Metodi e tecniche di ottimizzazione innovative per applicazioni elettromagnetiche

Algoritmi stocastici

Parte 3 Artificial Immune Systems

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Introduction

Why Immune System can be interesting for optimization/information processing?

- it is made by distributed agents with low centralized processing
- agents can recognize information in associative and incomplete way
- they can manage, with scarce resources, an overwhelming variety of scenarios
- they have good dynamic properties but conserve memory of the past
"bodywide network of organs and cells evolved to defend the body against attacks by foreign intruders"

- body defenses are of two types:
  - passive barriers (skin, pH, temperature ...)
  - active agents which figth pathogens (bacteria, fungi, parasites, viruses ...) when they enter the body

- from the viewpoint of information processing these last organs are interesting
active part of Immune System can be subdivided also in:

- innate: cells whose behaviour is not changing through the individual life
- acquired: network of cells and molecules which are adaptively modified during the lifetime

the rules governing the evolution of this acquired part can be seen as a micro-evolution inside the organism and can be used as inspiration for algorithm development
nucleus of acquired system
IS: Self/Nonself (1/3)

- Immune System must fight against external agent *nonself*
- Immune System must be tolerant with body cells *self*
- in human body there are about $10^6$ self-pattern (proteins)
- Immune System must be able to recognize $10^{16}$ external patterns
- resources are scarce and must be used in a flexible way to cope with external enemies
  - dynamic (lymphocytes are short lived and $10^8$ new cells are produced every day)
  - approximate (recognition of similarity sub-patterns)
All molecules carry distinctive markers of characteristic shapes (epitope) that protrude from their surface.

Each individual has his own specific characteristic (transplant).

**Definition**

- **Antigen (Ag):** any substance capable of triggering an immune response.
- **Antibody (Ab):** molecule that can match and counteract Ag (Immunoglobuline).
IS: Self/Nonself (3/3)

Antigen

epitope

Antibody
IS: B-Cells (1/2)

- B-cells are lymphocytes and mature in bone-marrow
- they have the primary job of secreting Ab
- each B-cell is programmed to make one specific Ab
- **activation**: when a B-cell encounters its Ag it is "activated" it gives rise to many "plasma cells"
- **plasma cells** are factories for producing one Ab
IS: B-Cells (2/2)

B-cell

Plasma cells

Antibody
IS: Pathogen recognition (1/2)

- Each lymphocyte have approximately $10^5$ receptors on its surface that can match with Ag epitopes

- **Affinity**: is the number of receptors that bind to pathogen

- **Affinity response**: is not discrete (true/false) but some kind of fuzzy or approximate (structural proximity, associative recognition)

- **Affinity threshold**: a lymphocyte is "activated" if the number of bindings exceed a given limit (the higher the threshold the narrower the activation)

- recognition must be "associative" otherwise the probability of binding to a new Ag would be very small
IS: Pathogen recognition (2/2)

- High affinity: stimulated
- Low affinity: not stimulated
**IS: Affinity maturation**

- Once a lymphocyte is activated it undergoes an affinity maturation, a process that is aimed at improving the binding with Ag.
- This process is defined as a *micro-evolution* inside the organism.
- The process has the main characteristics of evolution: generation of new individuals + selection.
- New cells are "clones" of the older ones.
- Diversity of new cells is assured by a "somatic hypermutation" where genes of new cells are pieced together from widely scattered bits of DNA.
- The higher the affinity of the new cells with Ag the higher their possibility to generate new clones.
The somatic hypermutation has the risk of generating autoimmune cells

IS controls this fact by inhibiting new cells which are not self-tolerant

there are thus two stimulation actions:
- positive stimulation by Ab-Ag affinity (nonself)
- negative stimulation by Ab-Ab affinity (self)

the censoring performed by IS is distributed and not centralized
IS: Self Tolerance (2/2)

- IS implements the self (Ab-Ab) interaction by T-cells:
  - they mature in thymus where most of self-proteins are circulated
  - if one growing T-cell recognizes a self protein it is censored by the system
  - at the end of the growth they are able to discriminate between self and non-self patterns and are responsible for negative Ab-Ab stimulation
IS: Memory

- Ag recognition does not start everytime from scratch
- after being stimulated some of the lymphocytes become memory cells of the system
- Primary response: reaction to an Ag never met before
- Secondary response: reaction to an Ag with lymphocytes already present (second response is usually not even understood by the body)
Many mathematical models of the complex behaviour of Immune System have been attempted. The first applications of an immune algorithm have been presented in the ’80s. The biological immune system is still matter of research, thus there are different theories to explain its working principle. Several algorithms have been devised following different immune theories. All algorithms share the quest for diversity in configurations and thus are well suited for multimodal optimization.
AIS: Structure

- The algorithm has a two level structure
  - upper level: management of the cells and of the system
  - lower level: cloning and local selection of new cells
- upper level takes into account Ag-Ab and Ab-Ab affinity relations stimulating most promising cells
- cardinality of population can be fixed or dynamic but new cells are generated throughout the process to explore as much as possible the space of configurations
AIS: Flowchart

1. random generation
2. network management
3. cloning
4. selection
5. exit criterion
6. exit criterion
AIS: optimization (1/2)

- AIS for optimization of real valued problems can be set up with:

  immune cell $\leftrightarrow$ array in real parameter space

  Ab-Ag interaction $\leftrightarrow$ value of the objective function

  Ab-Ab interaction $\leftrightarrow$ euclidean distance for real valued spaces or Hamming distance for binary strings
cloning + mutation $\leftrightarrow$ perturbation by summing a random vector

$$x_{\text{new}} = x_{\text{old}} + \alpha \ x_{\text{random}}$$

$$\alpha = \frac{1}{\beta} \exp(-f^*)$$

- exponential function should ensure that better configurations undergo smaller mutations
- usually dynamic effects (memory) are not taken into account into optimization
AIS: optimization

Test with analytical function (DeCastro)

16 maxima with different values

animation
Discussion

- Artificial Immune Systems are a suite of algorithms for learning and optimization characterized by:
  - diversity (important in multi-modal optimization)
  - adaptivity under scarce resources (important in analyzing real systems with overwhelming complexity)
- Algorithm definition is not yet assessed and work on control parameters is going on
- Interest in research is high (2002 IEEE Trans on Evolutionary Computation Special Issue on AIS)