



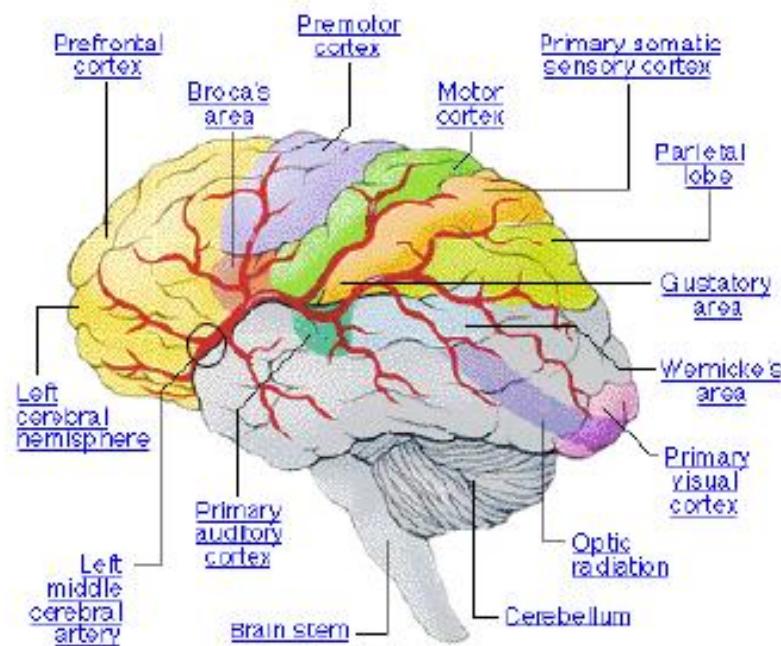
SELF-ORGANIZING FEATURE MAP

INT301 Bio-computation, Week 11, 2025



Self-Organizing Map – 自组织映射 · Biological Motivation

- Brain is a **self-organizing system** that can learn by itself by changing (adding, removing, strengthening) the interconnections between neurons.
- Neurons with similar functions are grouped together.



Self-Organizing Map – Biological Motivation

- Neurons with similar functions are grouped together.
- The brain processes multidimensional signals from the external world in a “2”-dimensional internal map. (生物假設)

THE JOURNAL OF COMPARATIVE NEUROLOGY 191:255-281 (1980)

Two-Dimensional Maps of the Cerebral Cortex

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Feature Maps 特征图

- Result of the **brain's self-organization** ???
 - formation of **feature maps** in the brain that have a linear or planar topology (that is, they extend in one or two dimensions)
- Examples:
 - **tonotopic map** - sound frequencies are spatially mapped into regions of the cortex in an orderly progression from low to high frequencies.
 - **retinotopic map** - visual field is mapped in the visual cortex with higher resolution for the centre of the visual field
 - **somatosensory map** - mapping of touch



Feature Maps

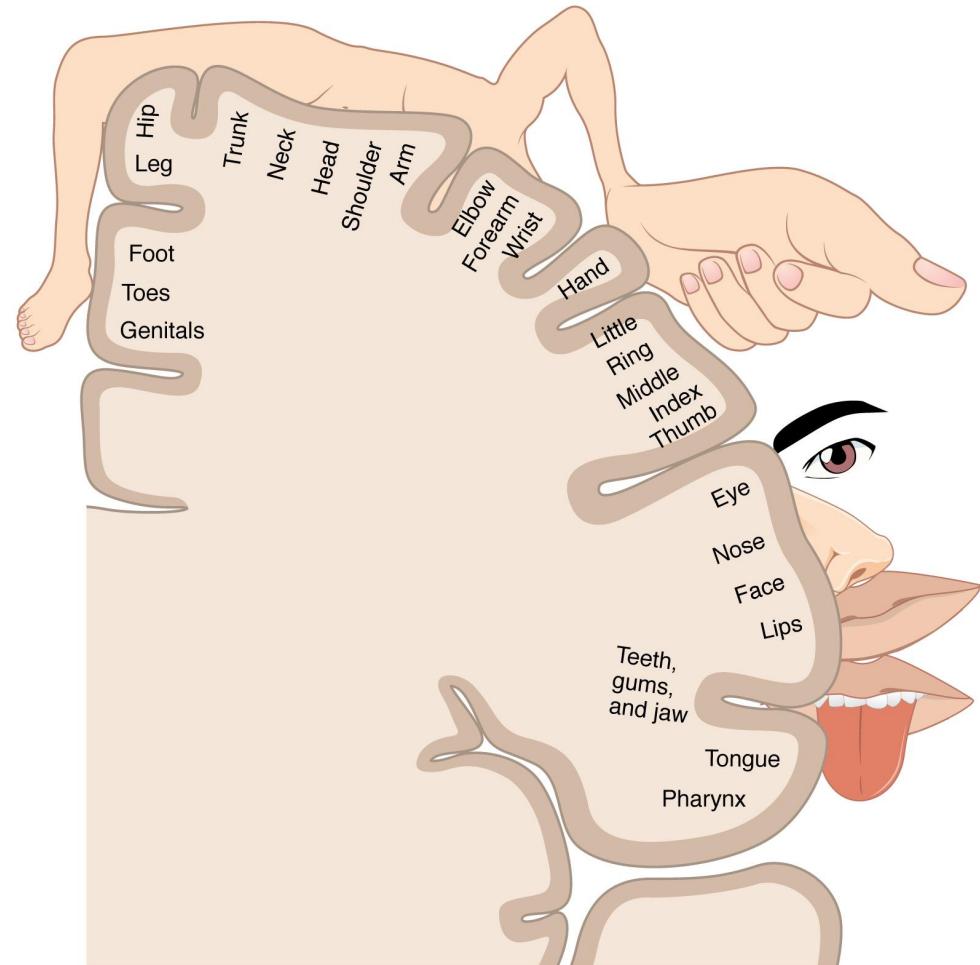
- Sensory experience is multidimensional
 - E.g. sound is characterised by pitch, intensity, noise...
- The brain maps the external multidimensional representation of the world into a similar 1 or 2 dimensional **internal representation**.
- That is, the brain processes the external signals in a **topology-preserving way**.
- So, if we are to have a hope of mimicking the way the brain learns, our system should be able to do the same thing.

Topographic Maps 地形图

- Extend the ideas of competitive learning to incorporate the neighborhood around inputs and neurons
- We want a nonlinear transformation of input pattern space onto output feature space which **preserves neighbourhood relationship between the inputs**
 - A feature map where **nearby neurons respond to similar inputs**
 - Neurons selectively tune to particular input patterns in such a way that the **neurons become ordered with respect to each other so that a meaningful coordinate system for different input features is created**

Topographic Maps

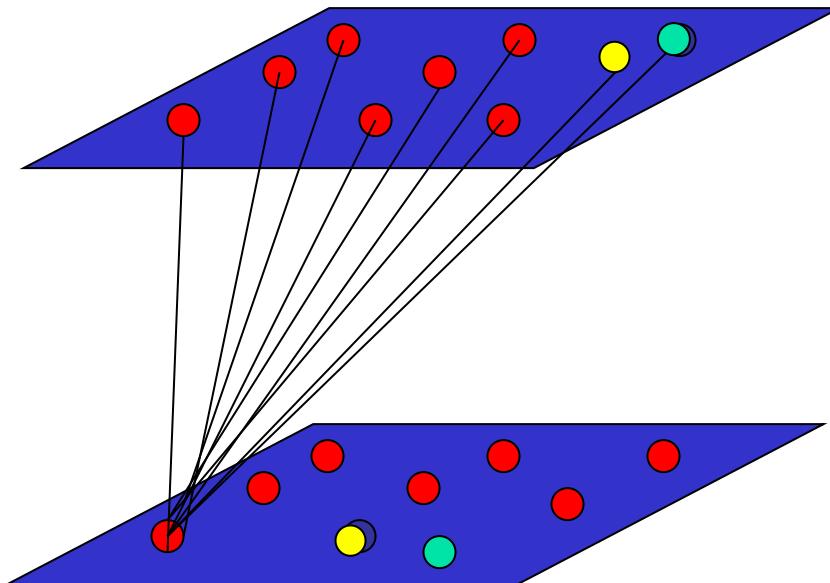
- E.g. the cortical homunculus, a map of somatosensory areas of the brain

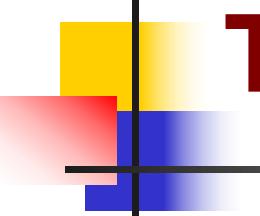


Topographic Maps

???

- Spatial locations are indicative of the intrinsic statistical features of the input patterns: i.e., close in the input → close in the output





Topographic Maps

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- Activity-based self-organization (von der Malsburg)
- Incorporation of competitive and cooperative mechanisms to generate feature maps using unsupervised learning networks

Proc. R. Soc. Lond. B. **194**, 431–445 (1976)

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How patterned neural connections can be set up
by self-organization

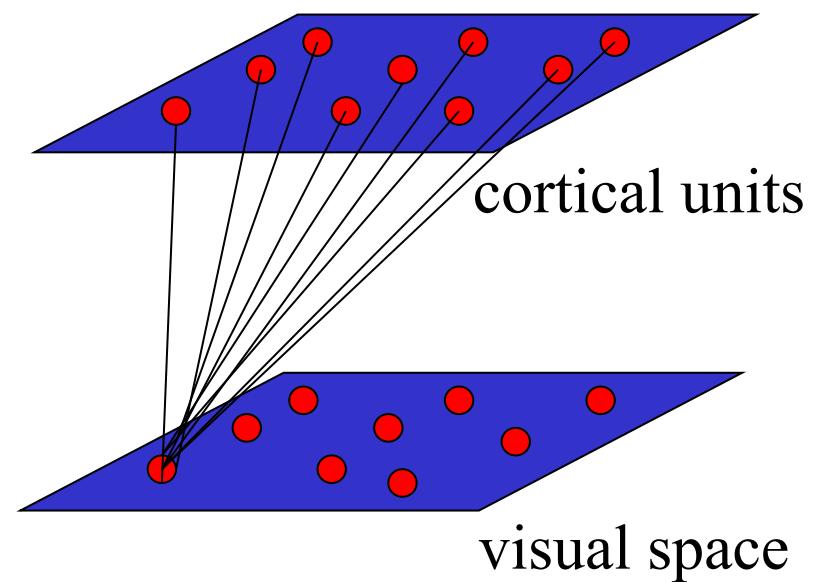
BY D. J. WILLSHAW AND C. VON DER MALSBURG

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Topographic Maps

???

- **Biologically motivated:** how can activity-based learning using highly interconnected circuits lead to orderly mapping of visual stimulus space onto cortical surface?
- 2 layer network each cortical unit fully connect to visual space via Hebbian units
- Interconnections of cortical units described by 'Mexican-hat' function: short-range excitation and long-range inhibition



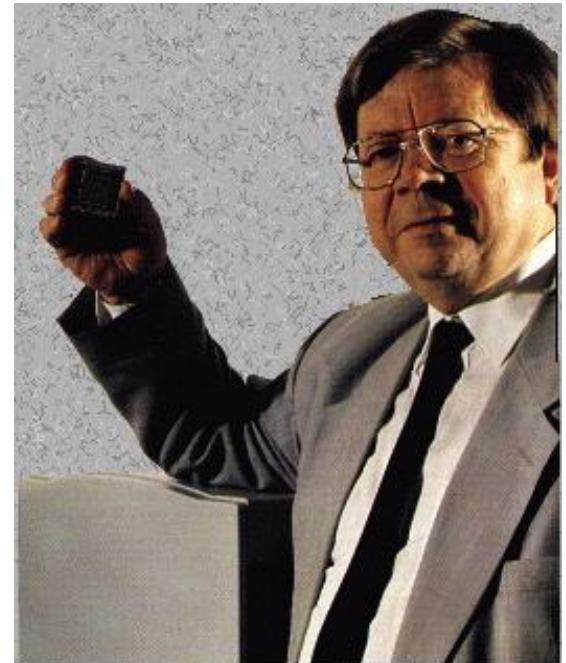
Topographic Maps

- Activity-based self-organization (von der Malsburg): after learning, a topographic map appears. However, input dimension is the same as output dimension
- Kohonen simplified this model and called it **Kohonen's self-organizing map (SOM) algorithm**
 - more general as it can perform dimensionality reduction
 - SOM can be viewed as a vector quantization type algorithm

无监督竞争型网络

Self-Organizing Map (SOM)

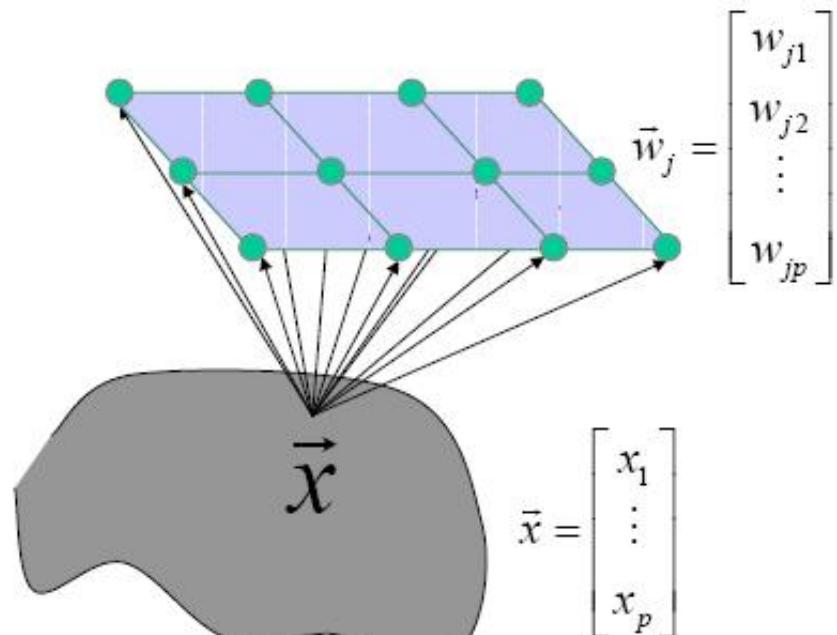
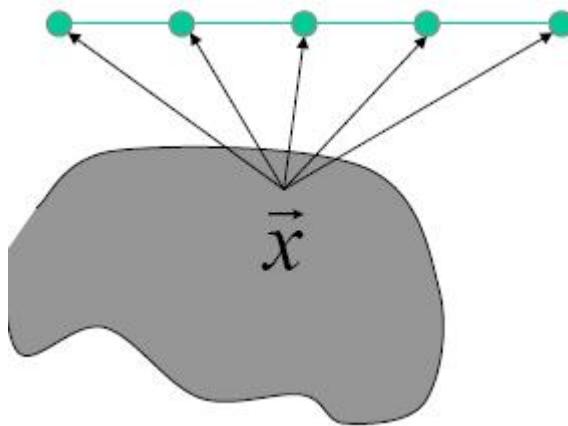
- a.k.a. as Kohonen networks
 - represents the embodiment of the ideas we have discussed so far
 - named after Dr. Eng. Teuvo Kohonen, Helsinki Uni of Technology



SOM

- The idea in an SOM is to transform an input of arbitrary dimension into a 1 or 2 dimensional discrete map

Two possible architectures



SOM

- The idea in an SOM is to transform an input of arbitrary dimension into a 1 or 2 dimensional discrete map
- Again, 2 layers of neurons with all inputs connecting to each output. Output neurons are held in a one or (usually) 2D lattice, where position in the lattice defines the distance between the neurons

SOM

- Once weights of net initialized, algorithm comprises 3 processes:
- 1. Competition
 - Given an input pattern, outputs compete to see who is winner based on a discriminant function (e.g. similarity of input vector and weight vector)
- 2. Cooperation
 - Winning neuron determines spatial location of a topological neighborhood within which output neurons excited
- 3. Synaptic Adaptation ?
 - Excite neurons adapt weights so that value of discriminant function increases (a similar input would result in enhanced response from winner)

SOM Training Algorithm

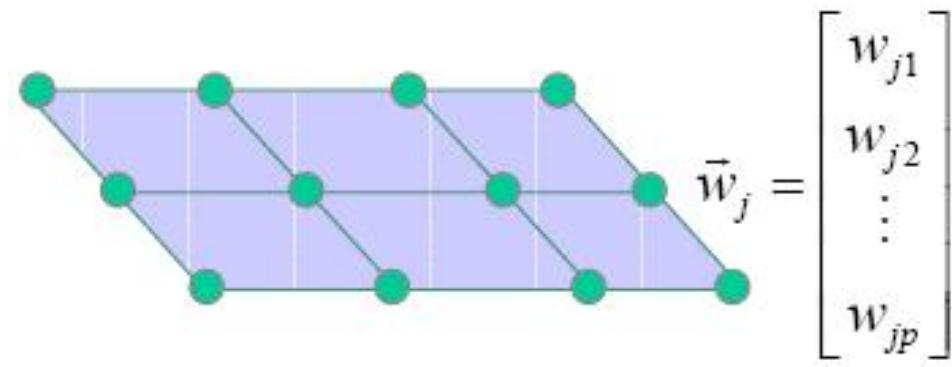
- Competition
- Cooperation
- Synaptic Adaptation

Learning Principle

Competitive learning where winning "spills over" to neighbors

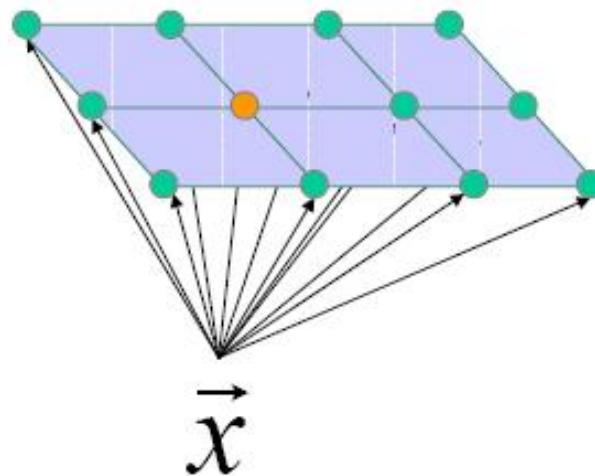
Initialization

Grid: size and structure fixed a priori (most of the times, 2-dimensional grid are used)



1

Competitive Process



Winner neuron

$$(1) \quad j^* = \operatorname{argmax}_j (w_j^T x)$$

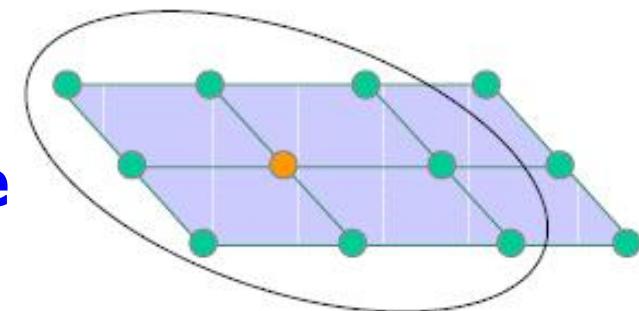
$$(2) \quad j^* = \operatorname{argmin}_j (\|x - w_j\|)$$

A continuous input space of activation patterns is mapped onto a discrete output space of neurons by a process of competition among the neurons in the network.

Cooperative Process

"The winning neuron locates the center of a topological neighborhood of cooperating neurons"

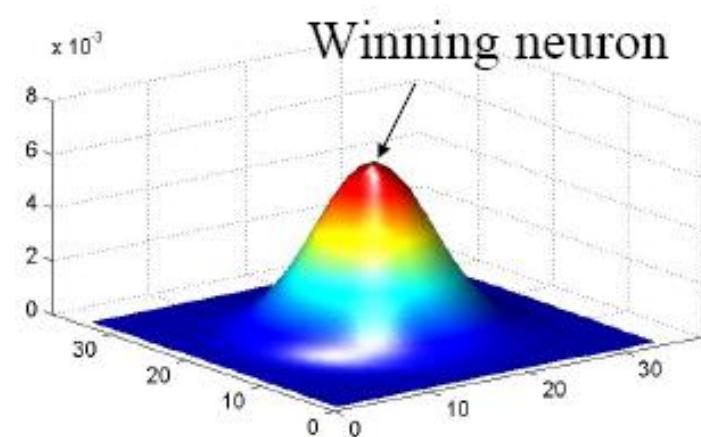
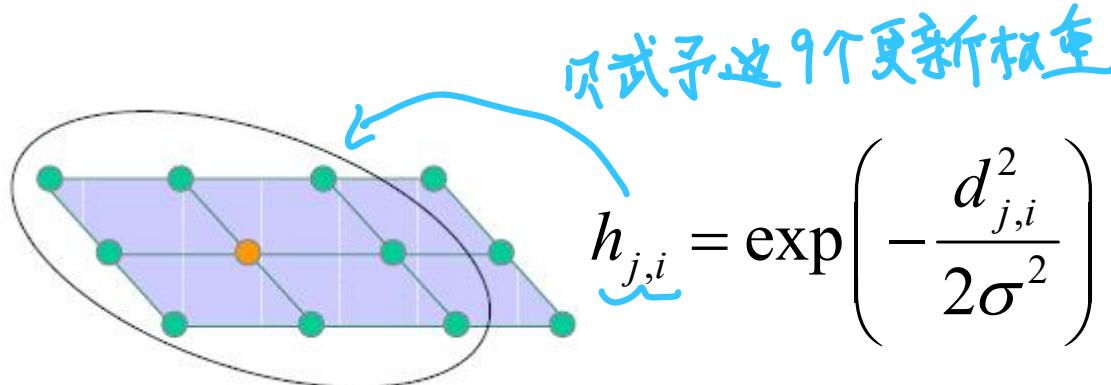
"... a neuron that is firing tends to excite the neurons in its immediate neighborhood more than those further away from it ..."



Cooperative Process

The topological neighborhood $h_{j,i}$

- symmetric around the winning neuron and achieve its maximum value at the winning neuron
- the amplitude decreases monotonically with the increasing lateral distance



Cooperative Process

- The topological **neighborhood** $h_{j,i}$ shrinks with time

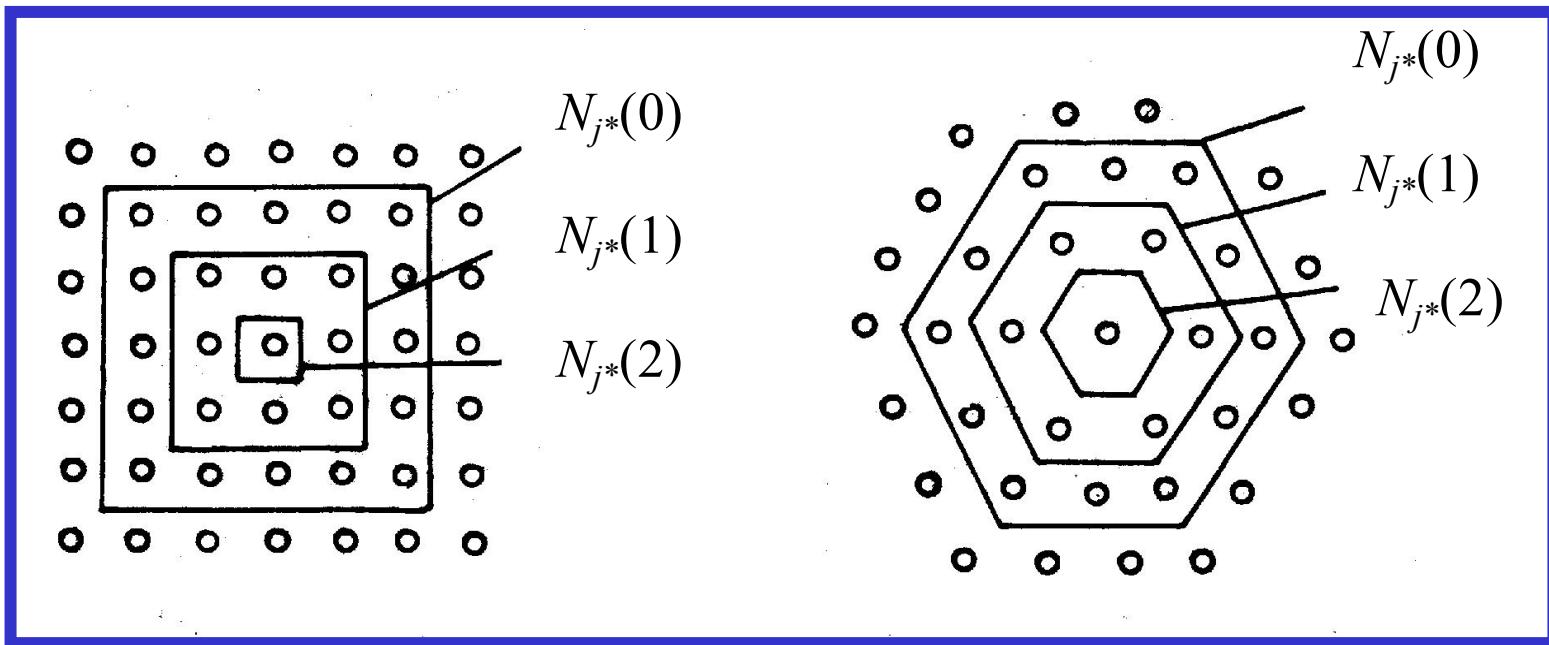
$$\sigma(t) = \sigma_0 \exp\left(-\frac{t}{\tau_1}\right) \quad h_{j,i}(t) = \exp\left(-\frac{d_{j,i}^2}{2\sigma^2(t)}\right)$$

- **Neighbors** of the winning node are also allowed to update, even if they are not close to winning!

Neighborhood

- Large neighborhood
 - Good global ordering
 - Bad local fit
- Small neighborhood
 - Bad global ordering
 - Good local fit
- By gradually shrinking the neighborhood we can get the best of both!
 - Ordering phase (large neighborhood)
 - Convergence phase (small neighborhood)

Neighborhood



Using a planar array of neurons with **rectangular** or **hexagonal** neighborhoods, an input vector \mathbf{x} is applied simultaneously to all nodes.

Adaptive Process

Update the weights in relation to the inputs

$$\mathbf{w}_j(t+1) = \mathbf{w}_j(t) + \eta(t) h_{j,i}(t)(\mathbf{x} - \mathbf{w}_j(t)) \quad ?$$

Learning rate

$$\eta(t) = \eta_0 \exp\left(-\frac{t}{\tau_1}\right)$$

Neighborhood function

$$h_{j,i}(t) = \exp\left(-\frac{d_{j,i}^2}{2\sigma^2(t)}\right)$$

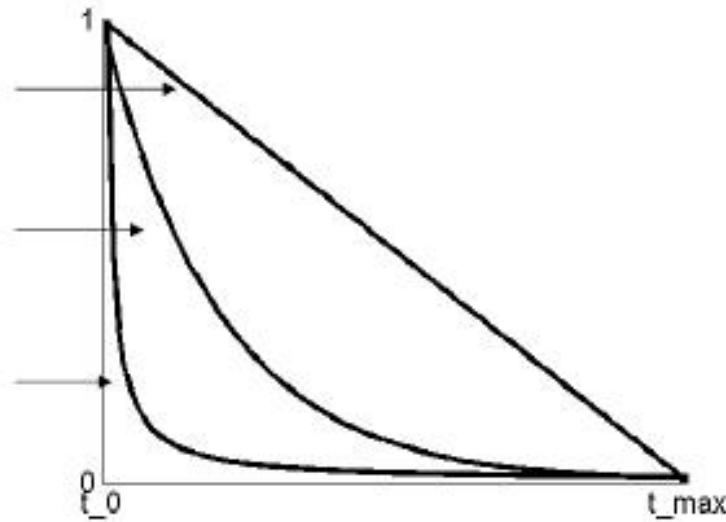
Learning Rate

Possible options:

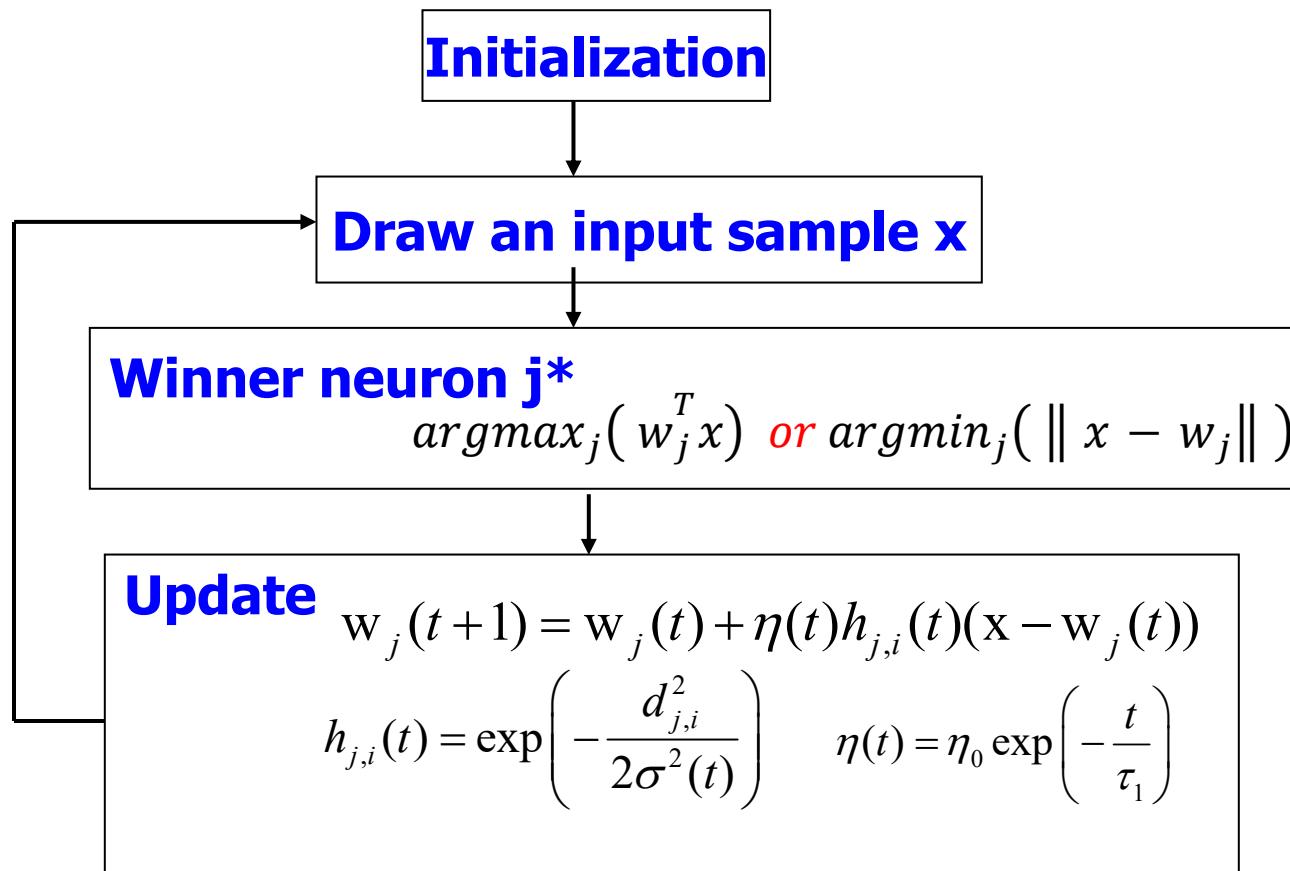
$$\eta(t) = -at + b$$

$$\eta(t) = \exp(-at) + b$$

$$\eta(t) = \frac{1}{at} + b$$



Summary



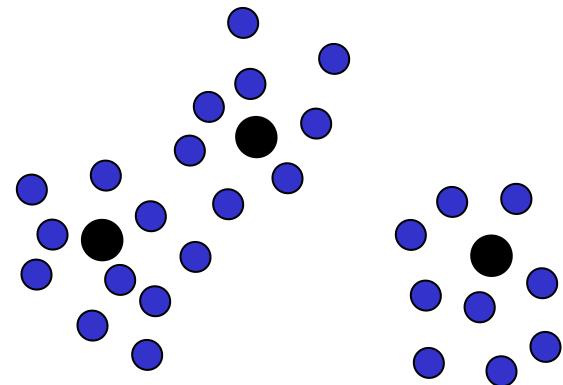
Property of SOM

- Approximate the input space
- Topological ordering
- Density matching
- Feature selection (features of the underlying distribution)

Recall:

Unsupervised Competitive Learning

- initialize K prototype vectors
- present a single example
- identify the closest prototype,
i.e., the so-called **winner**
- move the winner even
closer towards the example



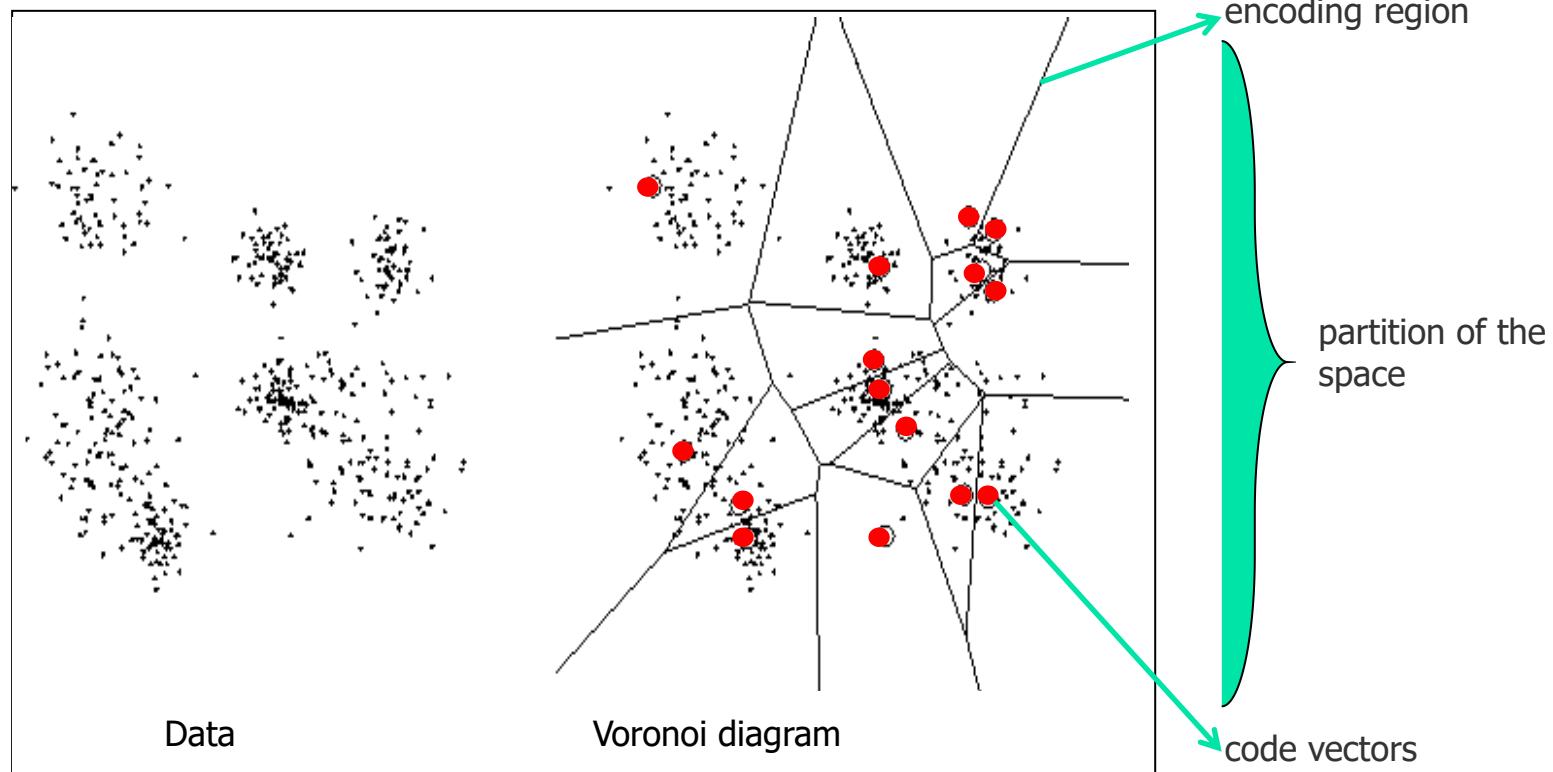
Intuitively clear, plausible procedure

- places prototypes in areas with high density of data
- identifies the most relevant combinations of features

Recall:

Vector Quantization

用少量码向量替代高维输入向量



A Voronoi diagram is a partitioning of a plane into regions based on distance to points in a specific subset of the plane. For each seed there is a corresponding region consisting of all points closer to that seed than to any other. These regions are called Voronoi cells.

More on Vector Quantization

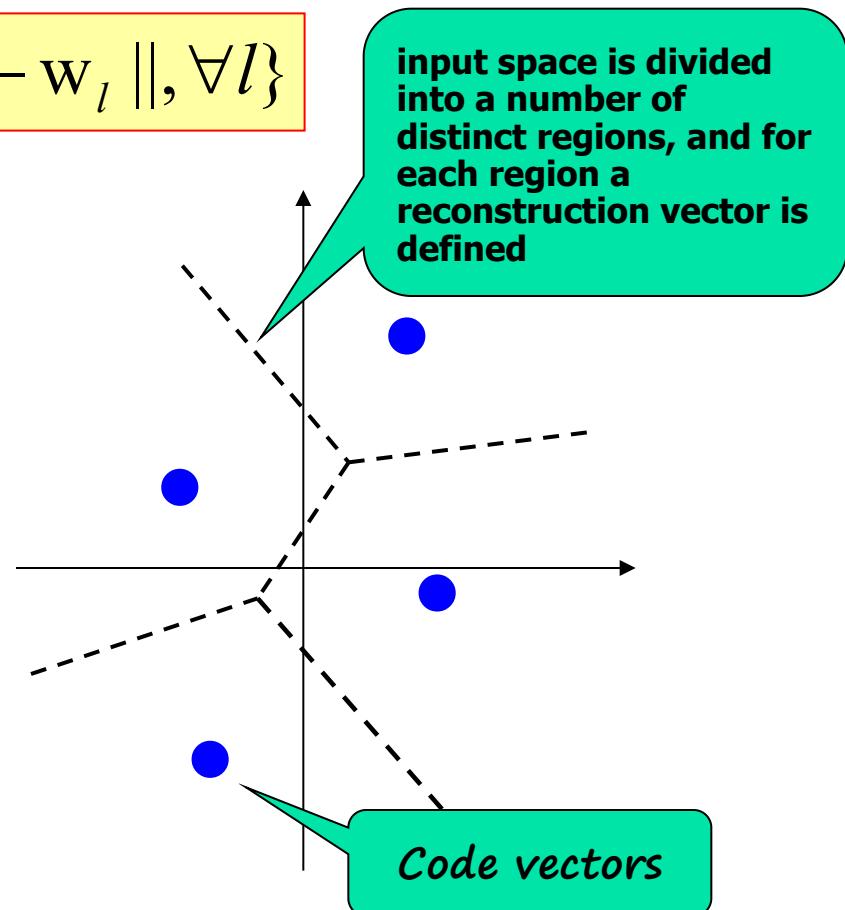
- In VQ techniques, a number of local Voronoi centers are formed to **represent input vectors**.
- For a set of M reference vectors, $\{\mathbf{w}_1, \dots, \mathbf{w}_M\}$, an input vector \mathbf{x} is considered being *best matched* by \mathbf{w}_k in the sense that an appropriately defined distortion measure such as the squared Euclidean distance $||\mathbf{x} - \mathbf{w}_k||^2$ is minimal.
- The reference vectors partition the input space R^L into the Voronoi cells/polygons defined as

$$V_i = \{\mathbf{x} \in R^L \mid ||\mathbf{x} - \mathbf{w}_i|| \leq ||\mathbf{x} - \mathbf{w}_j||, \forall j\}$$

Vector Quantizer

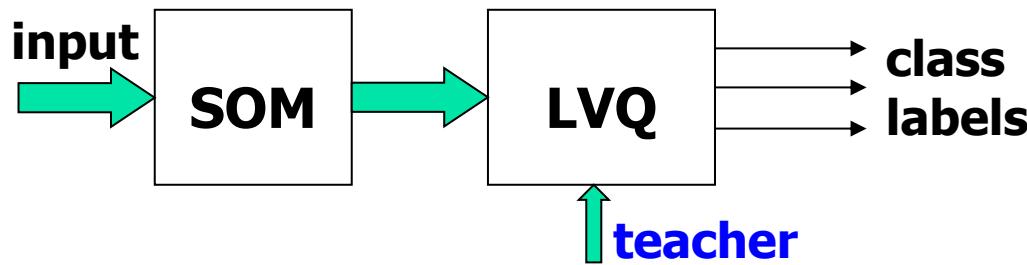
$$V_k = \{x \in R^L \mid \|x - w_k\| \leq \|x - w_l\|, \forall l\}$$

- The collection of possible reference vectors is called the **codebook** of the quantizer, and its members are called **code vectors**.
- The SOM algorithm provides *an approximation method* for computing the Voronoi vectors in unsupervised manner.



Learning Vector Quantizer (LVQ)

???



- LVQ is a **supervised learning** technique that uses **class information** to move the Voronoi vectors slightly, so as to improve the quality of the classifier decision regions.

LVQ1



- An input vector \mathbf{x} is picked at random from the input space.
- If the class labels of the input vector \mathbf{x} and a Voronoi vector \mathbf{w} agree, the Voronoi vector \mathbf{w} is moved **in the direction** of the input vector \mathbf{x} .
- If the class labels of the input vector \mathbf{x} and the Voronoi vector \mathbf{w} disagree, the Voronoi vector \mathbf{w} is moved **away from** the input vector \mathbf{x} .

if the winner belongs to the right class

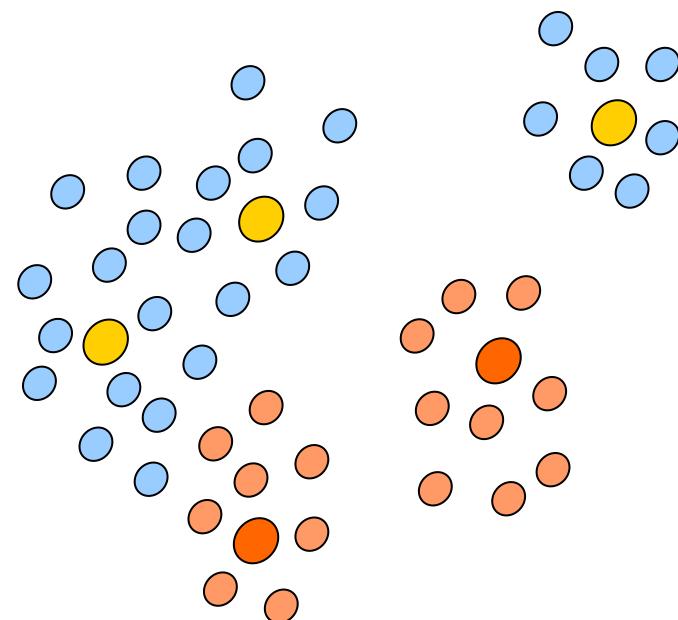
$$\mathbf{w}^{new} = \mathbf{w}^{old} + \eta(\mathbf{x} - \mathbf{w})$$

if the winner belongs to the wrong class

$$\mathbf{w}^{new} = \mathbf{w}^{old} - \eta(\mathbf{x} - \mathbf{w})$$

LVQ2

- Initialize prototype vectors (for different classes)
- Present a single example
- Identify closest **correct** and closest **wrong** prototypes
- Move the corresponding **winner** towards / away from the example



LVQ Discussion

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■ Stopping criteria

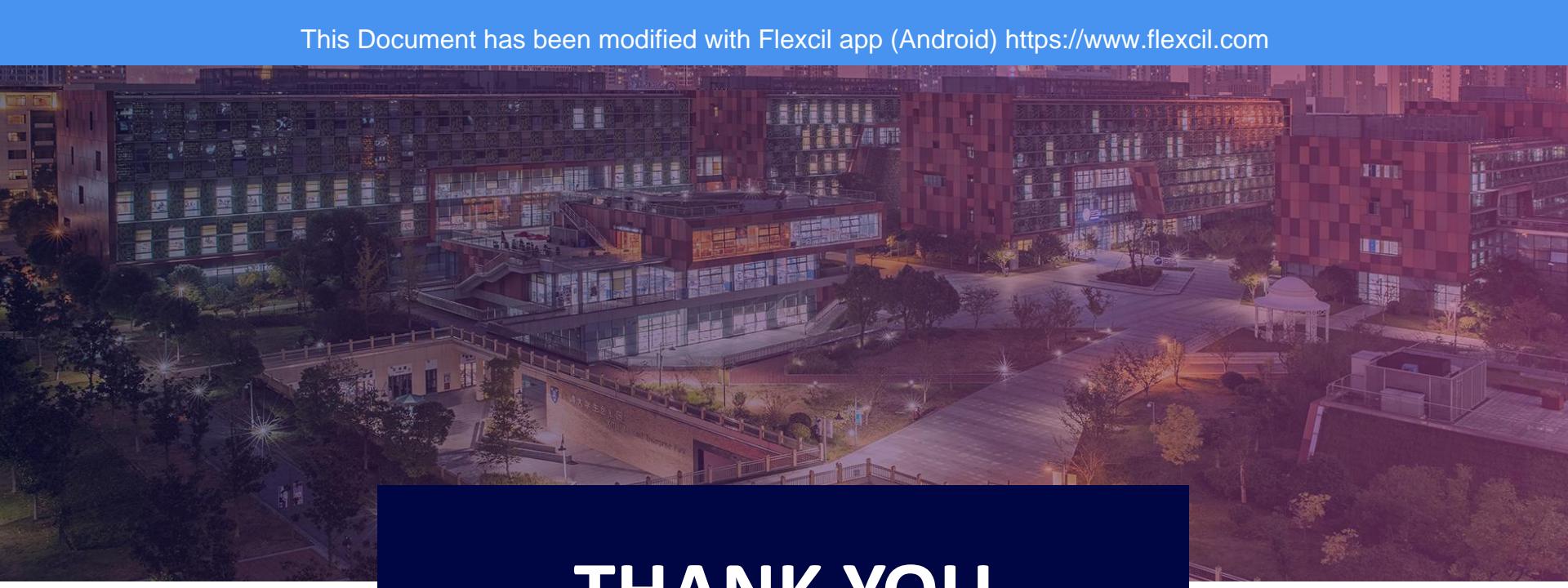
- Codebook vectors have stabilized
- Or maximum number of epochs has been reached

■ Advantages

- Appear plausible, intuitive, flexible
- Fast and easy to implement
- Frequently applied in a variety of problems involving the classification of structured data

■ Disadvantages

- Not stable for overlapping classes

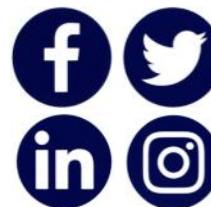


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