# A Neural Network Filter For Complex Spatio-Temporal Patterns*

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**Abstract—This paper proposes a four-layer neural network filter for complex spatio-temporal pat-** [redacted] **temporal pattern, it can be constructed according to the order of the spatio-temporal pattern. Moreover, it is demonstrated by the simulation results.**

## I. INTRODUCTION

Filtering and recognition of spatio-temporal pat- [redacted]

temporal correlator network is proposed to solve the problem of spatio-temporal pattern learning, recogni- [redacted] on a Kohonen's self-organizing map and a fuzzy ART network. However, the number of the processing neurons in some layer varies with the complexity of spatio-temporal patterns, which makes difficult to implement the network.

In this paper, we propose a neural network based filter for any given complex spatio-temporal pattern [redacted]

$\mathcal{S}^c = P_1, \cdots, P_{m_0} P_1$. And $m_0$ is called the length of the spatio-temporal cycle.

**Definition 2.** *When a spatio-temporal pattern $\mathcal{S}$ is not periodic, the order of $\mathcal{S}$ is defined by*

$$\begin{aligned} r(\mathcal{S}) &= min\{k : P_i P_{i+1} \cdots P_{i+k-1} \neq P_j P_{j+1} \cdots P_{j+k-1} \\ &\quad for \;\; all \;\; i, j \leq m-k+1, and \;\; i \neq j.\} \end{aligned} \quad (1)$$

Clearly, the order of $\mathcal{S}$ is the minimum of the number $k$ which enable all the possible $k$-step blocks in $\mathcal{S}$ are different. Surely, it is a positive integer in the range $[1, m]$. For clarity, $r(\mathcal{S})$-step blocks of $\mathcal{S}$ are called basic blocks of $\mathcal{S}$. When the order of $\mathcal{S}$ is just one, it is called a simple spatio-temporal pattern. In this case, all the spatial patterns are different. When the order of $\mathcal{S}$ is larger than one, it is called a complex spatio-

The proof will be given in [11].

According to Theorem 1, we certainly have that the map from $\mathcal{S}$ to $\mathcal{B}_\mathcal{S}$ is one to one in the cases of both complex spatio-temporal pattern and cycle. That is, $\mathcal{B}_\mathcal{S}$ uniquely corresponds to its true spatio-temporal pattern or cycle when $\mathcal{S}$ is complex. Thus, a complex spatio-temporal pattern or cycle can be recognized from its basic blocks. We will use this idea to design the neural network spatio-temporal filter.

## III. THE NEURAL NETWORK SPATIO-TEMPORAL FILTER

Suppose that $\mathcal{S}$ is a given complex spatio-temporal pattern of finite length (i.e., $m$ is finite) or a given complex spatio-temporal cycle and its order is $k(> 1)$.

a fixed $n$-dim binary pattern, we define

$$d_H(X,C) = \sum_{i=1}^{n} |x_i - c_i| \tag{4}$$

[illegible]

as the Hamming distance between $X$ and [illegible] then

[illegible]

define the $t$-neighborhood of $C$ over the $n$-dim binary space $\{0,1\}^n$ as follows:

$$R_t(C) = \{X : d_H(X,C) \le t\}. \tag{5}$$

The definition of the perceptive neuron is given as follows.

**Definition 1** *If a binary neuron with a fixed weight* [illegible]

[illegible]

*value $\theta$, satisfies the following input-output relation:*

$$y(X) = Sgn(\sum_{i=1}^{n} w_i x_i - \theta) = \begin{cases} 1 & \text{if } X \in R_t(C) \\ [illegible] \end{cases} \tag{6}$$

*it is called a $t$-neighborhood perceptive neuron of (pattern) $C$.*

For a binary neuron, we can consider that it per-

otherwise, the neuron is inhibited and we consider the input pattern cannot be recognized as $SP_i$. $\varepsilon$ is selected according to the noise environment.

When the input pattern $X$ and the spatial pattern [illegible]

[illegible]

second order binary neuron, called matching neuron.

[illegible]

Actually, a second order binary neuron is defined by $\mathbf{W}$ which is an $(n+1)$-order real symmetric matrix. For an input signal pattern $X$, the output signal $y$ of the second order binary neuron is computed by

$$y = Sgn(H(x)) = \begin{cases} 1 & \text{if } H(x) > 0 \\ 0 & \text{otherwise} \end{cases} \tag{9}$$

[illegible]

$$H(X) = \sum_{i,j=0}^{n} w_{ij} x_i x_j, \qquad x_0 = 1.$$

[illegible]

Then, a matching neuron of the spatial pattern $SP_i$ is defined by such a second order binary neuron that

$$\begin{cases} -1 & \text{if } l = j, \\ [illegible] \end{cases}$$

At each time with an input pattern, if some $U_{j_l}$ is activated, it sends a signal to the receiving box where [illegible]

[illegible]

the first left block of the shift register. Otherwise, the [illegible]

[illegible]

i.e., it has sent one or more positive signals to the output neuron, its contribution to the output neuron is [illegible]

[illegible]

all the signals in the $m$ times, the output neuron will [illegible]

[illegible]

$k$-step blocks. The errors can be filtered by the output neuron if the threshold value is properly selected. Therefore, the neural network filter can recognize $\mathcal{S}$ in a noisy environment.

We further consider the case that $\mathcal{S}$ is a spatio-temporal cycle, i.e., $\mathcal{S} = P_1 \cdots P_{m_0} P_1$. In this situation, we design the neural network spatio-temporal filter as for the spatio-temporal pattern $\mathcal{S}' = P_1 \cdots P_{m_0} P_1 \cdots P_{k-1}$, i.e., $m = m_0 + k - 1$. Clearly, when the input spatio-temporal cycle enters the neural network spatio-temporal filter in such a way as $\mathcal{S}'$, we have the same result as above. Moreover, since the output neurons all check whether all or most of the basic

[illegible]

period of $m$ times and there is not any other require-

[illegible]

of the real number $x$). For a filtering or recognition system, only when the radius of the error-correcting hypersphere of each $S_i$ is just $t_i^*$, the error probability of recognition reaches the minimum in a noisy environment.

Based on the Hamming distances between these sample patterns, we have

$$(t_1^*, t_2^*, t_3^*, t_4^*, t_5^*, t_6^*, t_7^*, t_8^*, t_9^*, t_10^*)$$
$$= (3, 6, 5, 4, 9, 4, 5, 8, 3, 4).$$

Then, we can design the binary neuron $U_i$ in the second layer of the neural network filter as the $t_i^*$-

[illegible]

Theorem 2.

[illegible]

[2] C. Staneley and W.L. Kilmer, "A wave model of temporal sequence learning," *Int. J. Man-Machine Study*,