbf{m}_2 = \begin{pmatrix} -1 \\ 1 \\ -1 \\ 1 \end{pmatrix} \quad \mathbf{x}_1 = \begin{pmatrix} 0 \\ 1 \\ -1 \\ 0 \end{pmatrix} \quad \mathbf{x}_2 = \begin{pmatrix} 1 \\ 1 \\ 0 \\ 0 \end{pmatrix}$$

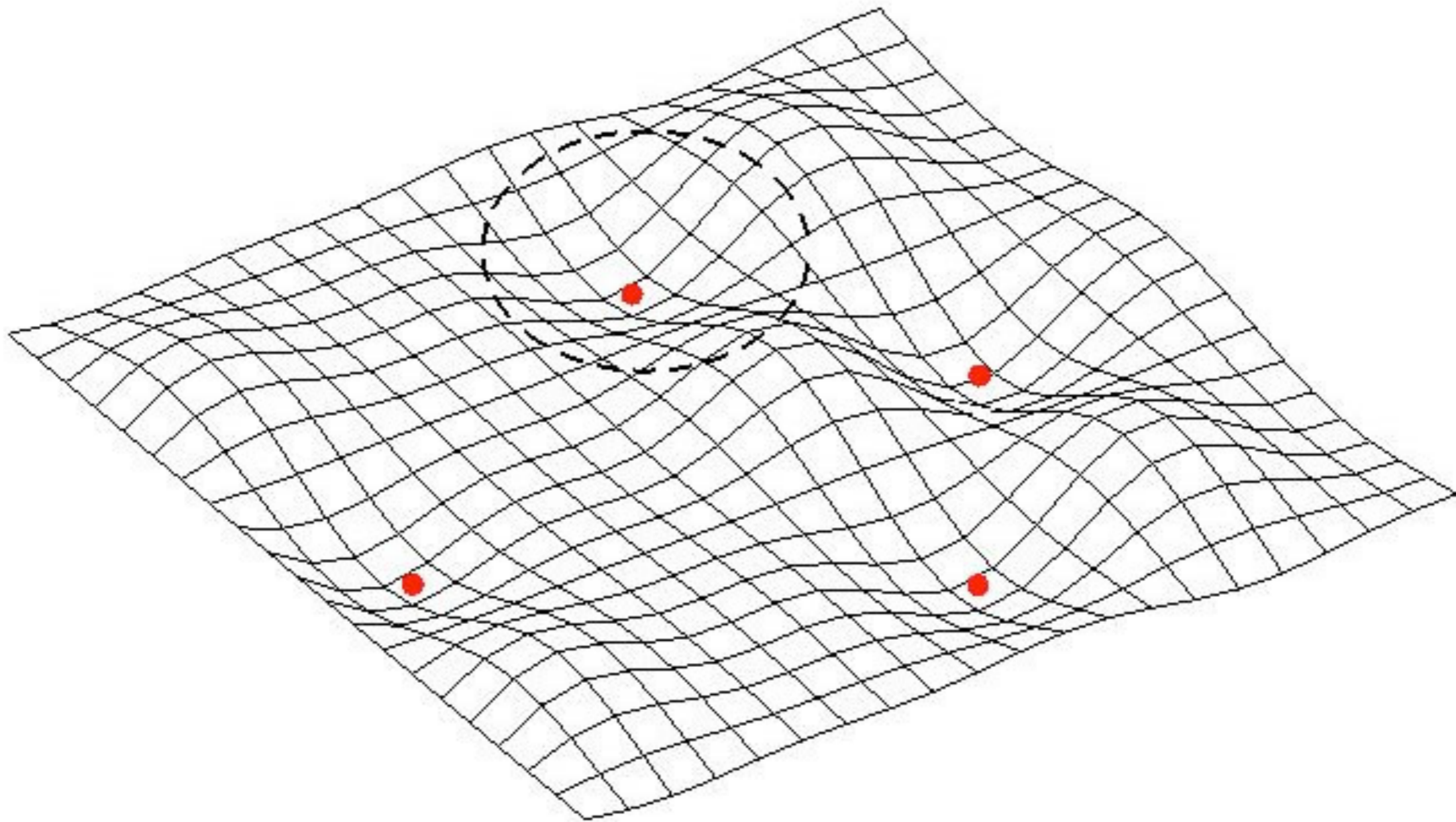
$$w(i,j) = \sum_{k=1}^L a(i)a(j)$$

Learning rule

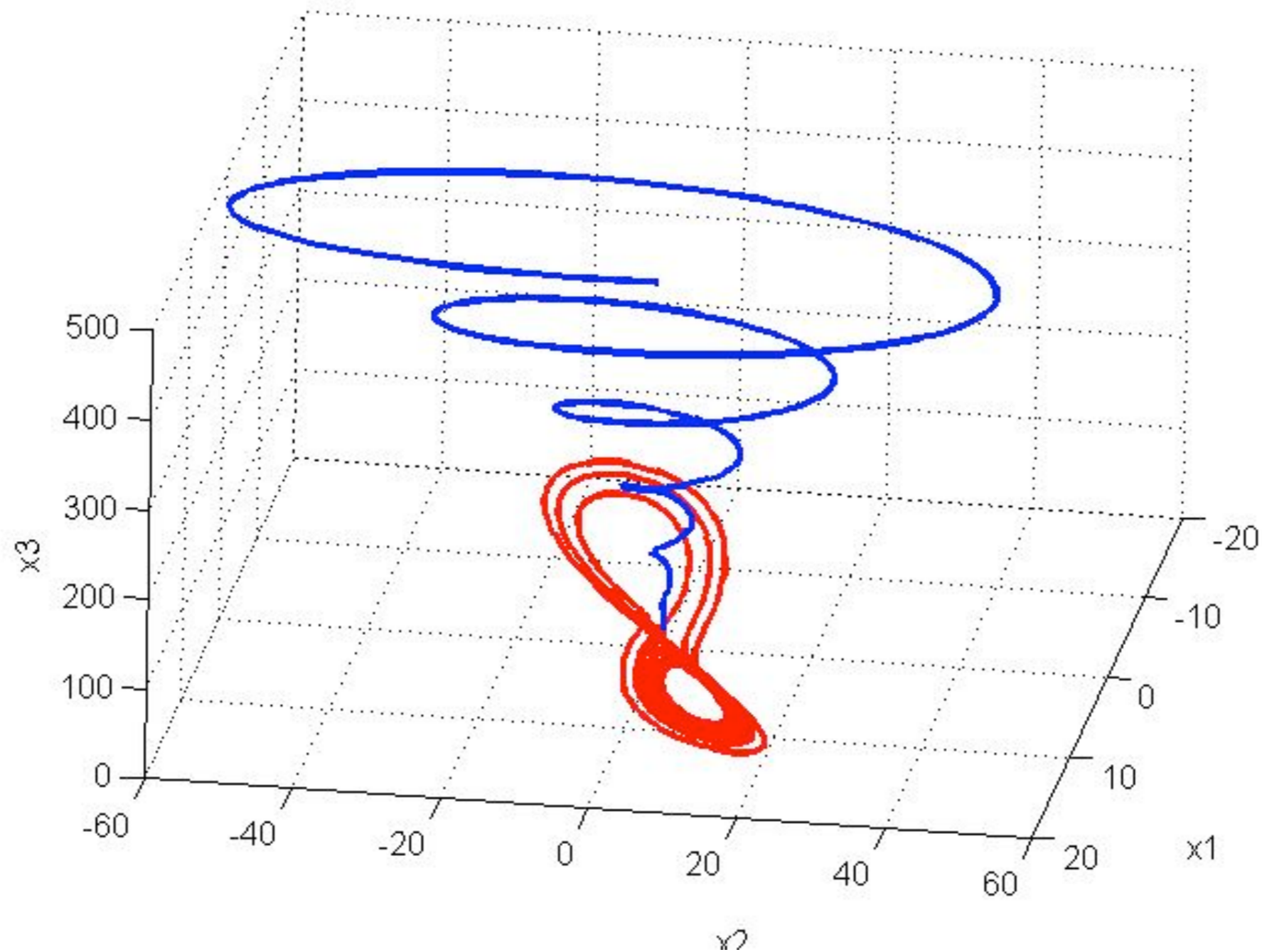
$$a(i) = \operatorname{sgn} \left( \sum_{j=1}^N w(i,j)a(j) \right)$$

Dynamic rule

# Further intuitions

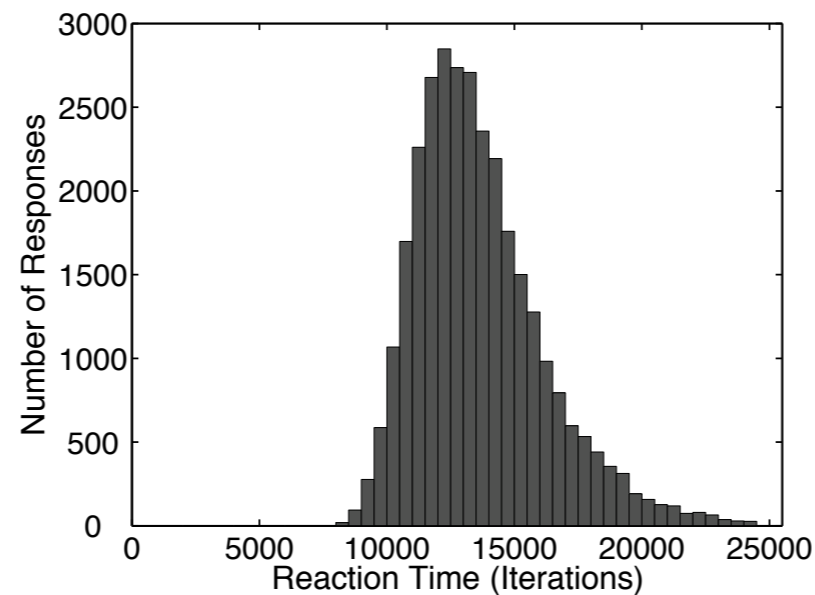


# Further intuitions



# Temporal dynamics (asynchronous)

- Reaction Time: Number of updates before activations stabilize



- Adding noise ( $\epsilon$ ) to the threshold value of zero improves the network's performance

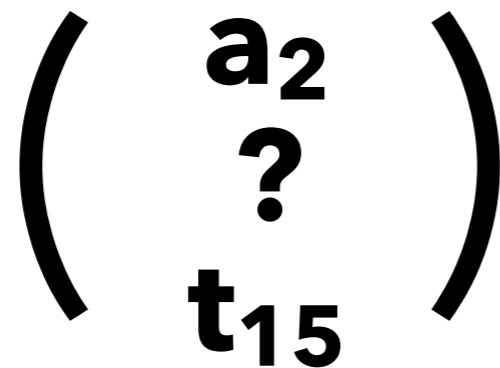
# Associations and context

$$\begin{pmatrix} a_1 \\ \vdots \\ a_N \\ \hline b_1 \\ \vdots \\ b_N \\ \hline t_1 \\ \vdots \\ t_N \end{pmatrix} = \begin{pmatrix} \mathbf{a} \\ \mathbf{b} \\ \mathbf{t} \end{pmatrix}$$

# Associations and context



**test probe**





# Hopfield Net Properties

- Reaction Time: Number of updates to complete a pattern
- Failure to recall: No pattern completed within a given interval
- Similarity based interference arises from adding weights
- Learning can be gradual