# The *Kohonen* type neural network in the process of identification of orchard pests

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## Abstract

One of advantages of suggest a procedure is the ability of the *Kohonen* neural network to determine the degree of similarity occurring between classes. The *Kohonen* network can be also used to detect regularities occurring in the obtained empirical data. If at the network input, a new unknown case appears which the network is unable to recognise, it means that it is different from all the classes known previously. The Kohonen network taught in this way can serve as a detector signalling the appearance of a widely understood novelty. Such a network can also look for similarities between the known data and the noisy data. In this way, it is able to identify fragments of images presenting photographs of e.g. orchard pests.

*Key words: Kohonen* neural networks, recognition of an image.

## Introduction

The *Kohonen* neural networks are modelled on the topological properties of the human brain. These networks are also known as self-organizing feature maps (***SOFM*** - ***S****elf* ***O****rganizing* ***F****eature* ***M****aps*). The *Kohonen* networks are most frequently used for a widely understood classification (Tadeusiewicz R., 1990). They perform this task in a relatively untypical way. Thanks to the processing of output values carried out within the *postprocessing*, the result of the network activity is an output variable of nominal character. Each value of this variable represents one definite class. Appropriate neurons occurring in the output layer of the network correspond to particular classes. The connection of the neuron with a given class is indicated by the label with the class name attributed to it. During the action of the network, after the input signal has appeared, the winning neuron is indicated each time (that is the neuron of the lowest activation, which indicates the highest compatibility of weights and the given input pattern). The label of the neuron determines the class to which the input case is ascribed. This untypical structure enables the user to define the output layer of the *Kohonen* network as a specific two-dimensional "map" of the input multi-dimensional data set. It enables to place in it an optional number of neurons that are distinguished and established points in this map.

The topology of the *Kohonen* network differs considerably from the structures of other neural networks. The structure discussed is basically a one-layer network. It consists of an input layer and an output layer which processes the data presented. The output layer is built of radial neurons. This layer is also defined as a layer forming a topological map. Neurons in the layer forming the topological map are taken into consideration as if they were placed in space according to some predetermined order - usually for convenience and better perception we imagine them to be nodes of a two-dimensional network.

## The nature of the teaching process of the *Kohonen* network

During the teaching of the self-organizing networks by competition at the input of each neuron, an $n$-dimension signal $x$ from the set of teaching patterns is provided (randomly or in an established sequence). The weights of the synaptic connections create a vector $W_i = [W_{i1}, W_{i2}...., W_{in}]$. Next, input vectors are normalised and then the network is stimulated by the teaching vector *x*. In the adaptation process, this neuron whose weights differ the least from vector *x* presented at the input, wins in the competition. The winning *w*-th neuron fulfils this relation (Tadeusiewicz R., Flasinski M., 1991):

$$d = (x, W_w) = \min_{1 \le i \le n} d(x, W_i) \tag{1}$$

where:

$d(x, W)$ - determines the measurement of distance between vector $x$ and vector *W,*
$n$ - number of neurons,
$x$ - input (teaching) vector,
$W_w$ -“winning” vector of weights.

The distance between vector *x* and weight vector of the winning neuron $W_i$ can be calculated using different definitions e.g.:

- Euclidean measurement:

$$d(x,W_i) = \|x - W_i\| = \sqrt{\sum_{j=1}^{N} (x_j - W_{ij})^2} \tag{2}$$

- scalar product measurement:

$$d(x,W_i) = x \cdot W_i = \|x\| \cdot \|W_i\| \cos(x, W_i) \tag{3}$$

where:

$\|x\|, \|W_i\|$ - modules of vectors *x* and $W_i$..

Around the “winning” neuron, a topological neighbourhood is assumed of a definite radius that is decreasing in the course of the teaching process. The “winning” neuron and all neurons situated within the neighbourhood area undergo a process of adaptation, changing their weights vectors toward the input vector $x$ according to the formula:

$$W_i(k+1) = W_i(k) + \eta_i(k)(x - W_i(k)) \tag{4}$$

where:

$\eta_i$ - teaching coefficient (decreasing in time),
k - number of steps (iteration).

The numbers of neurons winning in consecutive presentations of vectors $x$ create the so-called code book. In classical coding, the algorithm k – mean values is usually applied, whose equivalent in the case of neural networks is the *WTA* (***W**inner **T**akes **A**ll)* algorithm. In this algorithm, after the presentation of vector $x$ the activity of each neuron is calculated. The winner is the neuron of the biggest output signal. When using normalised vectors, it equals the smallest Euclidean distance between the input vector and the neuron weight vector. The winner adopts its weight in the direction of vector $x$ according to the formula:

$$W_w \leftarrow W_w + \eta(x - W_w) \tag{5}$$

where:

$\eta$ - teaching coefficient,

$x$ - input vector,

$W_w$ - weights vector of the winning neuron.

It should be noted that the remaining neurons do not undergo adaptation. The *WTA* algorithm takes into account the so-called fatigue of neurons by considering the number of victories of each of them and favouring the less active neuron to equal their chances. Such a modification is used in the initial stages of the algorithm switching it off after activation of all neurons. In the *WTA* algorithm only the "winner" modifies its weights.

In the *WTM* (***W**inner **T**akes **M**ost*) algorithm, apart from the winner its neighbouring neurons also update their weights. The longer the distance of the neuron from the winner, the smaller the change of value of the neuron weights. The weights adaptation process can be described using the dependence relationship:

$$W_i \leftarrow W_i + \eta_i G(i,x)[x - W_i] \tag{6}$$

for all $i$ - th neurons belonging to the "winner's" neighbourhood.

In the formula, the teaching coefficient $\eta_i$ of every neuron is separated from its distance with reference to vector $x$ included using the neighbourhood function $G(i,x)$ defined in the following way:

$$G(i,x) = \begin{cases} 1 & for\ i = n \\ 0 & for\ i \neq n \end{cases} \tag{7}$$

where:

$G(i,x)$ - function of neighbourhood,

$n$ - number of the "winner".

There are many types of *WTM* algorithm, which differ first of all in the neighbourhood function $G(i,x)$. In the classical algorithm put forward by the Finnish scholar *T. Kohonen* the neural network initiates by assigning to neurons definite place in space, associating it next in a specific way with neighbours. The moment the „winner" is called, the updating includes not only the weights of the „winning" neuron but also the weights of its neighbours from the closest neighbourhood. In the algorithm discussed, the function of neighbourhood $G(i,x)$ takes the following form:

$$G(i,x) = \begin{cases} 1 & for\ d(i, w \leq \lambda) \\ 0 & for\ remainder \end{cases} \tag{8}$$

where:

$d(i,w)$ - means the Euclidean distance between the weights vectors of the "winner" neuron $w$ and the $i$ - th neuron or the distance measured in the number of neurons,

$\lambda$ - means the radius of neighbourhood, whose value decreases in time to zero.

This type of neighbourhood is called rectangular. Another type of neighbourhood used in the *Kohonen* network is the Gaussian type, which can be described using the following formula:

$$G(i,x) = \exp\left(-\frac{d^2(i,w)}{2\lambda^2}\right) \tag{9}$$

where:

$\lambda$ - is the neighbourhood radius decreasing in time,

$d(i,w)$ - measure of distance between the weights vector of the "winner" neuron $w$ and the $i$-th neuron.

The adaptation degree of neurons from a neighbourhood is determined not only by the distance of the $i$ - th neuron from the "winner" ($w$ - th neuron), but also the neighbourhood radius.
In the neighbourhood of the *Gaussian* type the degree of adaptation varies and depends on the value of the *Gaussian* function, whereas in the rectangular type neighbourhood every neuron belonging to the winner neighbourhood undergoes adaptation to an equal extent. The final formula for adaptation of neighbours weights can be presented as follows:

$$W_i(k+1)=W_i(k)+\eta\exp\left(-\frac{d^2(i,w)}{2\lambda^2}\right)(x-W_i(k)) \quad (10)$$

where:

$\lambda$ - radius of the neighbourhood,
$\eta$ - teaching coefficient (decreasing in time),
$d(i,w)$ - distance between the vector of weights of the winner neuron $w$ and the $i$-th neuron,
$k$ - number of iteration,
$W_i$ - weights vector of the $i$ - th neuron.

The neighbourhood is decreased with the passage of teaching time. Initially, the neighbourhood includes a relatively large number of neurons. At the final stages, the neighbourhood has a zero range. The algorithm makes use of the time-variable coefficient of teaching that is applied for determination of the weighted sum and causes that the initially large and rapid changes become increasingly smaller during successive epochs. Teaching the *Kohonen* networks is frequently carried out in two clearly divided stages: at the beginning a relatively short phase with a large teaching coefficient and extensive neighbourhood, and a long phase of "repeated and supplementary teaching" with a small value of the teaching coefficient and a zero or almost zero neighbourhood.

## Characteristics of selected orchard pests

The research material for recognition of images presenting orchard pests consisted of photographs obtained from the book entitled "Pests on fruit trees [in Polish: Szkodniki drzew owocowych]" written by Prof. dr hab. Kazimierz Wiech. The subject of recognition concerned selected pests of fruit trees. An orchard is an excellent location for different types of organisms to feed. A quick recognition of the danger (optimally in the larval state) can protect the orchard-owner from heavy losses caused by the appearance of a pest. The presentation was limited to five species of pests occurring in the larval state. The insects belong to different families and feed on different fruit trees. The following species have been selected:

1. Apple leaf curling midge (Dasyneura mali Kieff)
   Systematics:
   Order - dipteran (Diptera)
   Family - Itonididae – Cecidomyidae

Fig. 1. Apple leaf curling midge (Dasyneura mali Kieff)

A small sized – about 1.5 to 2 mm dipteran – in appearance resembling a mosquito. Red elongated eggs. Larvae of the midges are cylindrical, initially cream white, later orange or orange-red, legless, moving in a characteristic rolling way. The host plants are apple trees.

Larvae of the midge feed collectively on the youngest leaves of the apple tree, causing their edges to curl inwards, deformations as well as appearance of pink coloration. The heaviest losses are caused in nurseries and new planting of apple trees. Larvae winter in earth cocoons, in the superficial layer of the soil. Females fly out in April and lay eggs on the edges of leaves. Larvae suck into the skin at the spot where they were hatched. Several larvae of the midge live on one leaf. After a few weeks of feeding, larvae drop to the ground and pupate on the superficial layer of the soil. During one year three generations of the pest can grow.

In new planting of apple trees and in strongly cut lined orchards, protective treatments should be carried out after finding the first damages. To fight the pest, phosphoorganic products and those containing chloemezyl are recommended.

2. (Dasyneura piri Bonche)

Systematics:
Order – dipteran (Diptera)
Family – (Ifonididae – Cecidomyidae)

Fig. 2. Dasyneura piri Bonche

A small dipteran of a dark, brown-black body, about 2 mm long, in appearance resembling a mosquito, with long legs and antennas. White elongated eggs difficult to notice. Cylindrical larvae, white, legless, jumping, grow up to 2 mm length. The host plants are pear trees. Leaves at the top of young tree growth, as well as on root shoots do not grow as a result of the pest feeding, and their edges are folded inwards, thickened, fragile in some varieties after some time they become red. Inside the deformed leaves there are numerous white larvae. They winter in underground colonies buried shallow under the surface of the soil. Flies appear in May. A few days following their fly-out females lay eggs in the folds of the growing top leaves. After four days, larvae are hatched. They feed sucked to the edge of the leaf causing an inhibition of its growth and deformation. After feeding is completed larvae fall to the ground, bury in the shallow layer and pupate. During a year, three generations of this pest can grow.

From year to year, the gall midge invades the same trees. Root shoots and useless sprouts growing from the trunk on which deformed leaves have been noticed should be removed and destroyed. Use treatments with protective agents, particularly in young strongly cut orchards, after the first damages have been noticed.

3. European fruit lecanium (Parthenolecanium corni Bouche)

Systematics:
Order – Homoptera
Family – Coccidae

Fig. 3. European fruit lecanium (Parthenolecanium corni Bouche)

Females have reduced limbs and do not have wings. Their body is covered in hardened cherry-brown "coat" of cuticle in the shape of a convex 3 – 4 mm long bowl. They spend their lives motionless, attached with the proboscis to the background. Males are winged and able to fly, have reduced oral organs. Their body length is 2.5 mm, and width 1 mm. The eggs are white, oval in shape, covered in wax secretion of the female. The larvae are flat, motile, at the first stage greenish, turning brown. Male larvae are elongated and uniformly brown whereas the female larvae are oval and have a light stripe on the back. They feed most frequently on apple trees and plum trees but they attack other plants as well.

Both larvae and females are harmful – sticking the proboscis into wood they introduce saliva containing a substance causing the cells to die. Feeding of a large number of larvae and females on a shoot causes it first to bend and next to dry out. The fruit crop is decreased.

Larvae of the second stage of development winter in bark cracks. In March, they move onto shoots and thin twigs and begin to feed by sucking out plant juice. In April, larvae differentiate into males and females. In May, after copulation, the female begins to lay eggs in the hatch chamber placed under the bowl. Soon afterwards it dies. Fertility of the female dwelling on a plum tree ranges from 600 to 1000 eggs. Maximally, a female can lay even 5000 eggs.

Larvae should be fought (using e.g. preparations containing fosalon) in the period of the white flower bud and in June when they come out from under the scutella.

4. Leopard moth (Zeuzera pyrina L.)
   Systematics
   Order – butterflies (Lepidoptera)
   Family – (Cossidae)

Fig. 4. Leopard moth (Zeuzera pyrina L.)

Butterflies of white, black speckled wings, wingspan 5 – 7 cm. Oval, pale yellow eggs. The caterpillar is yellow with two rows of black warts. They feed on many different species of trees and are dangerous first of all in young orchards. In July and August, females lay (single) eggs on the bark, leaf tails and in other places. Caterpillars feed initially collectively under the bark, in the second year they hollow tunnels in branches. The pest can be destroyed introducing into tunnels cotton wool soaked in an organophosphoric product.

5. Goat moth (Cossus cossus L.)
   Systematics:
   Order – butterflies (Lepidoptera)
   Family – (Cossidae)

Fig. 5. Goat moth (Cossus cossus)

A very large butterfly with grey wings, wingspan from 7 cm (male) to 9 cm (female). The body of the butterflies is thick and hairy. Eggs are oval, dark brown, striped. The caterpillar is pink-red, up to 10 cm long. They attack different fruit, park and forest trees. Caterpillars hollow corridors under the bark (the first year of development) as well as tunnels in the trunk and thick boughs (second year). From the tunnels, sawdust falls mixed with the caterpillar's excrements. They smell of vinegar. The attacked and damaged trees can wither. The caterpillars winter. Pupation takes place in May, and the butterflies appear in June and July. Females lay up to 1000 eggs in the cracks of bark, trunks and boughs. After hatching, caterpillars feed collectively underneath the bark. In the second year of development they hollow individual tunnels. They pupate in shoots, in May. The goat moth attacks old trees growing in neglected orchards. The pest can be destroyed introducing to the tunnels cotton wool soaked with an organophosphoric product.

## Neural recognition of selected orchard pests

To create the *Kohonen* network, the *Statistica Neural Networks v.4.0* program was used. The input data consisted of 24 input variables and one nominal output variable (that served to label the topological map after completing the teaching process).

In order to obtain the representation of knowledge appropriate for the neural network i.e. to process the information included in the image into a sequence of numbers, the previously created program called „ObrazKoh" (Boniecki P., 2003) was used. It serves to digitalise the image presented in the file format *.bmp (of previously defined dimensions), carrying out the classification based on the model of RGB colours. The result of application operation is then recorded in the text file. The result is presented in the form of a sequence of numbers of a length adequate for the adopted number of pixels in the marked fragment of the image e.g. 2*2 generates a sequence of 12 numbers changing within the range from 0 to 255.

The text file generated using the „ObrazKoh" program was used to create a teaching set for the designed *Kohonen* neural network, whose aim was to carry out classification based on the model of RGB colours.

Making use of the „ObrazKoh" program, 540 cases were generated per one insect, which - for 5 pests - resulted in a set of 2700 teaching cases. The data were divided randomly into teaching data, validating data and testing data. The technique of random mixing of cases was used.

In the process of teaching of the *Kohonen* type neural network the knowledge of the output variable is not necessary since the process of teaching this network develops in an "unsupervised" way. The teaching of the *Kohonen* type neural network was implemented in two separate stages. In the first phase, a high teaching coefficient was applied (~0.7) in combination with a large range of neighbourhood (~1). At this stage, modification of neuron weights was the most extensive. However, in the second phase of teaching a small value of teaching coefficient was used (~0.2 – 0.1) in combination with small neighbourhood (equal to 0). At this stage, the weights of neurons were modified to a minimum extent and the process of the so-called repeated and supplementary teaching of the network was carried out.

## The obtained results

The results of action of the generated *Kohonen* type neural network are presented separately for the teaching set and the validation set. According to the standard procedure the teaching set was used in the teaching process of the neural network. To check appropriateness of action of the generated neural network the so-called validation set was used which was randomly isolated from the set of the data possessed. It included cases not presented in the course of teaching the network. It enabled to carry out a verification of quality of the generated and taught neural network. The following values of the RMS error were obtained (mean-square error root):

| Error ***RMS*** learning file | Error ***RMS*** validation file |
|---|---|
| 0,0472009 | 0,06778 |

Fig. 6. The results of teaching the *Kohonen* network

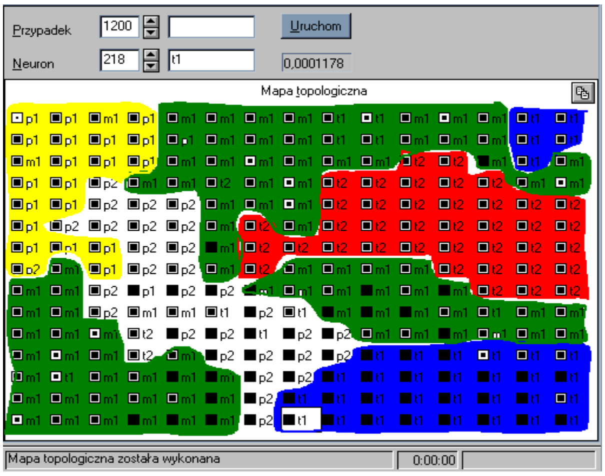
The topological map creates the output layer of the *Kohonen* network. Neurons in this layer are usually placed in two-dimensional space, and every neuron represents one cluster of teaching data.

In the case discussed, neurons in the topological map were assigned specific classes representing particular orchard pests. In the generated topological map, the clusters of data are marked with colours assigned as follows:

- yellow– refers to Dasyneura piri Bonche (p1),
- white – refers to Dasyneura mali Kieff (p2),
- blue – refers to Zeuzera pyrina L. (t1),

- red – refers to Cossus cossus L. (t2),
- green – refers to Parthenolecanium corni Bouche (m1).

The topological map representing graphically the classification abilities of the generated *Kohonen* network is shown in Fig. 10.



Przypadek 1200

Neuron 218 t1

0,0001178

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| p1 | p1 | m1 | p1 | m1 | m1 | m1 | m1 | t1 | t1 | m1 | m1 | m1 | t1 | t1 |
| p1 | p1 | p1 | p1 | p1 | m1 | m1 | m1 | t1 | t1 | m1 | m1 | m1 | t1 | t1 |
| m1 | p1 | p1 | p1 | m1 | m1 | m1 | m1 | m1 | m1 | t2 | t2 | m1 | t1 | m1 |
| p1 | p1 | p2 | m1 | m1 | t2 | m1 | m1 | t2 | t2 | t2 | t2 | t2 | m1 | m1 |
| p1 | p1 | p2 | p2 | p2 | m1 | m1 | m1 | t2 | t2 | t2 | t2 | t2 | t2 | t2 |
| p1 | p2 | p2 | p2 | p2 | m1 | t2 | m1 | t2 | t2 | t2 | t2 | t2 | t2 | t2 |
| p1 | p1 | p1 | p2 | p2 | m1 | t2 | t2 | t2 | t2 | t2 | t2 | t2 | t2 | t2 |
| p2 | m1 | p1 | p2 | p2 | m1 | t2 | m1 | m1 | m1 | m1 | t2 | t2 | t2 | t2 |
| m1 | m1 | p2 | p1 | p2 | p2 | m1 | m1 | m1 | m1 | m1 | m1 | t2 | t2 | t2 |
| m1 | m1 | p2 | m1 | m1 | t1 | p2 | t1 | m1 | m1 | m1 | m1 | t1 | m1 | m1 |
| m1 | m1 | m1 | t2 | p2 | p2 | t1 | p2 | p2 | m1 | m1 | m1 | m1 | m1 | m1 |
| m1 | m1 | m1 | t2 | m1 | p2 | p2 | p2 | p2 | t1 | t1 | t1 | t1 | t1 | t1 |
| m1 | t1 | m1 | m1 | m1 | m1 | p2 | p2 | t1 | t1 | t1 | t1 | t1 | t1 | t1 |
| m1 | m1 | m1 | m1 | m1 | m1 | p2 | t1 | t1 | t1 | t1 | t1 | t1 | t1 | t1 |
| m1 | m1 | m1 | m1 | m1 | m1 | p2 | t1 | t1 | t1 | t1 | t1 | t1 | t1 | t1 |

Mapa topologiczna została wykonana

0:00:00

Fig. 7. Tpological map

At the top the case number (1200) was provided, next the number of the neuron in the topological map (218) and the class to which a given case was classified. After establishing for every neuron the location assigned to it in the topological map, a filled in square is drawn representing the degree of activation of a given neuron, and the bigger squares filled indicate a larger closeness of the model of a given neuron with reference to the tested case. Additionally, the winning neuron is surrounded with a rectangular frame.

## Final notes

The acceptance of the colour of the analysed image as the main attribute has an effect on the quality of action of the taught neural network as a tool for identification of the presented object in the form of an image. It can be supposed that taking into consideration other attributes of the image (as i.e. texture, exposure to light or other physical features), accuracy of reactions of the taught neural network could be improved. It should be noted that to teach the *Kohonen* network it is sufficient to possess only a set of teaching data – known models are not necessary. The knowledge of names of pests was used only for labelling the *Kohonen* topological map. It facilitated to visualise the functioning of the network during its exploitation. It should be emphasized that the *Kohonen* neural network demonstrated also a certain ability to generalize, in such a way that, the cases "similar" to those known to itself it tried to classify to the classes. The cases unknown to the network (representing other pests) were classified as foreign.

The desirable feature enables the *Kohonen* neural network to identify the pests correctly based on the presentation of images not originating from the teaching set i.e.: noisy photographs taken under different light exposure conditions and using different quality of the equipment.

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