Implementation of the Synergetic Computer Algorithm on AutoCAD Platform

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Abstract: - In this paper the results of the experiments for adaptation of the synergetic computer algorithm to AutoCAD environment are presented. While the algorithm implemented is based largely on H. Haken models, the significant differences to the basic characteristics of the classical model were introduced and successfully tested in one of the most popular CAD environment. Namely, in our approach, the number of meaningful elements of the prototype pattern vectors is varied and the number of features per pattern is allowed to be smaller, then the number of patterns (M≥N). For the first time ever the synergetic computer was implemented on AutoCAD platform. The presented research constitutes the next intermediate step to the development and research of the fully functional Autonomous Design System (ADS). The resulted system forms important practical and theoretical foundations for an ongoing research in this field.

Key-Words: - Self-organization, Synergetic computer, CAD, Synergetics, Pattern recognition, Synergetic neural networks

1 Introduction

The concept of the synergetic computer was introduced by Hermann Haken in late eighties of the last century and it is based on the profound analogy between pattern formation and pattern recognition. Thus, the mathematical theory of synergetics was possible to use in derivation of the basic equations of synergetic computer. Synergetics (H. Haken's interpretation) can be considered as one of the modern, most promising research programs. It is oriented towards the search for common patterns of evolution and self-organization of complex systems of any kind, regardless of the concrete nature of their elements or subsystems (see e.g. [1], [2]).

In this paper the technical details of the theory of the synergetic computer and its possible realization on CAD (Computer Aided Design) and ADS platforms are discussed. For the general analysis of the possibilities for using synergetics in modelling the creative part of the engineering design systems and in ADS, as well, as for the brief philosophical outlook, see [3].

2 Standard Haken Model

In this section a short overview of the mathematical background of the synergetic computer concept is presented. For in-depth discussion of the standard model see [4].

The basic dynamic equation of the synergetic computer or synergetic neural network is as follows:

$$\dot{q} = \sum_k \lambda_k v_k (v_k^+ q) - B \sum_{k' \neq k} (v_{k'}^+ q)^2 (v_k^+ q) v_k - C(q^+ q) q + F(t), \tag{1}$$

where q is the state vector of a test (input) pattern with initial value q_0, λ_k is attention parameter, v_k is the prototype pattern vector, v_k^+ is the adjoint vector of v_k, which obeys the orthonormality relation

$$(v_k^+ v_{k'}) = \delta_{kk'}. \tag{2}$$

B, C are positive constants and $F(t)$ is fluctuating forces, which may drive the system out from its equilibrium state. Expression $v_k \cdot v_k^+$ acts as a matrix. This matrix has occurred in number of other publications and is called the learning matrix. The term

$$\xi_k = (v_k^+ q) \tag{3}$$

is called the order parameter. The equation (1) describes the dynamics, which pulls the test pattern $q(t)$ into one of the prototype patterns v_{k_0}, namely the one to which $q(0)$ was closest. This means the pattern is being recognized by the system.

The corresponding dynamic equation of order parameters reads:

$$\dot{\xi}_k = \lambda_k \xi_k - B\sum_{k'\neq k} \xi_{k'}^2 \xi_k - C\sum_{k'=1}^{M} \xi_{k'}^2 \xi_k . \qquad (4)$$

The order parameters obey the initial condition

$$\xi_k(0) = (v_k^+ q(0))$$

by which the initial values of order parameters in the evolution series are determined.

The equations (1) and (4) could be derived from corresponding potential function equations (5) and (6). That is

$$\dot{q} = -\frac{\partial V}{\partial q^+}, \quad \dot{q}^+ = -\frac{\partial V}{\partial q},$$

$$V = -\frac{1}{2}\sum_{k=1}^{M} \lambda_k (v_k^+ q)^2 + \frac{1}{4}B\sum_{k\neq k'} (v_k^+ q)^2 (v_{k'}^+ q)^2 + \frac{1}{4}C(q^+ q). \qquad (5)$$

And

$$\dot{\xi}_k = -\frac{\partial \tilde{V}}{\partial \xi_k},$$

$$\tilde{V} = -\frac{1}{2}\sum_{k=1}^{M} \lambda_k \xi_k^2 + \frac{1}{4}B\sum_{k'\neq k} \xi_{k'}^2 \xi_k^2 + \frac{1}{4}C(\sum_{k'=1}^{M} \xi_{k'}^2)^2. \qquad (6)$$

The potential function is used to represent the potential field in the space of k order parameters in which the fictitious particle, representing the dynamics of the test pattern or the corresponding order parameter, moves. The example of the potential V is shown on Fig.1.

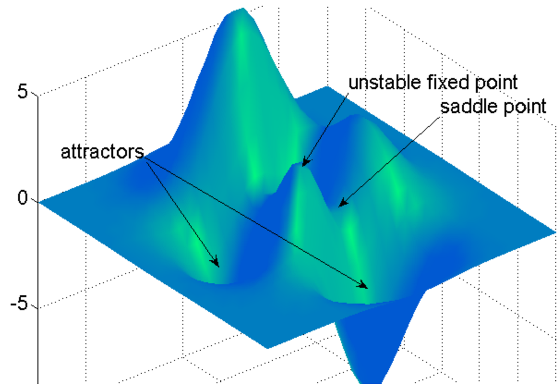

Fig.1 Example of potential function

In this plot the attractors are clearly visible. The attractors are the stable fixed points, which are represented by a bottom of each valley. The top of each mountain is an unstable fixed point. All points in the landscape from which the particle can roll down to the same attractors form the basin of attraction. Points of minimal height on ridges are saddle points.

The stable fixed points are at $q = v_k$, i.e. at the prototype patterns, and there are no other stable fixed points. The stable fixed points are equally characterized by $\xi_k = 1$, all other ξ's = 0.

The Haken's classical model is built up upon a number of assumptions. The most important of which are as follows:

- all attention parameters are equal and positive (i.e. balanced attention parameters)

$$\lambda_k = \lambda > 0, \quad \lambda = C \qquad (7)$$

- the number of patterns is smaller than or equal to the number of features

$$M \leq N \qquad (8)$$

- vectors v_k are subject to the condition

$$\sum_k v_k = 0 \qquad (9)$$

- the following normalization holds

$$(v_k^T v_k) \equiv \sum_{j=1}^{N} v_{kj}^2 = 1 \qquad (10)$$

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- the number of features per pattern should be the same for all prototype and test vectors (equality of vectors' meaningful dimensions). That is, for each

$$v_1(k), v_2(l)...v_n(m);$$
$$k = l = ... = m, \tag{11}$$

where *k, l,…,m* are vectors' meaningful dimensions.

As vectors v_k are not necessarily orthogonal to each other, we need to construct the adjoint vectors, which may be formed as superpositions of the transposed vectors v_k^T:

$$v_k^+ = \sum_{k'} a_{kk'} v_{k'}^T. \tag{12}$$

The coefficients $a_{kk'}$ must be determined to satisfy the orthogonality condition (2). This may be done by multiplying (12) by $v_{k'}$ and interpreting $a_{kk'}$ and scalar products $(v_{k'}^T v_k)$ as elements of the corresponding matrices *A* and *W*

$$A = (a_{kk'})$$
$$W = [(v_{k'}^T v_{k'})].$$

Equation (12) then can be written in the form

$$I = AW \tag{13}$$

and can be solved formally by $A = W^{-1}$.

2.1 Synergetic neural network

Synergetic computer may be realized by artificial neural networks, which act in fully parallel manner. The resulting system is then called Synergetic Neural Network or SNN. SNN may be realized e.g. as one- or three-layer network. By using order parameter concept the network can be considerably simplified. As order parameters are defined by (3), and satisfy

$$\dot{\xi}_k = \xi_k(\lambda - D + B\xi_k^2), \tag{14}$$

where

$$D = (B + C)\sum_{k'} \xi_{k'}^2, \tag{15}$$

then, for a three layer network, we may use order parameters' as neurons' representation in the network's second layer. The input layer is represented by input (test) pattern vectors $q_j(0)$, and if SNN has to act as an associative memory, the third layer should consist of

$$q_j(t) = \sum_k \xi_k(t) v_{kj}, \tag{16}$$

where q_j is the activity of the cell *j* at the output layer, ξ_k the final state of order parameter cell layer with $\xi_k = 1$ for $k = k_0$ (i.e. the pattern has been recognized) and $\xi_k = 0$ otherwise. The network may be further simplified by introducing a common reservoir *D* as in (14). In this way the number of connections may be further reduced.

3 Synergetic Computer on AutoCAD

Implementation of the synergetic computer core functionality on AutoCAD platform is the intermediate step towards the realization of SNN in real life design process as a main tool in ADS modelling. ADS is defined as an advance CAD system, which has AI functionality and particularly the functionality to solve the creative tasks of the engineering design process.

To this end, the objective was established to create an AutoCAD application that can recognize a number of simple geometric structures. At first the MATLAB prototype was created in order to test the basic functionality of the model and then the algorithm was implemented in AutoCAD environment. For the sake of simplicity of the presentation, in AutoCAD environment only three different patterns were implemented. Actually, the number of patterns tested (in MATLAB) was bigger and the noisy patterns were elaborated as well.

The prototype patterns for our case were chosen among AutoCAD (Acad) polygon entities (more specifically, these constitute of polyline objects in Acad database), namely, the triangle, square and hexagon. As Acad is a vector graphics software, we had to invent the way of representing our prototype vectors properly. We had chosen to code vectors' elements as a relative measure between entities' endpoints i.e. the distances between polygons' vertices, as shown on Fig. 2.

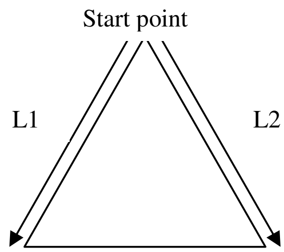

Fig. 2 Representation of prototype vectors' elements in AutoCAD graphics system

Thus, in a case of triangle the raw prototype vector is as simple as $v_k = (L_1, L_2)$. We have now three state vectors to recognize (shown as raw vectors):

$$
\begin{aligned}
v_0 &= (L_{01}, L_{02}, L_{03}) \\
v_1 &= (L_{11}, L_{12}) \\
v_2 &= (L_{21}, L_{22}, L_{23}, L_{24}, L_{25}).
\end{aligned} \tag{17}
$$

From (14) we may deduce a discrete equation for the order parameter evolution

$$
\begin{aligned}
&\xi_k(n+1) - \xi_k(n) \\
&= \gamma(\lambda_k - D + B\xi_k^2(n))\xi_k(n),
\end{aligned} \tag{18}
$$

where γ is the iteration speed and term D is according to (15). The corresponding evolution for the case of three order parameter is shown on Fig. 3.

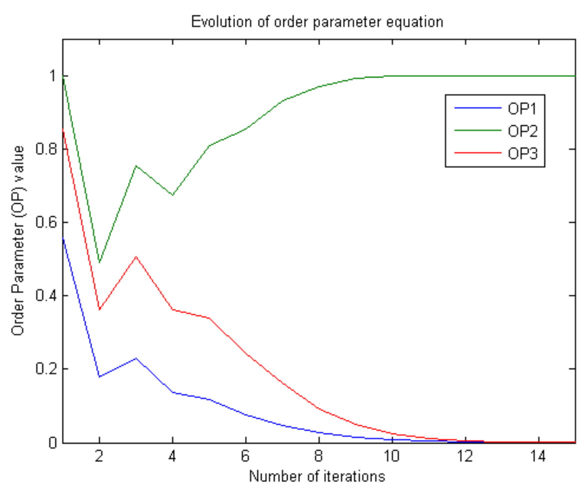

Fig. 3 Evolution of order parameter equations

From Fig. 3 is seen that the system converges after twelve steps, i.e. the winning order parameter becomes $\xi_1 = 1$ and others $\xi_2 = \xi_0 = 0$. Thus, the prototype pattern that corresponds to ξ_1 will be recognized. Note that due to the fact that the biggest initial order parameter $\xi_k(0)$ will always win the competition (in the case of balanced λ_k), the iteration (18) may be omitted and the resulted system remarkably simplified. The learning process will be then restricted to satisfying (10) and solving (13). If, however, we are dealing with normalized vectors, finding of adjoint vectors means just transposing and the whole dynamics reduces to forming the inner products $(v_k^T q_0)$, which further reduces the complexity of numerical computations.

The user interface of the resulted system is shown on Fig. 4.

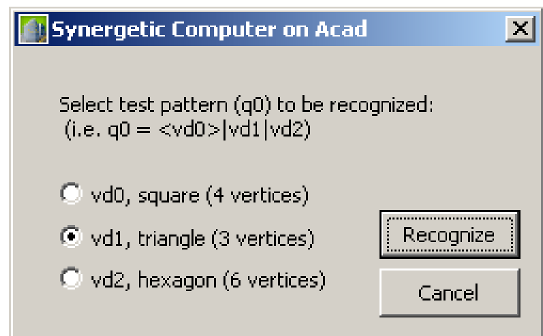

Fig. 4 GUI of SNN application

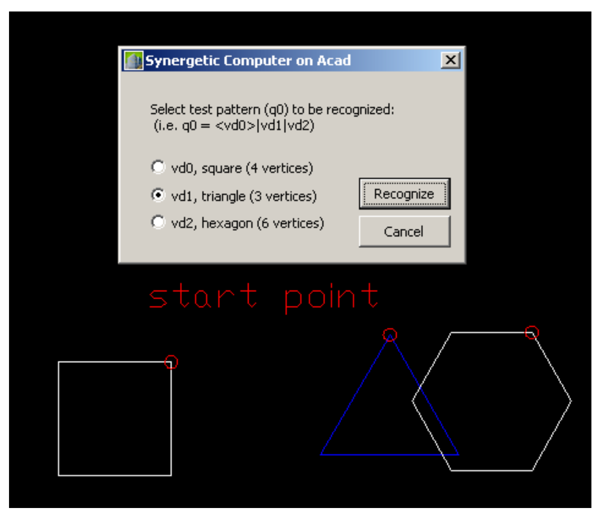

Fig. 5 AutoCAD graphics screen, the identified pattern is selected

The user may choose the pattern desired by selecting respective radio button, then by pressing the action button the system performs the

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recognition process and selects the identified polygon by changing its color property (to blue), see Fig. 5.

The location and position of the test patterns has no effect on the recognition results. The polygons may be rotated, or, even overlapped on each other, the system still successfully identifies the figures.

On Fig. 6 the Acad text window with implemented system's output messages is shown.

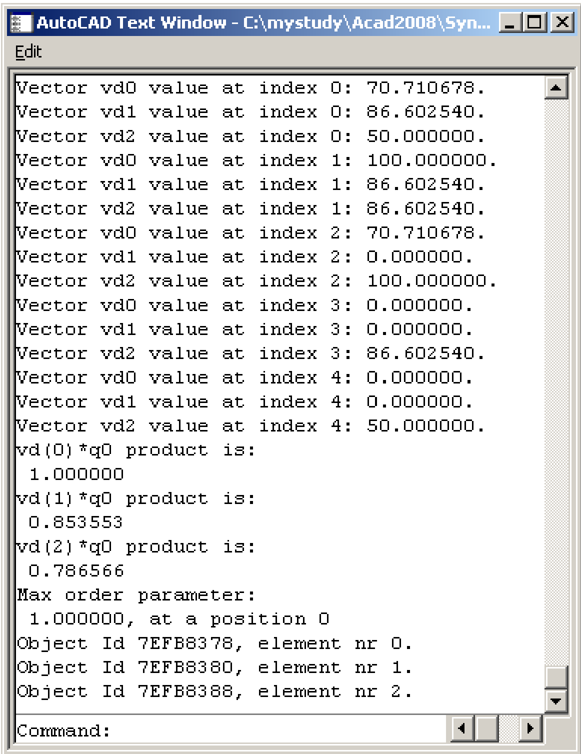

Fig. 6 AutoCAD text window, program control messages

3.1 Differences from standard model

The model differs from classic Haken representations by the following points: (8), (9) and (11). More specifically, in our Acad model the number of patterns allowed to be bigger or equal to the number of features $M \geq N$. Additionally, numerical simulations have shown that the model works well in situation where $M \gg N$.

We have omitted the condition (9) in our model, as tests have proved it to be redundant.

The size of the prototype vectors is different in our implementation, thus the (11) is not satisfied. However, the model still performs well. Here, of course, it is the number of meaningful dimensions that is important. For a system to be solvable, the trailing zeros should be added to vectors of different size:

$$v_0 = (L_{01}, L_{02}, L_{03}, 0, 0)$$
$$v_1 = (L_{11}, L_{12}, 0, 0, 0)$$
$$v_2 = (L_{21}, L_{22}, L_{23}, L_{24}, L_{25}).$$

All these modifications, while simplifying the system and allowing for a greater flexibility, do not degrade the model's performance nor obscure general properties of SNN. It is worth noting, that the recognition rate of the model so far was 100%. This could be explained e.g. by the fact that only the noiseless patterns were used for the test vectors.

3.2 Tools and technologies used

AutoCAD Architecture 2008 as a main framework for the model, VC++ 8.0, ObjectARX 2007, Eigen3, MATLAB 7.0.

3.3 Further research

In our model the balanced attention parameters were used (according to (7)) and $\lambda_k = C = B = 1$. It is possible to use the unbalanced attention parameter technique e.g. $\lambda_1 = 0,6$ and $\lambda_2 = 0,4$. In that case the biggest value will influence the evolution of the order parameters and it is possible for initially smaller order parameter eventually to win the competition. Attention parameters thus could be used as an additional instrument to guide the selection of order parameters in situations where selection criteria based solely on ξ_k values are not sufficient. Those situations are likely to arise when dealing with more complicated patterns and process objectives, as e.g. in ADS structures or, just as simple, as in treatment of vectors of different size, like (17). The implementation of SNN in ADS, as well as the treatment of noisy patterns, is a subject for a further research.

4 Conclusion

The paper describes the results of the synergetic computer implementation on AutoCAD platform.

A number of useful modifications to the standard model were committed, tested and successfully implemented in the form of AutoCAD application. This is the first documented usage of SNN on AutoCAD platform.

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The presented research constitutes another step to the development and research of the fully functional Autonomous Design System (ADS).

Synergetic computer has one major advantage, compared to the traditional neural computers, namely, there are no so-called pseudo-states, into which the system could be trapped in. It may be proved that besides the prototype vectors there are no other attractors. In addition, the functionality of SNN, especially pattern recognition mechanism and treatment of ambiguous and noisy patterns closely resembles the functionality of biological neural systems, including human brain [5]. This point supports the whole philosophical study of the self-organization phenomenon and is the main reason for selecting synergetic computer approach for ADS implementation. For the philosophical analysis of synergetic modelling and self-organization paradigm one may refer to e.g. [6], [7].

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