Spatial Formal Immune Network

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Abstract. A notion of Spatial Formal Immune Network is proposed for pattern recognition applications.

In our previous works [4], [6], we have proposed a rigorous mathematical notion of Formal Immune Network (FIN) inspired by N. Jerne's network theory of the immune system [3]. That FIN has been introduced as Integer valued (IFIN), where B-cells are coded by integers and formed ordered sequences (populations). Such IFIN provides a discrete mathematical model of immune response, which properties described by a row of theorems. However, IFIN is insufficient for real-world applications with multi-dimensional and real valued data, like those in surveillance of the natural plague or information security.

The present work makes an attempt to solve the above problem by introducing Spatial FIN (SFIN) as an expanded FIN for pattern recognition applications.

Define SFIN as a tuple

$$SFIN = < R^N, m, w, \Delta h, B\text{-}cells >,$$

where

$$B\text{-}cell = <S, P>,$$

R^N is N-dimensional Euclidean space considered as the *shape space* of SFIN, according to [1];

$P \in R^N$ is N-dimensional vector (point of the shape space) considered as the Formal Protein (FP) as well as the *receptor* of the B-cell (see, e.g., [6]);

m is the number of the nearest neighbors of any B-cell;

w is the Euclidean distance considered as the *binding energy* between FPs:

$$w: R^N \times R^N \to R^1, w_{ij} = |P_i - P_j|;$$

h is real valued *mutation step*: $h \in R^1$;

S is the state indicator of B-cell: $S = \{ltm, stm, del\}$, where *ltm* is long-term (memory) cell, *stm* is short-term (memory) cell, and *del* is deleted cell.

The behavior of the SFIN is determined by the following rules.

All B-cells update their states simultaneously in a discrete time $t = 0,1,2, \ldots$.

Let $\{B_i\}$ is current set (*population*) of B-cells: $S_i \neq del$, $i = 1,\ldots,n$.

Any B-cell B_i has no more than m nearest neighbors, which correspond to the m nearest points in the shape space (rule B_neighbor).

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Any B-cells B_i, B_j are *close* if $w_{ij}<h$.

Any B-cell B_i updates its state as follows.

Short-term cell B_j becomes deleted if it is close to any long-term cell B_i (rule B_delete).

In case of the deletion, consider that long-term cell B_i *recognizes* short-term cell B_j.

Short-term cell makes m copies (*proliferates*) by the mutation step to the directions of the nearest neighbors if it isn't close to any cell (rule B_prolif).

Short-term cell becomes long-term cell if it is close to any short-term cell but isn't close to any long-term cell (rule B_interf).

Long-term cell *drifts* by the mutation step to the direction of the nearest long-term cell if the cells are close (rule B_drift).

Two long-term cells B_i , B_j *fuse* if they are identical (rule B_fusion).

If any new FP (*antigen*) P_A intrudes to the SFIN, then new short-term cell (*antigen presenting cell*) appears, which expose the intruder as the receptor (rule A_pres).

The following conclusions can be done based on simple theoretical examples of immune response of SFIN, as well as on the applications of SFIN to predict risk of the plague infection and to detect intrusions in computer networks.

SFIN differs essentially from immune algorithms proposed by [2]. The algorithms represent special case of genetic algorithms, because immune cells are coded by bit strings and mutate by random rules. Unlike these features, cells of SFIN are coded by real-valued vectors and their behavior is deterministic.

Actually, SFIN represents a modification of hybrid cellular automata, which have been applied successfully to the modeling of rather complex dynamical process [5].

References

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