Image transfer in multilayered assemblies of lattices of bistable oscillators

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(Received 15 June 1998)

The process of transfer or transmission of spatial images in a multilayered system composed of interacting two-dimensional lattices (layers) with bistable oscillators as units is studied. It is found that for some conditions an image (stimulus) generated in one, the first layer, is transmitted as a self-organizing, self-replicating process from layer to layer preserving its key features with a controllable degree of fidelity even though the layers may be in a spatially chaotic state. The quality of the transmitted or self-replicated image relative to the original stimulus is quantified. The stability of the replication process to external weak noisy disturbances is also discussed. [S1063-651X(99)05804-3]

PACS number(s): 87.10.+e, 05.45.−a

I. INTRODUCTION

One of the fundamental features of self-organizing functions of biological and other natural systems is the possibility of copying or self-replicating structures, functions and patterns of behavior in their evolution [1–5]. Let us consider a lattice dynamical system composed of a number of interacting layers. Each layer is a two-dimensional lattice of identical bistable units, elements, or cells, where a unit has two stable steady states. The intralayer connections are local and of linear diffusive type, D. Thus, each single layer represents a dynamical system that is very much a self-organizing network similar to Haken's diffusive model capable of exhibiting a multiplicity of stable localized structures [6–8]. Due to the bistable dynamics of the cell with small diffusive coupling the layer may be taken as an appropriate tool to store information encoded as discrete (binary) stable steady patterns. On the other hand, it is known [9,10] that for suitable conditions of the system parameters, namely, for a strong enough interlayer coupling, h, a stimulus given to one layer is copied to the second layer, which may initially be in a spatially chaotic state.

Models of such a layered architecture or anatomy composed of oscillatory units may be of potential interest in the studies of the dynamics of complex neural (perceptual) networks allowing different functions of information processing, compression, coding, and transmission of visual images based on self-organizing principles [11,12]. Moreover, the possibility of synchronous states of oscillatory activity is a particular feature of such neural assemblies [13,14]. The neuron posseses a state of rest and a state of oscillatory activity [15], hence bistability.

In this paper we discuss and illustrate the replication phenomenon focusing our attention on the dynamic copying in multilayered systems that we choose as a layered structure of bistable oscillators. We also study some qualitative characteristics of the replication process including its stability to weak noisy signals. In Sec. II we define the model problem to be discussed. We also define the synchronization processes in one- and two-layer systems. Section III is devoted to a detailed account of the process of image transfer by replication. In Sec. IV we delineate the limitations of the replication process according to the ratio between the spatial scale of a stimulus and the lattice constant. Section V deals with the stability of the image replication to noise. In Sec. VI we provide a few concluding remarks.

II. MULTILAYER LATTICE DYNAMICAL SYSTEM

Let us take a bistable oscillator as the unit in the lattice. It has the rest state as a stable steady state and also a stable state of oscillatory activity (periodic oscillations with finite amplitude) as shown in Fig. 1(a). Connecting the cells in the layer by means of diffusive coupling D and each cell of one layer with the cells of two nearest layers, with parameter h, we obtain the multilayer structure shown in Fig. 1(b). The collective dynamics of the global multilayered system is described by the following system of equations:

$$\dot{A}^{(l)}_{j,k} = -A^{(l)}_{j,k} F(|A^{(l)}_{j,k}|^2) + D(\Delta A)^{(l)}_{j,k}) + h(A^{(l+1)}_{j,k} + A^{(l-1)}_{j,k} - 2A^{(l)}_{j,k}),$$

$$j,k = 1,2,\ldots,N, \quad l = 1,2,\ldots,M, \tag{1}$$

where $A^{(l)}_{j,k}$ describes the complex amplitude of the unit at site (j,k) in the layer l. For illustration we take $F(|A|^2) = 2a|A|^4 - a|A|^2 + 1$, $a > 8$, as the nonlinear function providing a stable steady state (the rest state) and a stable limit cycle (the excited state). $\Delta A^{(l)}_{j,k} = A^{(l)}_{j+1,k} + A^{(l)}_{j-1,k} + A^{(l)}_{j,k+1} + A^{(l)}_{j,k-1} - 4A^{(l)}_{j,k}$ is the discrete Laplace operator. As already indicated, D and h are the coefficients of intralayer and interlayer interaction, respectively. We impose Neumann zero flux boundary conditions in both j,k ''directions'' in each lattice and in the ''layer direction'' l.

For pattern replication we merely need the oscillation amplitude $r^{(l)}_{j,k}$ ($A^{(l)}_{j,k} = r^{(l)}_{j,k} e^{\varphi^{(l)}_{j,k}}$). Hence, we shall consider the multilayer architecture or anatomy where all oscillatory units

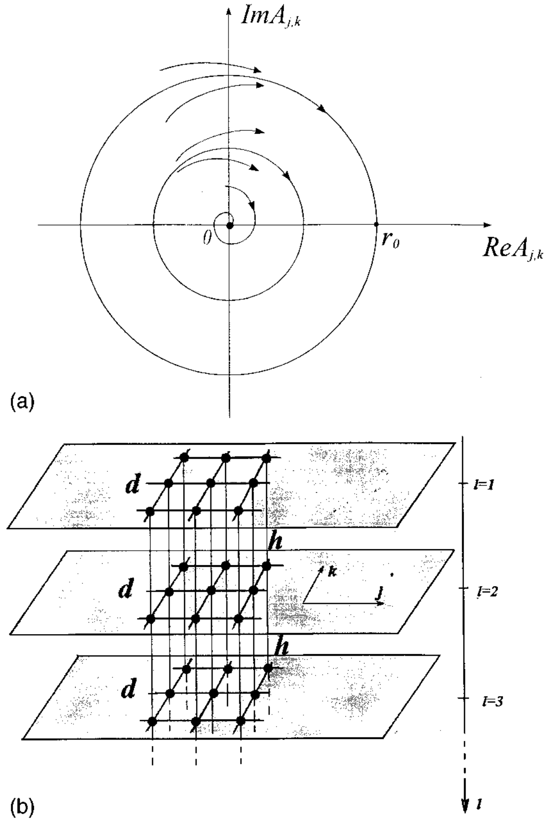

FIG. 1. (a) Phase portrait of a unit, element or cell. (b) Schematic diagram of the multilayer architecture.

are synchronized in phase, $\varphi_{j,k}^{(l)}=\varphi=\text{const}$. Then, the dynamics of the amplitudes of the in-phase oscillations is given by the system

$$\dot{r}_{j,k}^{(l)}=f(r_{j,k}^{(l)})+D(\Delta r)_{j,k}^{(l)}+h(r_{j,k}^{(l+1)}+r_{j,k}^{(l-1)}-2r_{j,k}^{(l)}) \quad (2)$$

with $f(r)=-2ar^5+ar^3-r$.

A. Steady patterns in a single layer

When $h=0$ each layer of the structure (1) represents a two-dimensional lattice system which is a discrete version of a reaction-diffusion medium. Such a system has a wealth of stationary patterns when its parameters are restricted within some region D_{ch} [8,16,17]. For the points of this region the single lattice has 2^{N^2} different stable in-phase motions (amplitude patterns). Each of them corresponds to a collective oscillation given by the cooperative or time-binded behavior of all units of the layer. Besides, the amplitudes of the cells are restricted within rather narrow regions called absorbing domains [17]. Then, the units in the lattice oscillate in some neighborhoods of either the rest state or the oscillatory state. The region D_{ch} is

$$D<D^*=\min\left[\frac{-f_{\min}}{4(r_0-r_{\min})},\frac{f_{\max}}{4(r_0+r_{\max})}\right], \quad (3)$$

where $r_{\min}$,$r_{\max}$ are the minimum and the maximum of the function $f(r)$, respectively. r_0 is the largest positive root of the equation $f(r)=0$ and corresponds to the amplitude of oscillations of an isolated unit ($D=0$), $f_{\min}=f(r_{\min})$, $f_{\max}=f(r_{\max})$ and $a>8$.

In the state space $\{\mathbf{Z}^2,\mathbf{R}\}$ each of the possible 2^{N^2} stable in-phase motions have some steady inhomogeneous amplitude distribution, which represents a stable steady pattern of oscillation amplitudes. Any pattern from the set can be coded by an $N\times N$ matrix of two symbols (for example, ''0'' and ''1'') and any given $N\times N$ matrix defines a possible spatial pattern. Thus for $h=0$ each layer displays high multistability and can exhibit many diverse steady patterns from simple, homogeneous, space periodic to disordered or spatially chaotic.

B. Replication by mutual synchronization. of amplitude patterns between the interacting layers

Consider the system (1) when $h\neq 0$. For a two-layer system it can be shown that when the inter-layer interaction is strong enough, $h>h^*$, $h^*=(7a-20)/20$, there is mutual synchronization of all in-phase motions from layer to layer in the system. Hence, the amplitudes of the in-phase motions become identical in all layers, $r_{j,k}^{(l)}=r_{j,k}^{(l+1)}$, $\forall l=1,2,...,M-1$. Thus, for $h>h^*$ starting from different steady amplitude distributions in the layers we evolve to a new single and common pattern of the oscillation amplitudes as the result of the synchronization. What spatial profile will have this pattern relative to the initial patterns and the values of the parameters of the system? We show here that for some conditions the profile of this pattern can copy with high or controlable degree of fidelity the form of a given image (or, at least, replicate its key features) which has been, initially, imposed on the first layer. This brings a replication process that may be observed in a multilayer system.

III. IMAGE TRANSFER BY REPLICATION

To illustrate the process of pattern replication we take as the stimulus the black and white portrait of a young lady (Fig. 2). The initial condition in the first layer of the three-dimensional (3D) architecture when ($h=0$) is associated with this picture in the following way. Let the initial phases of the oscillators in the first layer, $\varphi_{j,k}^{(1)}(0)$, be chosen arbitrarily distributed around a given value [for instance, near $\varphi_{j,k}^{(1)}(0)=0$] and the initial amplitudes $r_{j,k}^{(1)}(0)$ has some inhomogeneous distribution. As it has been earlier mentioned (see also Ref. [17]), in this case the system evolves to the coherent (in-phase) mode with the amplitudes restricted within small regions (absorbing domains) near the unperturbed rest state, $r=0$, and the excited state, $r=r_0$. Hence, the steady distribution of the amplitudes, $r_{j,k}^{(1)}$, in $\{\mathbf{Z}^2,\mathbf{R}\}$ has a bistable character. Thus, any black and white image can be encoded as a steady amplitude pattern of the coherent oscillation of the lattice layer by a suitable choice of the initial conditions for $r_{j,k}^{(l)}$. In our simulations we take the white color when the oscillators are near the state of rest and black color when near the oscillatory mode.

A. Replication in a two-layer system

Let us start considering the assembly of two layers [$M=2$ in system (1)] such that when $h=0$ the first layer con-

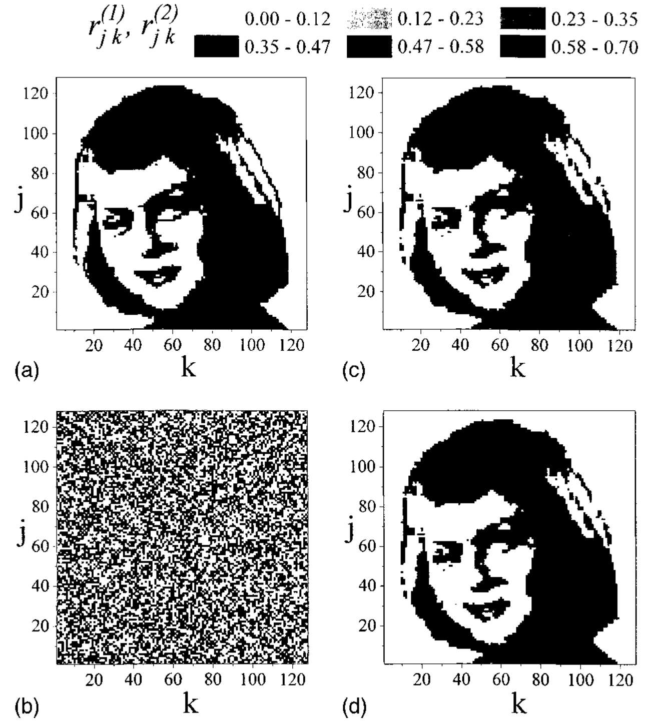

FIG. 2. Image replication in a two-layer system. (a), (b) initial amplitude patterns; (c), (d) terminal amplitude distribution in the layers. (a) A young lady's face encoded as the amplitude pattern, (b) disordered pattern—''pure'' state of the layer. Parameter values: $a=10.65$, $D=0.06$, $h=0.7$.

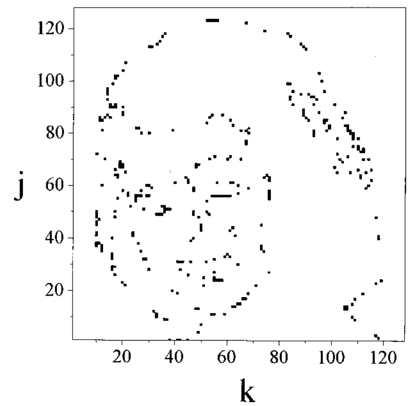

FIG. 3. Differential image obtained as the misprint signal between replicated copies [Fig. 2(c) and 2(d)] and the original image [Fig. 2(a)].

tains the amplitude pattern associated with the stimulus [Fig. 2(a)] while the second layer is in a spatially disordered, chaotic state. This state is given by the amplitude distribution which is also steady in time but random in space corresponding to a pseudo-random sequence generated by computer [Fig. 2(b)]. Thus, the second layer can be considered as structureless, ''raw'' material.

1. Two copies of the original image

When the interlayer interaction is switched on and becomes strong enough, $h>h^*$, after a rather short transient process the system tends to the synchronized state [Figs. 2(c) and 2(d)]. It is also a steady amplitude pattern which is a faithful copy of the initial image. Thus, the oscillators of the disordered layer become self-organized according to the ''template'' proposed by the stimulus. Note, that this ''template'' does not strictly force the disordered layer because there is mutual bidirectional interaction between the two layers. The replicated or off-spring copies always have some imperfection or distortions relative to the original image. Hence, our system does not work like a photocopying machine or a printing press but actually operates as a dynamically self-regulating machine.

Note, however, the interesting fact that replicated ''misprints'' do not occur at random. Figure 3 illustrates the misprint pattern built as the difference signal between the original image and its replicated copy. As this pattern clearly selects the contours of the lady's face we can say that it contains the key features of the stimulus. This is what may be of potential interest for redundancy reduction function as data compression tool in perceptual neural networks [9]. Let us take the difference signal in each unit as the output of the system. A general rule to have efficient data compression is to minimize the ''mutual information'' between the output and the input given with the original stimulus. Loosely, the ''mutual information'' has a high value if the output unit acts synchronously with the input and vanishes if the output state is different. In our case this measure for the output (Fig. 3) and the input [Fig. 2(a)] tends to have a rather low value. In other words, only few spatial sites, about 1% (points labeled by black dots in Fig. 3), are needed to preserve all key features of the stimulus. In fact, we have a 100:1 ratio in the data compression as the result of the self-organization process of the two interconnected layers.

2. Quality of replication

To estimate the quality of the copies hence the fidelity to the original we introduce a simple quantity Δ, called replication quality factor,

$$\Delta[\%]=\frac{N_1}{N^2}\times 100\%$$

where N_1 is the number of oscillators (pixels in the pictures of Fig. 2) correctly replicating the stimulus in a given point of the lattice. N^2 is the number of oscillators in each layer. Note, that the ratio $N^2{:}(N^2-N_1)$ characterizes the degree of compression, which is accurately described changing Δ. Hence, in what follows we deal only with Δ to quantify the fidelity of the replication process.

Figure 4(a) illustrates the replication quality factor as a function of the control parameter a for fixed h and different values of the intra-layer diffusion D. The values of the parameter a define the excitability of the unit. In particular, high values of a make the oscillator more easily ''excitable'' in the sense that a small perturbation of its rest state brings it to the oscillatory mode. Thus, the parameter a of the bistable unit regulates the basins of attraction of the stable steady point and the stable limit cycle in the phase plane [Fig. 1(a)]. When $D=0$ the replication quality factor depicted by the dashed curve in Fig. 4(a) takes only two values $\Delta\approx 76.6\%$ and $\Delta\approx 73.2\%$. The value of a at the discontinuity of the curve corresponds to the equal basins of attraction of the rest and oscillatory states. The replicated image in this case has

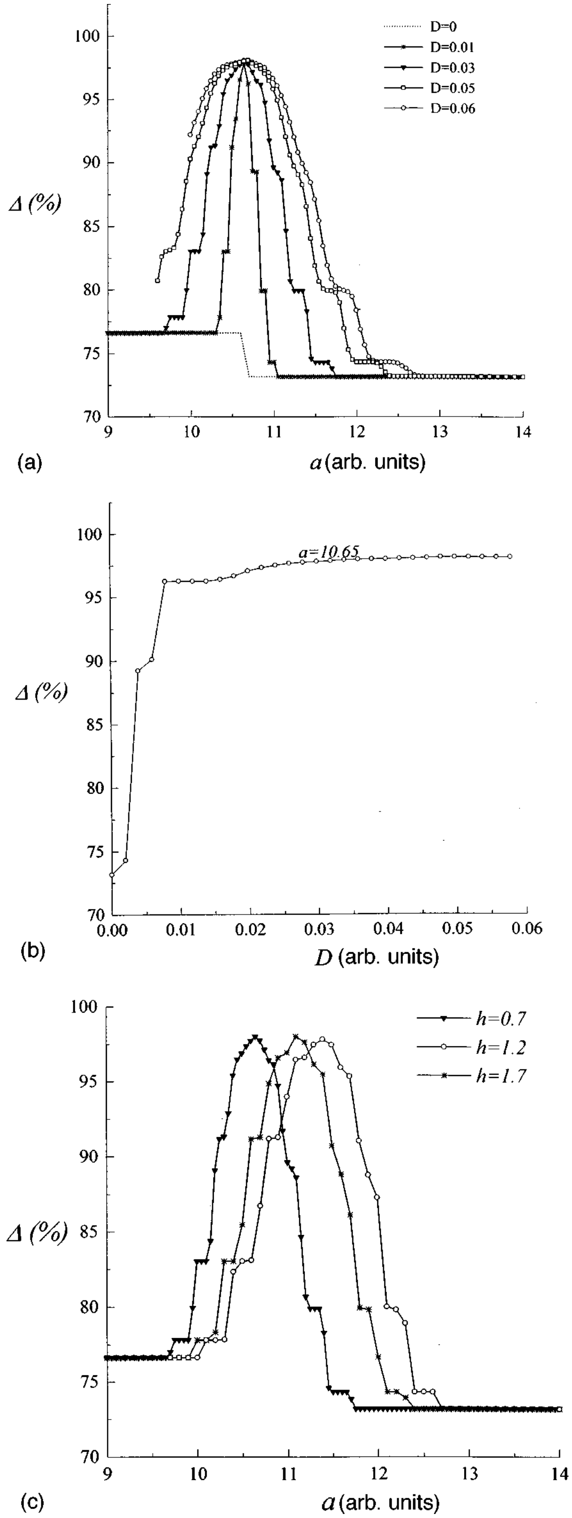

FIG. 4. Quality function $\Delta[\%]$ for pattern replication in a two-layer system. (a) Dependence of Δ on the excitability parameter a for $h=0.7$. Different curves correspond to different fixed values of the intralattice diffusion D. (b) Evolution of the peak value of Δ at $a=10.65$ with increasing D. (c) Shift of the ''resonance'' quality with the parameter h. Units are arbitrary.

rather significant distortions either in its core (black part of the pattern) or in its background (white part). The behavior of Δ for different values of $D\neq 0$ is shown in Fig. 4(a). Each curve has an apparent maximum at $a\approx 10.65$. This maximum appears not instantly albeit very rapidly when increasing the intralayer diffusion D. For that value of a, the dependence of Δ on D is shown in Fig. 4(b). Note, that the quality factor at the maximum point is very high ($\Delta\approx 98\%$). The replicated image is shown in Figs. 2(c) and 2(d). It looks very much like the original. Values of a on either side of the maximum result in the appearance of some distortions of the copies either in the core of the image or in its background.

It follows that the role of rather small but nonzero D is significant. The system, in fact, acquires a kind of *selectivity* property. Actually, the curve of replication quality for $D\neq 0$ looks very much like a resonance curve in frequency selection systems. But in our case we have to do with a specific kind of spatial selection. It can be called a *synergetic image selection* when the system replicates any regular spatial image independently of its concrete structural context. For instance, with nearly the same quality the system will process an image of a man's face or a form of capital letters [11]. Note, that our synergetic resonance has nothing to do with the time behavior (frequencies) of the local units. It deals only with the steady amplitude patterns which can be described in terms of system (2) and have no oscillatory dynamics [3,4].

Figure 4(c) shows how changing the strength of the interlayer interaction h results in the shift of the resonance peak corresponding to the highest replication quality. The three curves are calculated for a fixed value of D and for three different values of h.

3. Replication as pattern competition

Dynamically, the replication process is a competition of corresponding pairs of oscillators taken independently from cells of the two layers. Since the intralayer diffusion D must be in the region D_{ch} (to have the wealth of steady patterns in a layer) it takes very small values. Therefore, approximately (at zero order of perturbation theory, $D=0$) the process of pattern interaction is given by a two-dimensional dynamical system describing a strongly coupled pair of bistable oscillators

$$\dot{r}=-rF(r)-h(r-\rho),$$

$$\dot{\rho}=-\rho F(\rho)+h(r-\rho), \qquad (4)$$

where r is the amplitude of the oscillator from the first layer and ρ that of the corresponding oscillator from the second layer. For strongly coupled layers, $h\gg 1$, the system has three fixed points, two stable nodes and a saddle. The two nodes correspond to the synchronous states of the lattices, i.e., either both oscillators are excited or they are at rest. The incoming separatrices of the saddle divide their basins of attraction. Then, the replication process appears as a competition of the two accessible states. The initial conditions for the competition are determined by the intralayer diffusion D acting on the two initial steady patterns [11]. It appears that in this competition the (rest or excited) state of a cell from the regular stimulus has advantage relative to the state of the corresponding unit from the disordered layer. At the maximum of the quality function [Fig. 4(a)] this dominance of regular cells occurs for about $\Delta\approx 98\%$ of the competing pairs. Hence, the regular stimulus acts as an order

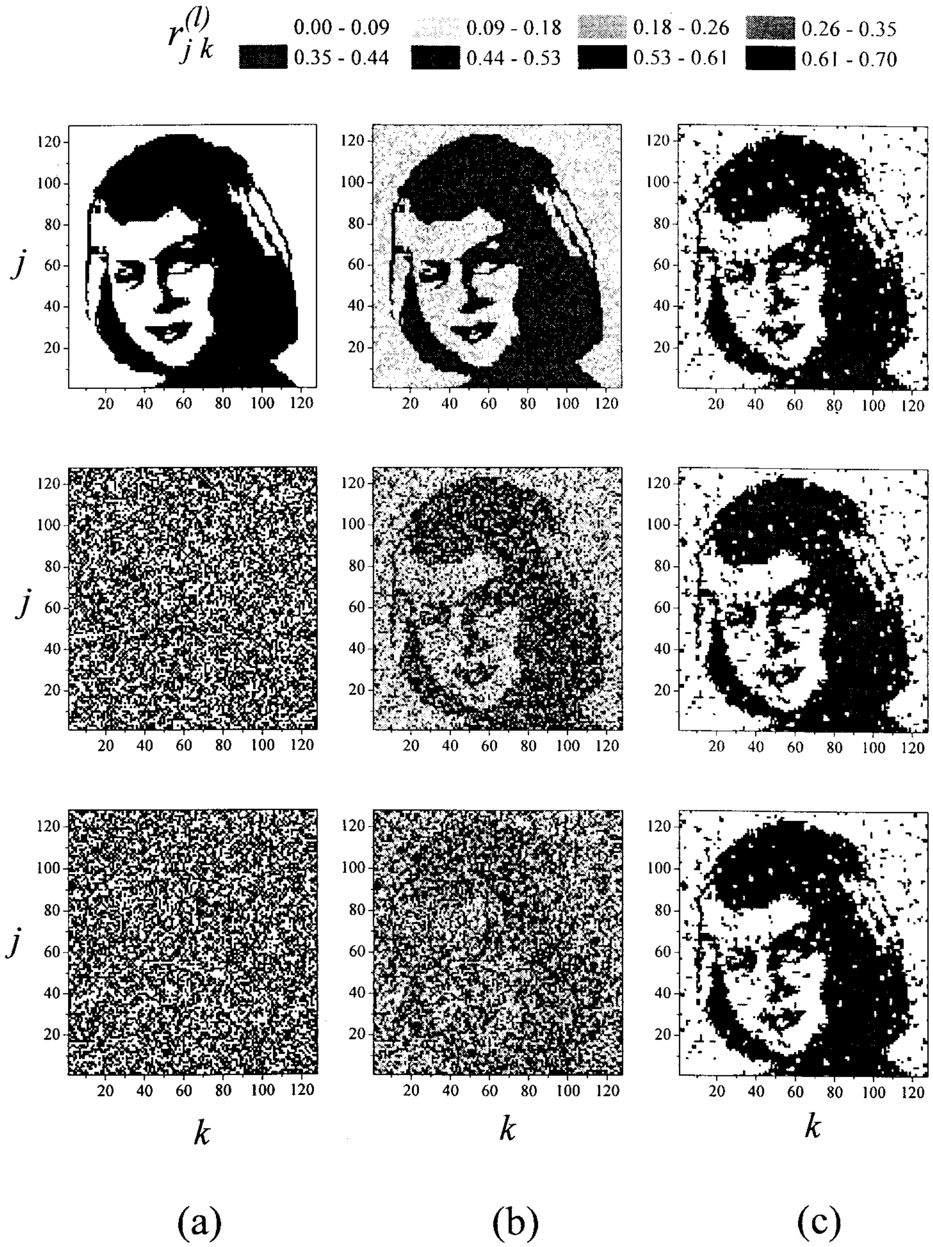

FIG. 5. Image transfer by replication in a three-layer architecture or anatomy. (a) Initial, structured and structureless, amplitude patterns in the layers before the interaction is switched on. (b) A snapshot of the layers after $t \approx 2$ time units. (c) Synchronized copies of the original stimulus. Parameter values: $a = 10.6$, $D = 0.06$, $h = 0.7$.

parameter and enslaves the disordered pattern [3,4]. Accordingly, almost all cells of the second layer change their original states to be able to copy the ''template'' from the first layer.

B. Image transfer in multilayer assemblies

1. One original leading to many copies

Let us consider now the multilayer system composed of three lattice layers ($M = 3$). Similarly to the case of $M = 2$ when $h = 0$ the first layer contains the original black and white image of the lady's face encoded as a steady amplitude pattern. The other two layers are in spatially chaotic, ''pure'' states given by two different disordered patterns. The column (a) in Fig. 5 illustrates the initial states of the three layers in $\{\mathbf{Z}^2, \mathbf{R}\}$ space. As for the two-layer system a strong enough interlayer interaction, $h > h^*$, leads to the mutually synchronized steady patterns. Figure 5(b) shows the snapshot of the layers at some instant of time during the interaction and Fig. 5(c) the terminal, synchronized patterns. We obtain three self-replicated patterns which are faithful copies of the original image.

2. Replication as a process of image transfer

Let us analyze the replication process in the three-layer architecture or anatomy as a competition of the states of three interacting oscillators each one taken at the same relative site (j,k). The approximate system describing the ampli-

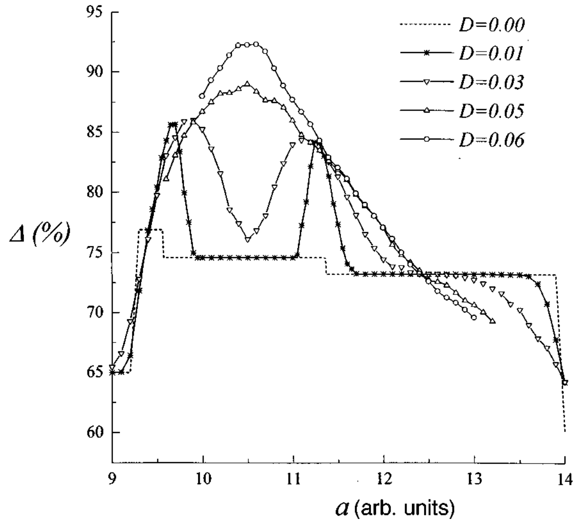

FIG. 6. Replication quality Δ[%] as a function of parameter a for fixed $h=0.7$ and different values of D in a three-layer image transferring system. Units are arbitrary.

tudes of three strongly coupled oscillators ($h>h^*$) is of third order. The analysis of this system which would allow us to predict the ''winning'' and ''slaved'' units in this competition is very difficult and represents a separate problem. We rather consider the replication in multilayer systems from another point of view.

Note that the replicated images in the second and the third layers do not appear simultaneously, but rather sequentially [see column (b) in Fig. 5]. As we are using nearest-neighbors interaction, first the lady's face appears in the layer nearest to the stimulus and after that in the next one. Therefore, the replication process can be considered approximately as a sequence of independent acts of image transfer from layer to layer. As the connection between the layers is of diffusive type (1), the process of appearance of the image in the disordered layers looks like image diffusion in the direction of the ''space coordinate'' l in a real three-dimensional space. Each ''act'' of transfer represents the image replication in two interacting lattices and has been described in Sec. III A 1. It is clear that distortions or misprints of ''self-transferred'' images will accumulate during the multiple acts of the replication process with foreseen quality losses in the terminal pattern relative to the original figure (see Fig. 5).

3. Quality of a transferred image in the multilayered architecture or anatomy

To find the conditions of best quality of image transferring in the three-layer system we analyze the replication quality function Δ[%] (Sec. III A 2). Figure 6 shows the dependence of Δ[%] on the parameter of excitability a. The curves are calculated for fixed parameter h and for different values of the intralattice diffusion D. Analogously to Fig. 4(a) the curves represent ''resonance'' characteristics of the three-layer architecture or anatomy as a synergetic image transfer system. The behavior of the curves looks rather different to that obtained for the two-layer system. First, for smaller values of D the function has two maxima (''peaks'') corresponding to nearly the same quality (about 85%) of the copies. However, the distortions or misprints in the replication are quite different for the two ''peaks.'' The transferred images for the two values of a are shown in Figs. 7(a) and 7(b) and the distortions appear either in the core or in the background of the image. Figures 7(c) and 7(d) illustrate the distortions of a transferred image for fixed a and different values of D. With increasing values of D the two maxima ''merge'' into one of higher value (see Fig. 6). Comparing the curve for $D=0.06$ with the corresponding one from Fig. 4(a) we find that the maximum value of Δ becomes lower for the three-layer system but it stays rather high (about 93%) hence providing a faithful transfer of the stimulus (see Fig. 5).

IV. SPATIAL RESOLUTION OF THE IMAGE REPLICATING SYSTEM AND FIDELITY

A warning should now be given. In the replication process discussed here the characteristic spatial scale of the input image relative to the lattice constant is crucial for achieving an acceptable quality. For instance, let us, for illustration, consider a system with just two layers and take as the input image given to one of them the chessboard of Fig. 8(a) the spatial scale of which is δ. Then, decreasing δ, the replication quality factor $\Delta(\delta)$ shows that below a certain value δ_c the replication process fatally fails and the original chess-

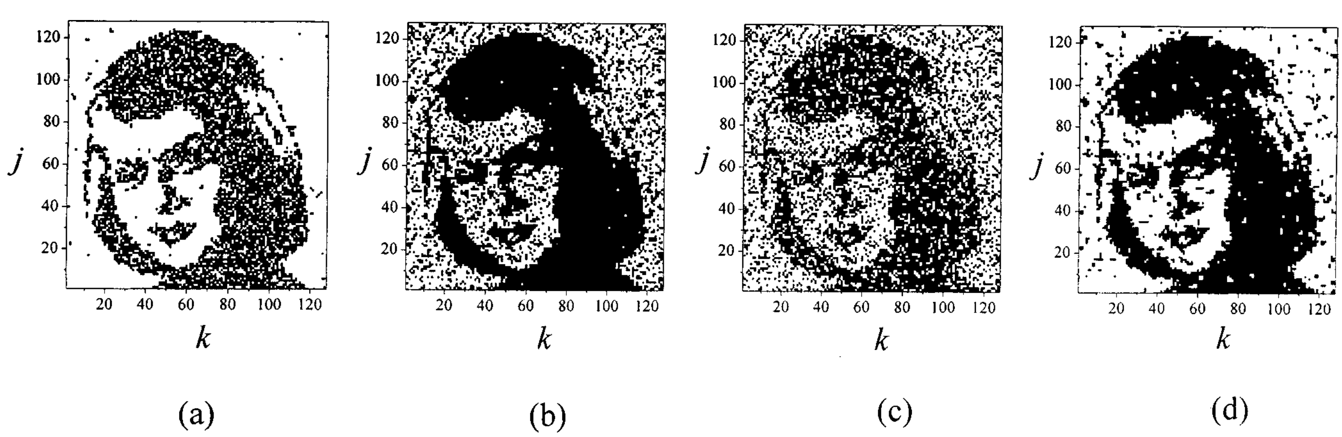

FIG. 7. Distorted copies of the stimulus replicated in a three-layer architecture or anatomy for different points of the ''resonance'' curves of Fig. 4(a) obtained for fixed $h=0.7$. (a) $a=9.85$, $D=0.03$, (b) $a=11.15$, $D=0.03$, (c) $a=10.6$, $D=0.03$, (d) $a=10.6$, $D=0.06$.

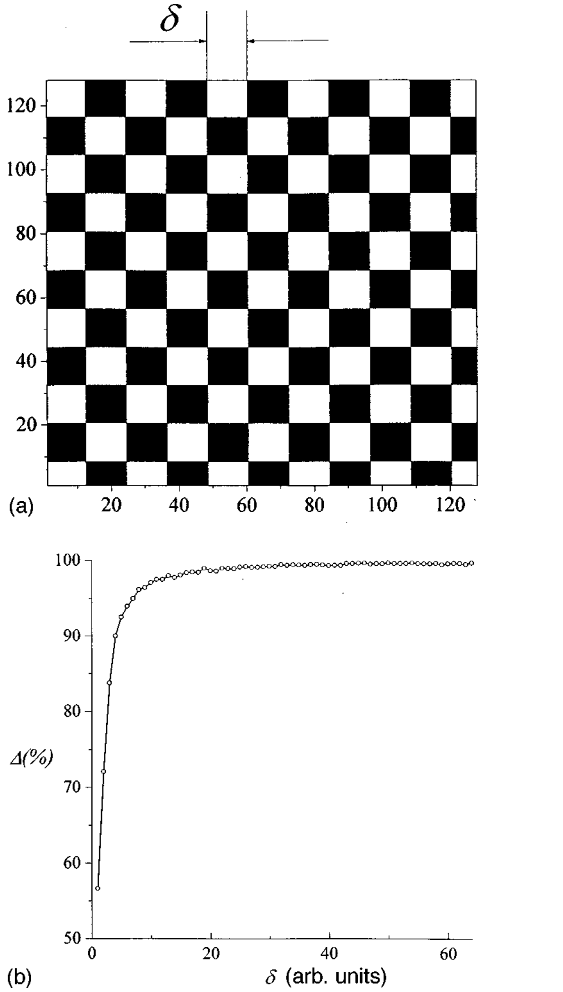

FIG. 8. (a) Pattern used to test the spatial resolution of the image reaplication system. (b) Dependence of the replication quality on the relative characteristic spatial scale of the test image δ, $a=10.6$, $D=0.06$, $h=0.7$. Units are arbitrary.

board fades way. In the particular case considered, $\delta_c=6\div 10$ units [Fig. 8(b)]. It is the spatial resolution of the replicating system. Thus, those features of the input image whose characteristic spatial scale is below δ_c cannot be replicated with acceptable degree of quality $[\Delta \geqslant \Delta(\delta_c)]$.

V. STABILITY OF THE IMAGE REPLICATION PROCESS TO NOISY DISTURBANCES

Let us now consider the influence of external random fluctuations to the dynamic replication of images in the multilayer system. Let us assume that each unit is independently perturbed by a weak external noise. Since the replication process deals with only amplitude distributions of oscillators synchronized in phase we introduce the noise only in the amplitude equations (2),

$$\dot{r}_{j,k}^{(l)}=f(r_{j,k}^{(l)})+d(\Delta r)_{j,k}^{(l)})+h(r_{j,k}^{(l+1)}+r_{j,k}^{(l-1)}-2r_{j,k}^{(l)})+\xi_{j,k}^{(l)}(t), \tag{5}$$

where $\xi_{j,k}^{(l)}(t)$ is a ''white'' Gaussian noise with zero mean value and variance σ^2,

$$\langle \xi_{j,k}^{(l)}(t)\rangle=0, \quad \langle \xi_{j,k}^{(l)}(t)^2\rangle=\sigma^2,$$

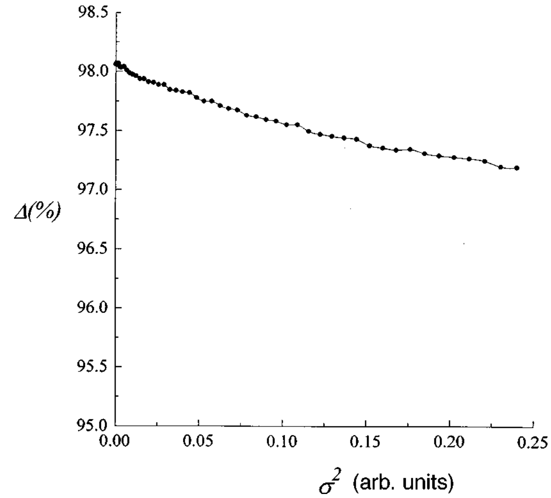

FIG. 9. Dependence of replication quality factor Δ[%] on the variance of a Gaussian noise σ^2 for a two-layer system forced with noise. The parameter values and the initial conditions coincide with the values used in the noise-free case shown in Fig. 2. Units are arbitrary.

$$\langle \xi_{j,k}^{(l)}(0)\xi_{j',k'}^{(l')}(t)\rangle=\delta_{jj'}\delta_{kk'}\delta_{ll'}\delta(0).$$

For simplicity, we only consider a two-layer architecture or anatomy. The parameters and initial amplitude distributions are the same as in Fig. 2 corresponding to a deterministic case. It appears that in the presence of weak noise the initial stimulus (the lady's face) is still replicated faithfully in the spatially disordered second layer (Fig. 2). Figure 9 illustrates the dependence of the replication quality factor Δ on the noise variance σ^2. Increasing the noise intensity to $\sigma^2=0.25$ the value of Δ goes down only by 1% relative to the deterministic case.

VI. CONCLUSION

We have shown how dynamic replication of images can be achieved with a controllable degree of fidelity in a multilayer architecture or anatomy of diffusively coupled *bistable* oscillators. Each layer forms and preserves black and white images or two-level encoded forms or functions as two-dimensional steady patterns of amplitudes of coherent, in-phase oscillations. Spatially chaotic, disordered patterns are used as ''raw'' frames capable to be ''filled'' according to the form of any stimulus.

We have shown that with appropriate interlayer interaction the system in the process of its evolution can replicate in multiple copies an original image imposed as a stimulus in one of its layers. Thus, the multilayer architecture or anatomy shows cloninglike properties, as it is capable of repeating many times at least the key features of an original. The misprints of replicated images arising as the result of pattern competition can be treated as some additional ''degrees of freedom'' in the copying system. Then, the distorted copies may acquire new (useful) features, new information appearing, for example, from the accumulation of misprints in multiple acts of image replication or as the result of specific action of some fluctuations.

Studying the replication phenomenon we have found that it can be considered as a process of image transfer (image diffusion) from layer to layer inside the multilayered structure. The quality of the transferred image given by the replication quality function Δ has a ''resonance'' character. The system possesses somewhat image (synergetic) selectivity. The high quality of transferring occurs only for specific values of the parameter a responsible for the ''excitability'' of the units. Taking the difference signal between the input stimulus and the self-replicated image we have illustrated that processes in layered lattices provide an efficient information compression.

In summary, we note that although the multilayer lattice model discussed here is very simple, yet the properties of bistability of the unit, element, or cell, in each lattice with a state of rest and oscillatory state, and the diffusive coupling between the cells, suffice for a faithful replication process. More complex dynamics of a unit and/or more sophisticated intralayer and interlayer interactions can indeed be used to further upgrade the results reported here.

ACKNOWLEDGMENTS

The authors have benefited from fruitful discussions with Professors H. Haken, G. Nicolis, R. Llinas, A. Fdez de Molina, L. O. Chua, and F. Werblin. This research has been supported by the BCH Foundation (Spain), by the Russian Foundation for Basic Research under Grant No. 97-02-16550, by the program ''Soros Post Graduate Students'' under Grant No. a97-853 (Russia), by NATO under Grant No. OUTR LG96-578, by the EU under Network Grant No. 96-10, and by DGICYT (Spain) under Grant No. PB96-599. V.I.N. would like to thank the Ministry of Education and Culture of Spain for financial support.

[1] F. Crick, *Life Itself. Its Origin and Nature* (Simon and Shuster, New York, 1981).
[2] G. Nicolis and I. Prigogine, *Self-Organization in Non-Equilibrium Systems* (Wiley, New York, 1977).
[3] H. Haken, *Synergetics*, 3rd ed. (Springer-Verlag, Berlin, 1983).
[4] H. Haken, *Principles of Brain Functioning* (Springer-Verlag, Berlin, 1996).
[5] *Evolution from Molecules to Men*, edited by D. S. Bendall (Cambridge University Press, Cambridge, 1983).
[6] P. C. Bressloff, Physica D **110**, 195 (1997).
[7] P. C. Bressloff, Phys. Rev. Lett. **75**, 962 (1995).
[8] R. S. MacKay and J.-A. Sepulchre, Physica D **82**, 243 (1996).
[9] M. G. Velarde, V. I. Nekorkin, V. B. Kazantsev, and J. Ross, Proc. Natl. Acad. Sci. USA **94**, 5024 (1997).
[10] V. I. Nekorkin, V. B. Kazantsev, M. I. Rabinovich, and M. G. Velarde, Phys. Rev. E **57**, 3344 (1998).
[11] R. Linsker, Annu. Rev. Neurosci. **13**, 257 (1990).
[12] R. D. Traub and R. Miles, *Neural Networks in the Hippocampus*, appendix by L. S. Schulman (Cambridge University Press, Cambridge, 1991).
[13] W. J. Freeman, *Mass Action in the Nervous System* (Academic, New York, 1975).
[14] C. von del Malsburg and W. Schneider, Biol. Cybern. **54**, 29 (1986).
[15] S. V. Chakravarthy and J. Ghosh, Biol. Cybern. **75**, 229 (1996).
[16] V. I. Nekorkin and V. A. Makarov, Phys. Rev. Lett. **74**, 4819 (1995).
[17] V. I. Nekorkin, V. A. Makarov, V. B. Kazantsev, and M. G. Velarde, Physica D **100**, 330 (1997).