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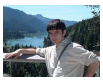
Hopfield model of neural **network** for pattern recognition



Bashir Magomedov, 7 Nov 2006

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The article describes the **Hopfield** model of neural **network**.

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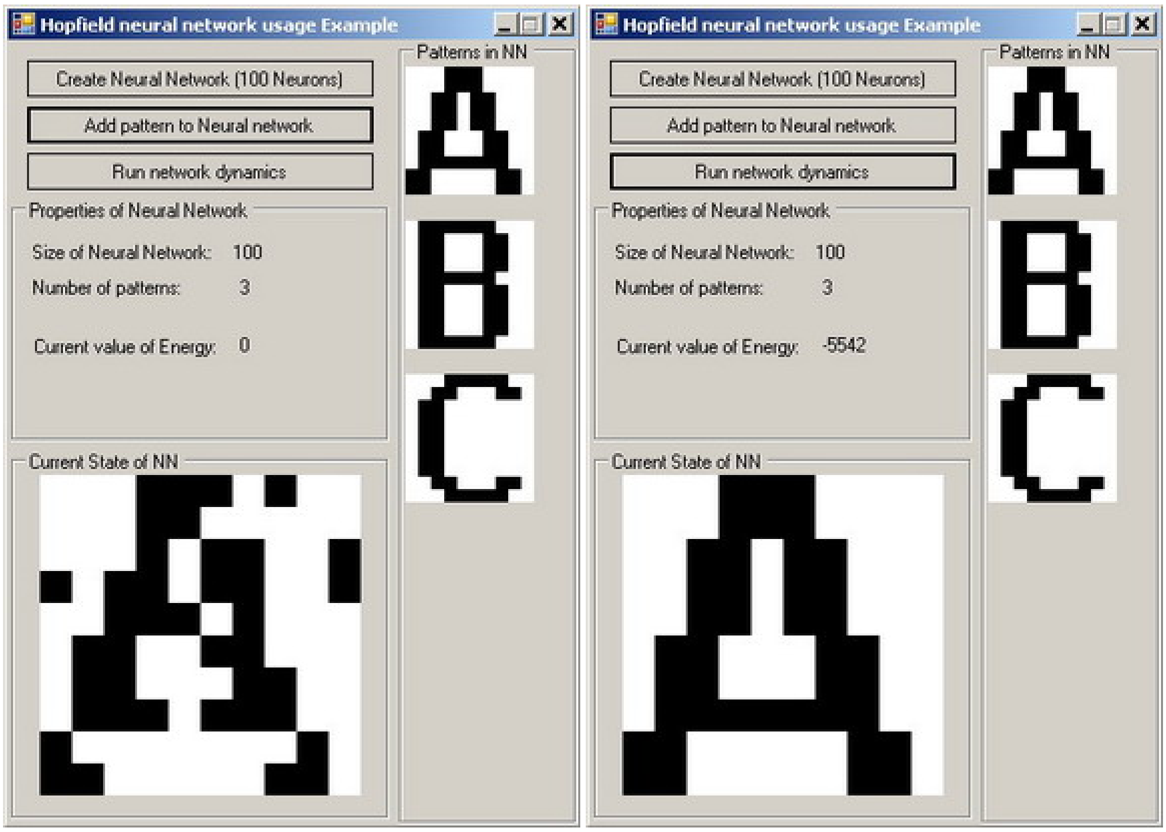
Hopfield neural network usage Example
Create Neural Network (100 Neurons)
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Run network dynamics
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Current State of NN
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Hopfield neural network usage Example
Create Neural Network (100 Neurons)
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Run network dynamics
Properties of Neural Network
Current State of NN
Patterns in NN

Size of Neural Network: 100
Number of patterns: 3
Current value of Energy: 0

Size of Neural Network: 100
Number of patterns: 3
Current value of Energy: -5542

Glossary

- **(A)NN** - (Artificial) Neural **Network**
- **HNN** - **Hopfield** neural **network**Background (optional)

Introduction

The article describes the **Hopfield** model of neural **network**. The theory basics, algorithm and program code are provided. The ability of application of **Hopfield** neural **network** to pattern recognition problem is shown.

Opening

Here I will not talk about NNs in whole. The main goal of this article is to describe architecture and dynamics of **Hopfield** Neural **network**. The base concept of NN, like artificial neurons, synapses, weights, connection matrices and so on, are explained in countless books. If you want to know more about these things, I advise you to start with Simon Haykin "Neural **network**s" book. The Google search is also useful. And finally you can try out very good article of Anoop Madhusudanan's, here on CodeProject.

Hopfield neural **network** (a little bit of theory)

In **ANN** theory, in most simple case (when threshold functions is equal to one) the **Hopfield** model is described as a one-dimensional system of N neurons – spins ($s_i = \pm 1$, $i = 1,2,\ldots,N$) that can be oriented along or against the local field. The behavior of such spin system is described by Hamiltonian (also known as the energy of **HNN**):

$$E = -\frac{1}{2}\sum_{i \neq j}^{N} T_{i,j} s_i s_j$$

Where s_i is the state of the ith spin and

$$T_{i,j} = \sum_{m=1}^{M} s_{mi} s_{mj}$$

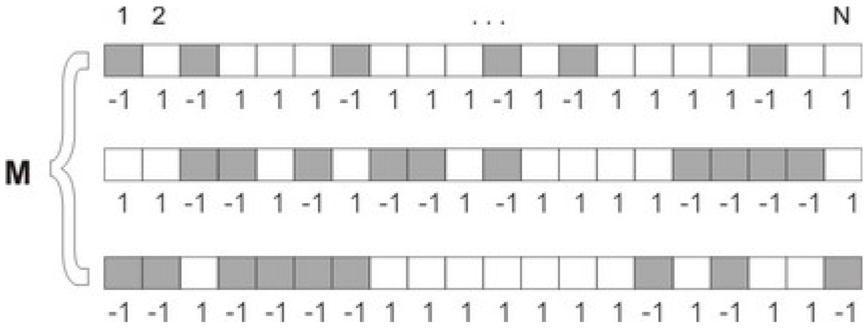
is an interconnection matrix organized according to the Hebb rule on *M* randomized patterns, i.e., on *N*-dimensional binary vectors $S_m=(s_{m1},s_{m2},\dots s_{mN})$ (m=1,2,...M). The diagonal elements of interconnection matrix are assumed to be zero ($T_{i,i}$=0). The traditional approach to such a system is that all spins are assumed to be free and their dynamics are defined only by the action of a local field, along which they are oriented. The algorithm of functioning of HNN is described as follows. The initial spin directions (neuron states) are oriented according the components of input vector. The local field $h_i = \frac{\partial E}{\partial s_i}$, which acts on the *i*th spin at time *t* (this field is produced by all the remaining spins of NN) is calculated as:

$$h_i = \sum_{j \neq i}^{N-1} T_{i,j} s_j$$

The spin energy in this field is $E_i = -s_i h_i$. If the spin direction coincides with the direction of the local field ($E_i < 0$), its position is energetically stable and the spin state remains unchanged at the next time step. Otherwise ($E_i > 0$), the spin position is unstable, and the local field overturns it, passing spin into the state $s_i(t+1)=-s_i(t)$ with the energy ($E_i(t+1) < 0$). The energy of the NN is reduced reducing each time any spin flips; i.e., the NN achieves a stable state in a finite number of steps. At some precise conditions each stable states corresponds to one of patterns added to interconnection matrix.

The same in other words

So, digressing from math, let's consider HNN from the practical point of view. Suppose you have *M*, *N*-dimensional binary vectors (fig. 3), and you want to store them in neural **network**.



-1 1 -1 1 1 1 -1 1 1 1 -1 1 -1 1 1 1 1 -1 1 1

1 1 -1 -1 1 -1 1 -1 -1 1 -1 1 1 1 1 -1 -1 -1 -1 1

-1 -1 1 -1 -1 -1 -1 1 1 1 1 1 1 1 -1 1 -1 1 1 -1

Fig. 3. The set of binary patterns

In this case, you have to add them into the interconnection matrix, using simple summing (fig. 4).

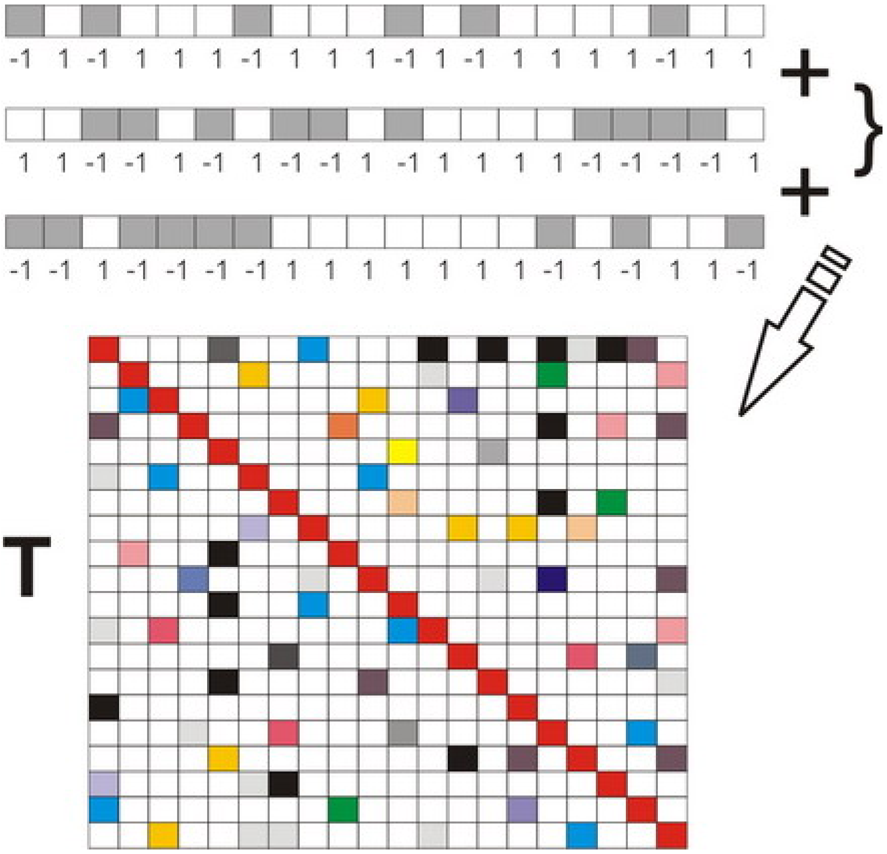


Fig. 4. The formation of the interconnection matrix

Now the **network** is ready to work. You must set some initial state of NN and run dynamical procedure. The properties of HNN is such that during dynamics it passes into the some stable state which corresponds to the one of the patterns. And NN will pass in that pattern, which is most like the initial state of HNN.

Playing with demo

To see how it works in practice, run demo project (***Hopfield****Recognizer.exe*).

1. In the main window press "Create Neural **Network** (100 Neurons)" button. The neural **network** will be created.
2. Then press "Add pattern to Neural **Network**" button and select any 10x10 image (you can find some in ABC folder). Add for example 3 patterns which correspond to A, B and C images.
3. Select one of the added patterns (for example A) by clicking on it and define the value of initial distortion level in percents (you can leave it equals to 10%).
4. Press "Run **network** dynamics" button. And here it is :)

Diving into the code

Let's consider the object model of neural **network**. It consists of two main classes: `Neuron` and `NeuralNetwork`. `Neuron` is a base class, which contains `State` property and `ChangeState()` method. `State` is an `Int32` number, but actually it takes only two values: +1 or -1 (These values are also accessible from static class `NeuronStates`. Where `NeorunStates.AlongField` is equal to 1 and `NeorunStates.AgainstField` is equal to -1). `ChangeState()` receives value of field acting on the neuron and makes decision, either to change own state or not. `ChangeState()` returns `true` if `State` was changed.

Hide Shrink ▲ Copy Code

```
public class Neuron
{
    private int state;
    public int State
    {
        get { return state; }
        set { state = value;}
    }
    public Neuron()
    {
        int r = new Random().Next(2);
        switch (r)
        {
            case 0: state = NeuronStates.AlongField; break;
            case 1: state = NeuronStates.AgainstField; break;
        }
    }

    public bool ChangeState(Double field)
    {
        bool res = false;
        if (field * this.State < 0)
        {
            this.state = -this.state;
            res = true;
        }
        return res;
    }
}
```

`NeuralNetwork` class contains the typed list of the neurons, methods for add patterns and run dynamics:

Hide Copy Code

```
public List<Neuron> Neurons;
public void AddPattern(List<Neuron> Pattern)
public void Run(List<Neuron> initialState)
```

The class constructor initializes all fields, creates lists and arrays and fills the interconnection matrix with zeros:

Hide Copy Code

```
public NeuralNetwork(int n)
{
    this.n = n;
    neurons = new List<Neuron>(n);
    for (int i = 0; i< n; i++)
    {
        Neuron neuron = new Neuron();
        neuron.State = 0;
        neurons.Add(neuron);
    }

    T = new int[n, n];
    m = 0;

    for (int i = 0; i < n; i++)
        for (int j = 0; j < n; j++)
        {
            T[i, j] = 0;
        }
}
```

The `AddPattern()` and `AddRandomPattern()` adds specified (or randomly generated) pattern into interconnection matrix:

Hide Copy Code

```
public void AddPattern(List<Neuron> Pattern)
        {
            for (int i = 0; i < n; i++)
                for (int j = 0; j < n; j++)
                {
                    if (i == j) T[i, j] = 0;
                    else T[i, j] += (Pattern[i].State * Pattern[j].State);
                }
            m++;
        }
```

The `Run()` method, runs dynamics of HNN:

Hide Copy Code

```
public void Run(List<Neuron> initialState)
{
    this.neurons = initialState;
    int k = 1;
    int h = 0;
        while(k != 0)
        {
            k = 0;
            for (int i = 0; i < n; i++)
            {
                h = 0;
                for (int j = 0; j < n; j++)
                  h += T[i, j] * (neurons[j].State);

                if (neurons[i].ChangeState(h))
                {
                    k++;
                    CalculateEnergy();
                    OnEnergyChanged(new EnergyEventArgs(e,i));
                }
            }
        }
        CalculateEnergy();
}
```

Every time when any spin changes its state, the energy of system changes and NN raises `EnergyChanged` event. This event allows to subscribers to track the NN state in time.

Using the code

To use this code in your project, you have to add reference to ***Hopfield**Neural**Network**.dll*. Then you need to create an instance of the `NeuralNetwork` class, and subscribe to `EnergyChanged` event (optional):

Hide Copy Code

```
NeuralNetwork NN = new NeuralNetwork(100);
NN.EnergyChanged += new EnergyChangedHandler(NN_EnergyChanged);
private void NN_EnergyChanged(object sender, EnergyEventArgs e)
{
  //...
}
```

After that, you need to add some patterns to the interconnection matrix.

Hide Copy Code

```
List<Neuron> pattern = new List<Neuron>(100);
//... some pattern forming code goes
NN.AddPattern(pattern);
```

And finally, you can run the dynamics of the **network**:

Hide Copy Code

```
List<Neuron> initialState = new List<Neuron>(100);
//... some initialState forming code goes
NN.Run(initialState);
```

Last word

The HNN was proposed in 1982, and it is not the best solution for pattern recognition problem. It is very sensible for correlations between patterns. If you'll try to add some very similar patterns to matrix (for example B and C from (ABC folder), they are flows together and form new pattern called chimera. It is also sensible for number of patterns stored in the interconnection matrix. It couldn't be more than 10-14% from number of neurons. In spite of such disadvantages the HNN and its modern modifications is simple and popular algorithms.

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About the Author

Bashir Magomedov

Software Developer (Senior)

United Kingdom 🇬🇧

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Work: HSBC (http://www.hsbc.co.uk/).
Regalia: PhD in CS, MCAD, MCPD: Web Developer, MCTS: .Net Framework 2.0., 3.5.
Interests: Programming, artificial intelligence, C#, .NET, HTML5, ASP.NET, SQL, LINQ.
Marital Status: Married, daughter
Blog: http://www.magomedov.co.uk

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question

th_cue 4-Jun-13 23:43

I meet error in line : imNNState.pixels = new int[imageDim, imageDim];
You can hepl me solve problems !!!

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My vote of 5

Kanasz Robert 6-Nov-12 18:01

very good article and well explained. good job bashir

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How do I change to recognize binary pattern?

shamlen 7-Jun-11 7:56

Hi,

Thanks for the posting. I am a newbie to AI world. I would like to understand, how could I change your algorithm to recognize binary pattern. For example,

I may have set of data as below

Day	Data
1	101010
2	110011
3	101110
4	011010
5	001100

I would like to predict the data for day 6. I have 1000 set of historical data. Please advice if this is achievable using your algorithm. I would appreciate if you could direct me to the right path.

Thanks

-Balan Sinniah-

Balan

Reply · Email · View Thread 5.00/5 (1 vote)

My vote of 5

Filip D'haene 26-May-11 22:39

Excellent article!

Thanks for sharing. ☺

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Hopfield NN for pattern recognition in visual prolog

ngelina 16-Nov-10 17:02

hi..

i wan to disscusss about hopfield NN for pattern recog in vis-pro.
can u give me advice about the algorithm?
thx 😊

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You asked me about the procedure NN_EnergyChanged()

phamvanloi_nd 31-Mar-10 17:05

Hi!
You asked me about the procedure NN_EnergyChanged(object sender, EnergyEventArgs e)

Why in the procedure CreateNNBut_Click(object sender, EventArgs e)you call procedure NN_EnergyChanged.

NN.EnergyChanged += new EnergyChangedHandler(NN_EnergyChanged);

I do not really understand this function.

Hope you can explain techniques are not for me!

thank you very much.

wish you a happy day! 😑

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You asked me about the procedure NN_EnergyChanged(object sender, EnergyEventArgs e)

phamvanloi_nd 31-Mar-10 17:03

Hi!
You asked me about the procedure NN_EnergyChanged(object sender, EnergyEventArgs e)

Why in the procedure CreateNNBut_Click(object sender, EventArgs e)you call procedure NN_EnergyChanged.

NN.EnergyChanged += new EnergyChangedHandler(NN_EnergyChanged);

I do not really understand this function.

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wish you a happy day! 😑

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Neural network

SajanakiSasiri 8-Dec-09 13:06

How can i design a neural network for image recognition with mathLab?
What is the neural network technology?

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Association Between Input and Reference Patterns

JackEMoore 9-Nov-09 5:40

In the example with patterns A, B, C, what is a good algorithm way to associate the result after the NN has acheived a stable state with the particular reference pattern?

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Question

sandreli 20-Jun-09 18:23

Can you please show the method CalculateEnergy

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Re: Question

Bashir Magomedov 20-Jun-09 18:38

What do you mean by show? You can see it in the code. Just download it. Please do not hesitate to ask if you need some details ot explanation about this method.

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Question

dennykidz7 18-Jun-09 15:18

What the Neuron Index..For what?

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Re: Question

Bashir Magomedov 18-Jun-09 15:27

Have you meant something certain by index? If not I can answer in general. To iterate trough all the neurons of system and either change the state of particular neuron or remain it unchanged.

Everything is possible!

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About Hopfield Neural network Source code

monisha101 30-Jul-08 17:58

I find out the code for Hopfield neural network from ur site....its demo working fine...but i need this code in C language instead of C++ language [D'Oh!]

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Ask

amal_kh 3-Jul-08 15:00

Can i ask you how did you use neural network in your project, i mean what was the input layer,hiddden layer, the function that you used and the output layer?

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Re: Ask

Bashir Magomedov 3-Jul-08 15:14

The deal is that this is not a multi-layer perceptron (as you might thought), but Hopfiled neural network (HNN). This is a special kind of neural network for pattern recognition and it doesn't have any layers. In general case each neuron of HNN has activation function but here (for the simplicity) it was reduced to bipolar function when each neuron can be either + or - 1.

Please read the article carefully, all these points were stated in it, and do not hesitate to contact me in future if you need help.

Everything is possible!

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HopfieldNeuralNetwork_demo is not working

mohammadnassif 17-May-08 2:00

pleas help me i download the project and try to run
from this icon : HopfieldRecognizer.exe
but the project dont run and return this message:
The application failed to initialize properly(0xc0000135).Click on ok to terminate the application.

pleas help me and tell me whats i can do.

thanks

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Re: HopfieldNeuralNetwork_demo is not working

Bashir Magomedov 17-May-08 13:12

It seems that you do not have .NET Framework installed on your machine. Please install .NET 2.0 (or later) Framework and try again.😎

Everything is possible!

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pleas help me

yasamin 5-Apr-08 14:43

hi
I'm yasamina
Ihave aproject in nural network Iwant to make astndared or model back propagation network but Idont have any idea how i can do this if any one have a code or idea pleas giv it to me
thank you

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hi

lulukuku 27-Nov-07 23:16

thank you very much,i saw it.😊

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Question!!

lulukuku 26-Nov-07 16:44

in the program of you,i don't see method you create neural's images(about 100 neuron)! you can explain for me!!!
thanks you very much.

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Re: Question!!

Bashir Magomedov 26-Nov-07 16:51

Here is requested code. This method is an event handler of "Create neural network (100 Neurons)" button. You can find it in the frmMain class (MainForm.cs file).

Hide Copy Code

```
<br />
        private void CreateNNBut_Click(object sender, EventArgs e)<br />
        {<br />
            NN = new NeuralNetwork(imageDim*imageDim);<br />
            panelStoredImages.Controls.Clear();<br />
            NN.EnergyChanged += new EnergyChangedHandler(NN_EnergyChanged);<br />
            Random rnd = new Random();<br />
            int r = 0;<br />
            imNNState.pixels = new int[imageDim, imageDim];<br />
            for (int i = 0; i < imageDim; i++)<br />
                for (int j = 0; j < imageDim; j++)<br />
                {<br />
                    r = rnd.Next(2);<br />
                    if (r == 0) imNNState.pixels[i, j] = Color.Black.ToArgb();<br />
                    else if (r == 1) imNNState.pixels[i, j] = Color.White.ToArgb();
<br />
                }<br />
            patternSelected = false;<br />
            butAddPattern.Enabled = true;<br />
            butRunDynamics.Enabled = false;<br />
            imNNState.Visible = true;<br />
            imNNState.Invalidate();<br />
            UpdatePropertiesPB();<br />
        }<br />
```

Thank you for your attention

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ERROR!!!

lulukuku 25-Nov-07 14:52

i meet ERROR "Warning 1 Could not find type 'ImageMagnifier.ImageMagnifier'. Please make sure that the assembly that contains this type is referenced. If this type is a part of your development project, make sure that the project has been successfully built. 0 0
" and "Warning 2 The variable 'imNNState' is either undeclared or was never assigned. C:\Documents and Settings\Administrator\Desktop\HopfieldRecognizer\MainForm.Designer.cs 175 0
"
You can hepl me solve problems !!!

where do i find "'ImageMagnifier.ImageMagnifier'" ?
Thanks you very much!!

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Re: ERROR!!!

Bashir Magomedov 25-Nov-07 17:18

Dear lulukuku!
This class (ImageMagnifier) is needed only for demo-project and located in the root folder of the project. It is possible that references are out of date, so you should remove reference from project and add it again by yourself.
If you are looking for the source-codes of this control, you can try out following link:
http://www.codeproject.com/cs/miscctrl/ImageMagnifier.asp[^]

Sincerely yours, Bashir

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help me!

lulukuku 23-Nov-07 23:46

please,help me!i need informaiton for hopfield model of neural network for pattern recognition. you can send me all code "Hopfield model of neural network for pattern recognition ".thanks you very much!!

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