Algorytmy immunologiczne

Dr inż. Michał Bereta
p. 144 / 10, Instytut Informatyki
mbereta@pk.edu.pl
beretam@torus.uck.pk.edu.pl
www.michalbereta.pl
Applications of AIS
Artificial Immune Systems

- Theoretical immunology:
  - Modelling the dynamics of the immune system
  - Immune network theory
  - Danger theory
- Anomaly detection
- Optimization
- Computer network security
- Agnet based systems
- Clustering, data analysis
- Supervised learning and multi-class classification
Artificial Immune Systems

• AIS – not only for optimization
• The primary goal of the immune system is to recognize the threat (pathogens, fungi, etc.)
• Classifier construction can be perceived as an optimization process.
• What should be optimized:
  – Error on training data?
  – Complexity of the classifier?
  – Margin?
  – All of the above? (multi-objective optimization)
Artificial Immune Systems

Recognition

Self structures (no danger) Pathogen (Danger!)

Two – class classification.
(Most of the Negative Selection based algorithms)

Applications:
• Anomaly detection
• Change detection
• Novelty detection
• Network security
Immune System

- Innate
- Adaptive

B lymphocytes
T lymphocytes

- Many Different Cells
- Complicated
- Distributed
- Ability to learn
- Ability to generalize
- Immune memory
Cells of the immune system

There are many different types of immune cells that cooperate with each other.
Lymphocytes

Due to the lymphocytes’ evolution, the immune system has the ability:
• to learn to recognize new pathogens
• to remember
• to adapt itself
• to regulate itself
The antibody on the molecular level
Antigen – Antibody Binding
Binary representation

1 0 0 1 0 1 0 1 0 0 0 1 1 1  \text{antigen}

1 0 1 1 0 1 0 1 1 1 0 0 1 1  \text{B-cell (T-cell)}

\underline{Stimulation level}

1 0 0 1 0 1 0 1 0 1 1 1 0 0 1 1 1
1 0 1 1 0 1 0 1 0 1 1 1 1 1 1 1 1

1 0 0 1 0 1 0 1 0 1 1 1 0 0 1 1 1
1 0 1 1 0 1 0 1 1 1 1 1 0 1 1 1

\underline{Hamming distance}

1 0 0 1 0 1 0 1 0 1 1 1 0 0 1 1 1
1 0 1 1 0 1 0 1 0 1 1 1 1 1 1 1

1 0 0 1 0 1 0 1 0 1 1 1 0 0 1 1 1
1 0 1 1 0 1 0 1 1 1 1 1 0 1 1 1

\underline{The longest common substring}
Real-valued representation

Example in 2D:

Antigen

[0.53, 0.47]

Lymphocyte (T-cell)

\{\text{Center} = [0.7, 0.65], \text{radius} = 0.2\}

Unrecognized antigen

Bound (recognized) antigen

Lymphocyte centre

Radius

Unrecognized antigen
Evolution of B-cells

They are created in the bone marrow by means of rearranging genes from special libraries.
Evolution of B-cells

During the circulation through the body, the activated cells proliferate and are mutated (hyper-mutation).

The cells, that are not activated, undergo apoptosis (cell death).

They are not usefull.
Clonal Selection

As the result of the process (clonal selection), cells, that are strongly specific for the given antigen, are created.
Suppression:
- interactions among the B-cells
- useless cells are eliminated
Clonal Selection

Suppression:
- important feature of clonal selection algorithm
- different meaning of “useless” (“usefulness”)

Until termination condition is satisfied

START

Randomly generate an initial population

Check the stimulation level of each B-cell

Create clones according to the stimulation level

Mutate clones at very high rate (somatic hypermutation)

Remove useless B-cells

SUPPRESSION
Negative Selection Algorithms

Training stage

1. Generate detector (candidate T-cell)
2. Recognizes any self sample?
   - Yes
   - No
      - Add candidate to the population
   - No
      - Enough detectors?
        - Yes
          - End
        - No
3. No

Detection stage

4. Acquire new sample
5. Bound by any detector (T-cell)?
   - Yes
     - Anomaly
   - No
     - Self (Normal)
B-lymphocytes bind directly to the surfaces of the pathogens’ cells.

T-lymphocytes bind to the pieces of MHC molecular chains presented by every cell.
Humoral response

B-cells cannot act on their own.

T-cells regulate the behaviour of B-cells by means of cytokines.
Cooperation of B-cells and T-cells

B-cells are not allowed to secrete antibodies until they receive a costimulation from the T-cells.

Only those B-cells that react properly are allowed to evolve.
Conclusion

1. B-cells and T-cells undergo different kind of evolution, as they have different tasks.

2. B-cells and T-cells cooperate.
Conclusion

1. In the most AIS clonal selection and negative selection have been used separately.

2. Immune system, although it inspired many algorithmic solutions, is a recognition system.
Artificial Immune Systems

- B lymphocytes
  - Clonal Selection Algorithms
  - Immune Network Theory

- T lymphocytes
  - Negative Selection Algorithms

"computational system based upon metaphors of the natural immune system"

"intelligent methodologies inspired by the immune system toward real-world problem solving"

"adaptive systems, inspired by theoretical immunology and observed immune functions, principles and models, which are applied to problem solving"
AIS vs. Neural Networks

1. The immune system is complementary to the nervous system in perceiving the world.

2. The immune system perceive the world on the molecular level.

3. There is only one type of the nervous cell – neuron.

4. There is variety of types of immune cells.

5. The complexity of the interactions among different types of immune cells is enormous.
AIS vs. Neural Networks

Basic unit

Neuron
Each neuron has about $7,000$ synaptic connections.

Lymphocytes (T, B, etc.): each has about $100,000$ receptors.

How many?

$10^{10} - 10^{11}$ neurons

$10^{12}$ lymphocytes only

Task

Pattern recognition, memory, consciousness

Recognition on the molecular level and protection against the threat
AIS vs. Neural Networks

Memory
- Synaptic connections
- Memory cells, Idiotypic networks, ????

Localization
- Localized.
- Distributed
- Brain – central organ
- No central organ.

Communication
- Electrical signals
- Direct
- Cytokines, ????
AIS vs. GA

1. AIS are similar to GA

2. In both, AIS and GA, there is evolution.

3. The cells in the immune system have to cooperate to protect the host.

AG  →  COMPETITION (Michigan and Pittsburgh approaches)

AIS  →  COOPERATION
Challenges in classification tasks

• Enourmous amount of data
  – Impossible to use all during classifier learning
  – Which examples should be selected?

• Very big number of attributes
  – Which attributes are important?
  – What are the relations among the features?

• Many others:
  – Model selection
  – Classifier evaluation, etc.
Clonal Selection

Application areas:
• optimization
• data analysis
• clustering
• classification

There are few clonal selection algorithms for classification problems formulated as supervised learning algorithms (e.g. Watkins' AIRS (2001), Carter (2000))
CS for classification

The clonal selection paradigms has much to offer while constructing supervised learning algorithms.

Natural Selection (e.g. Genetic Alg.)

COMPETITION

Immune System (Clonal Selection)

COOPERATION and COMPETITION
Cooperation in AIS

Cells of the immune system have to cooperate to protect the host.

None of the particular type of lymphocyte can protect the host against all types of pathogens.

Lymphocytes (and other cells) compete for resources. Cells more useful are sustained.
Suppression based on “usefulness”

Expectations and benefits:

Adaptation of the population size, i.e., for simple problems – small populations, for more difficult ones – bigger populations.

No need to estimate the “resources” available for the population (as in other CS algorithms).
AG in classification tasks

- The base classifier (e.g., neural network) has to be trained for each chromosome in the population
- One chromosome encodes the solution
- In the proposed immune algorithms – the whole population is the solution.
Pittsburgh vs Michigan

**Pittsburgh** – each individual in population describes a potential solution.

**Michigan** – the whole population describes the solution.
Examples