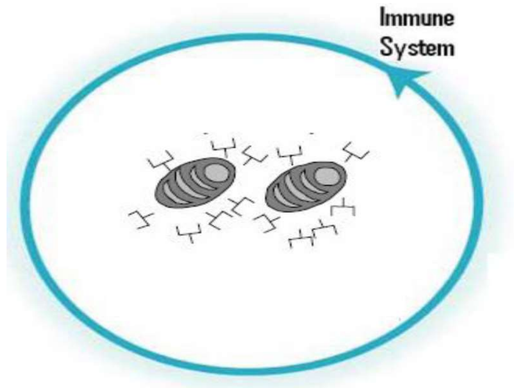
Artificial Immune Systems (AIS) & Symbiotic Organisms Search (SOS)



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Outline

- Definition
- Biological Immune System (BIS)
- BIS Response
- Why Artificial Immune System (AIS) ?
- Advancements in AIS
- Steps in solving a problem using AIS
- Theories of AIS
- Applications of AIS for (1) Data Clustering
  (2) Function Optimization
  (3) System Identification
  (4) Channel Equalization
  (5) Network Security
- Publications
- References

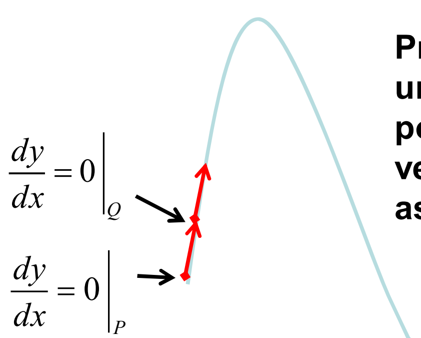
Why Nature Inspired Optimization ?

- **Problem associated with Derivative Based Optimization methods :**
  - ✓ **Based on first derivatives:**
    - Steepest descent
    - Conjugate gradient method
    - Gauss-Newton method
    - Levenberg-Marquardt method
    - And many others
  - ✓ **Based on second derivatives:**
    - Newton method
    - Least Mean Square (LMS)
    - And many others

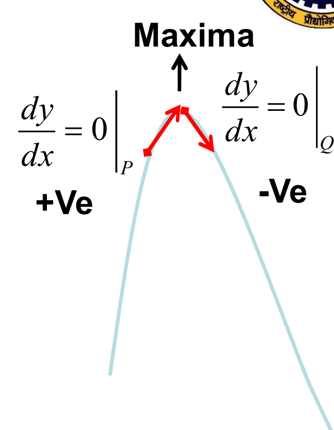
- **These traditional methods fail when the Optimization Problem is Multi Modal i.e. More than one optimum exists and the user has to determine global optimum ignoring the local optima.**

Uni-Modal vs Multi-Modal

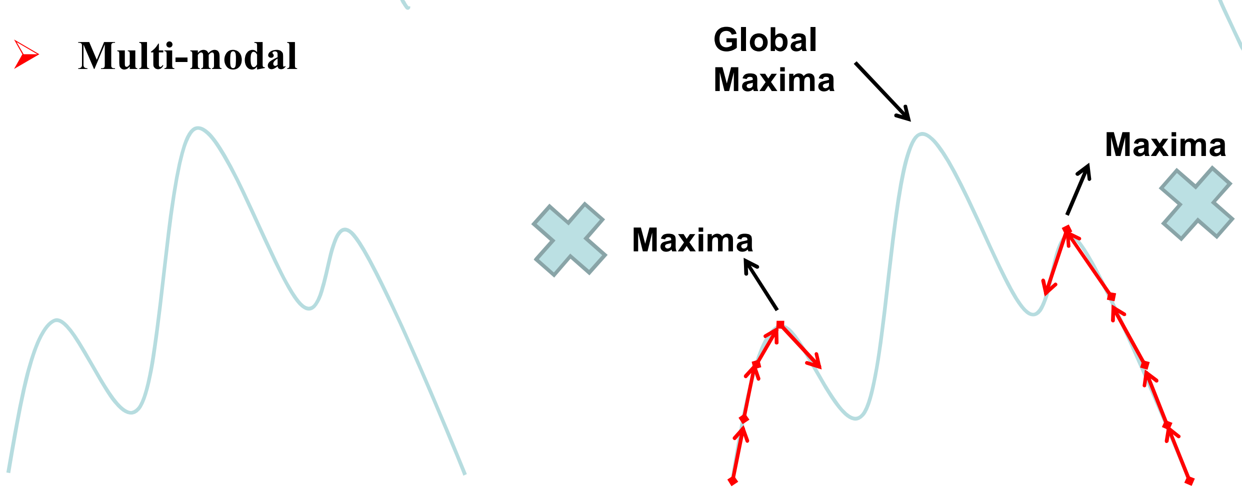
- **Uni-modal**



Process continues until and unless slope changes from positive to negative or vice versa where the algorithm assumes presence of maxima



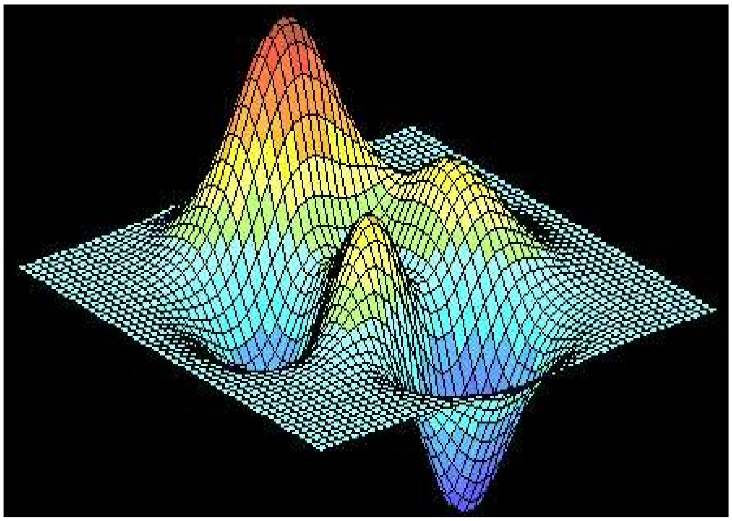
- **Multi-modal**



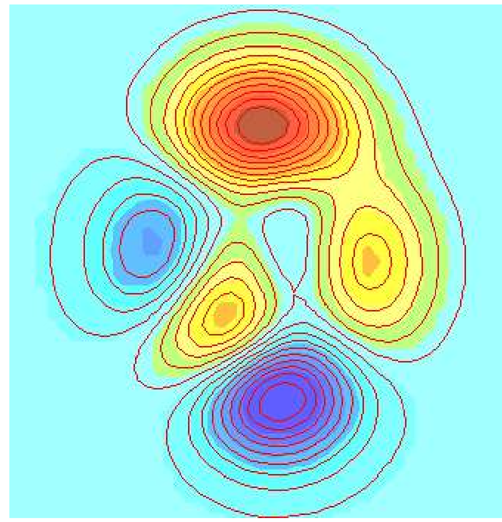
Multi-modal Optimization

- **Example : Find the maximum of the "peaks" in the function**

$$Z = f(x,y) = 3\times(1-x^2)\times e^{\left(-x^2-(y+1)^2\right)} - 10\times\left(\frac{x}{5}-x^3-y^5\right)\times e^{\left(-x^2-y^2\right)} - \frac{1}{3}\times e^{\left(-(x+1)^2-y^2\right)}$$



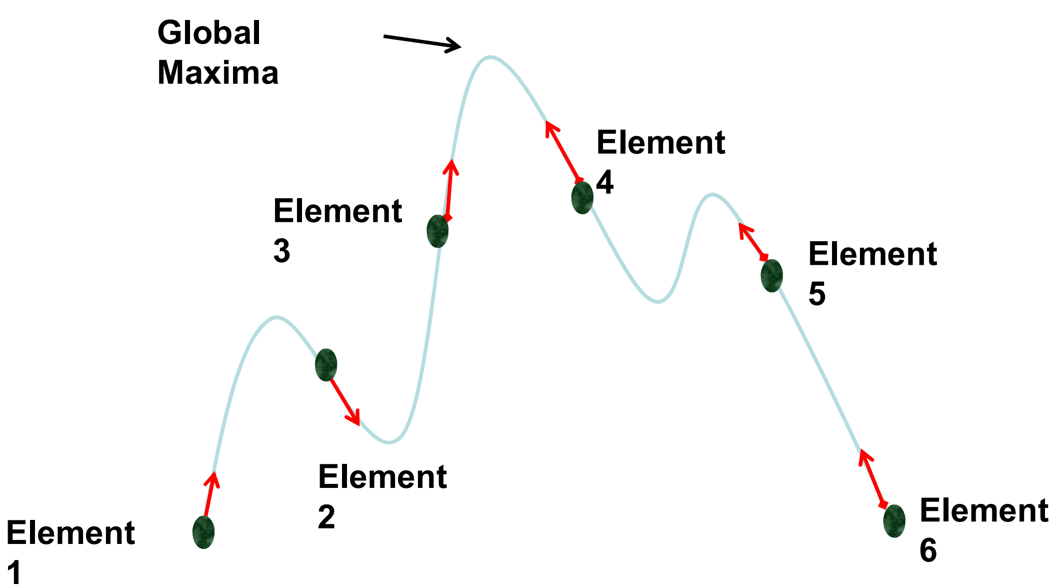
Characteristic of the function using 3D surface plot in MATLAB



Characteristic of the function using contour plot in MATLAB

Solution using Nature Inspired Optimization

- **Instead of beginning or end point the process start from random locations on the curve.**
- **A group of elements (birds, ants, molecules) simultaneously involve in the search process to make it accurate.**



Types of Nature Inspired Optimization Algorithms

Nature Inspired Optimization Algorithms		Inventor
Evolutionary Algorithms	Genetic Algorithm (GA)	Holland-1975
	Genetic Programming (GP)	Koza-1992
	Differential Evolution (DE)	Storn-1997
Swarm Intelligence	Ant Colony Opt. (ACO)	Dorigo-1992
	Particle Swarm Opt. (PSO)	Kennedy-1995
	Artificial Bee Colony (ABC)	Basturk-2006
	Fish Swarm Algorithm(FSA)	Li et al.-2002
Bio-inspired Algorithms	Artificial Immune System (AIS)	Charsto-2002
	Bacterial Foraging Opt. (BFO)	Passino-2002
Other Nature Inspired Algorithms	Cat Swarm Opt. (CSO)	S C Chu-2006
	Cuckoo Search Algo.(CSA)	X.S. Yang- 2009
	Firefly Algorithm (FA)	X.S. Yang- 2009

X.S. Yang, Nature-Inspired Metaheuristic Algorithms, Second Edition, Luniver Press, 2010, ISBN 1905986106.

Link : http://staff.ustc.edu.cn/~wjluo/ieee-cis-ais/

IEEE Computational Intelligence Society
Nature-Inspired Problem Solving

Evolutionary Computation Technical Committee

Task Force on Artificial Immune Systems

News

- Call for Papers: The special issue of Applied Soft Computing on Immune Computation: Algorithms & Applications
  Initial Paper Submission: February 15, 2020 (extended)
- Call for Papers: The Special Session on Artificial Immune Systems (AIS@CEC 2020), at the 2020 IEEE Congress on Evolutionary Computation (IEEE CEC 2020), part of WCCI 2020, Glasgow, UK, July 19 - 24, 2020
  Initial Paper Submission: January 30, 2020 (extended)
- Call for Papers: The 2020 IEEE Symposium on Immune Computation (IEEE IComputation'20), part of the 2020 IEEE Symposium Series on Computational Intelligence (IEEE SSCI 2020), Canberra Australia, December 1-4, 2020
  Initial Paper Submission: August 7, 2020

Artificial Immune System

❖ The Artificial Immune System, also known as Immune Computation, is a relatively new branch in the computational intelligence community, which is inspired by the structure, functions, models and information processing mechanism of biological immune system.

❖ The Artificial Immune System is a fast developing research area.

Popular Researchers working in Artificial Immune System :

1) Dipankar Dasgupta, University of Memphis, USA
2) Soumya Banerjee, University of Oxford, UK
3) Fernando J. Von Zuben, University of Campinas, Brazil
4) Mario Pavone, University of Catania, Italy
5) Uwe Aickelin, University of Melbourne, Australia
6) Emma Hart, Edinburgh Napier University, UK
7) Jon Timmis, University of York, UK
8) Carlos A. Coello Coello, CINVESTAV-IPN, Mexico
9) Pierre Parrend, ECAM Strasbourg-Europe/University of Strasbourg, France

Biological Immune Systems (BIS)

❖ Immunity refers to a condition in which an organism can resist disease. Cells & molecules responsible for immunity constitute BIS.

❖ Antigens are some foreign entity e.g. Bacteria or Viruses

❖ Immune system is a multilayer protection system
1. Innate immunity : Nonspecific response which are stimulated by tissue damage
2. Adaptive immunity : It is acquired immunity which is specific and it recognizes antigens

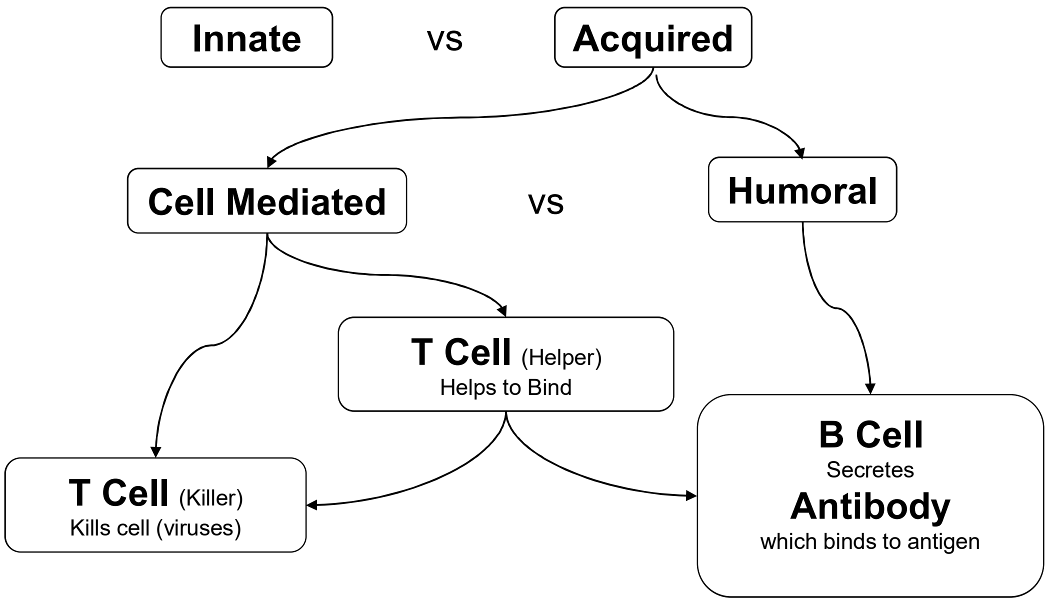
❖ Adaptive immunity once recognize antigens it triggers two responses

1. Humeral responses : It produces antibodies (B-Cells) which recognizes and binds to particular region of antigen
2. Cell mediated responses : It produces (T-Cells)

❖ A molecule Membrane Attacking Complex (MAC) is formed which destroys antigen

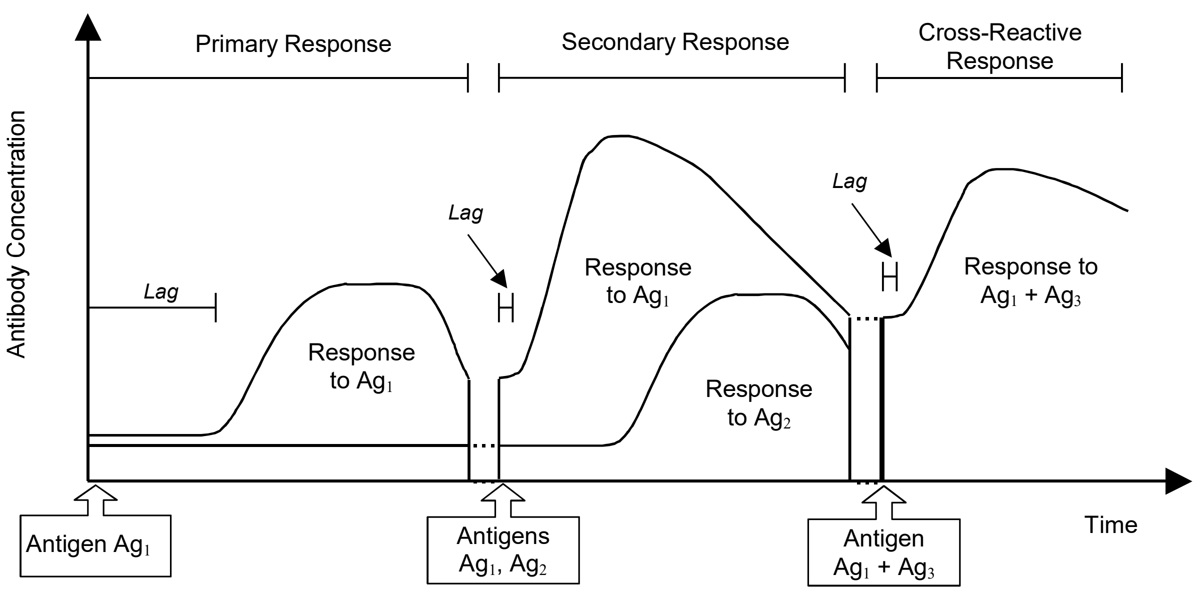
Biological Immune Systems (BIS)

The Biological Immune System



How do we protect the body against infection? (Antigens)

BIS Responses



D. Dasgupta, Artificial Immune Systems and their Applications, Springer-Verlag, 1999.

Why AIS ?

The biological immune system can do all this

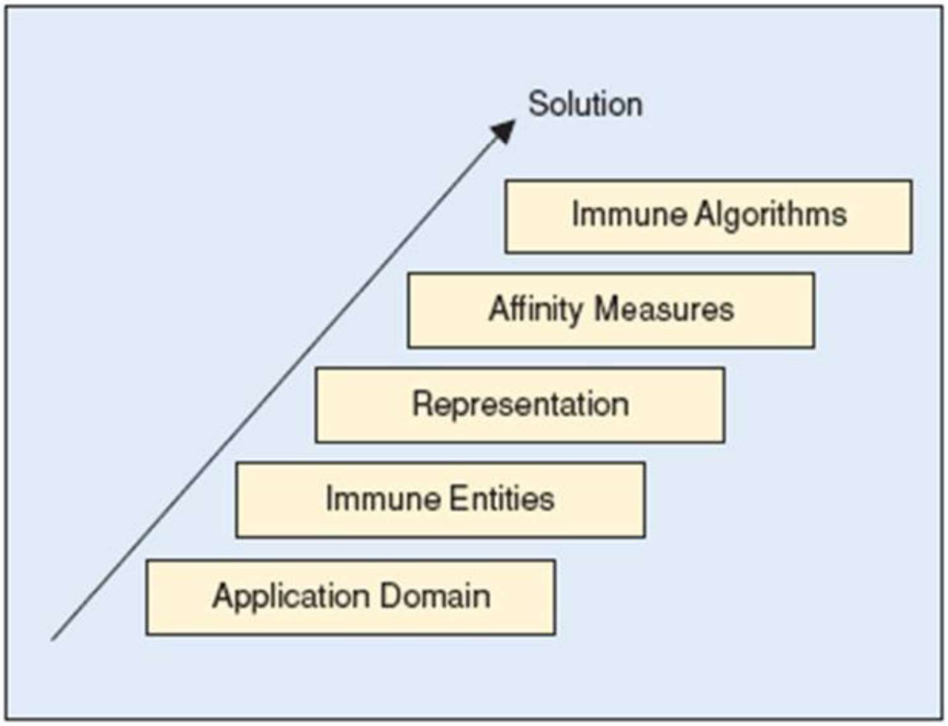
- **Recognition** : It can detect antigen
- **Robustness** : Disposability (Cell death is balanced by cell production)
- **Diversity** : Large amount of types of elements (Cells, molecules) altogether perform same role of protecting body
- **Distributed** : The immune cells, molecules are distributed all over the body and not centrally controlled
- **Multilayered** : Multiple layers of different mechanisms combine to provide overall high security
- **Reinforcement Learning** : It can learn structure of antigen
- **Memory** : It has the ability to recognize from previously seen antigen
- **Adaptive** : It can adapt itself no outside maintenance is required

1. **D. Dasgupta**, "Advances in Artificial immune Systems," *IEEE Computational Intelligence Magazine*, vol. 1, issue 4, pp.40 – 49, 2006.
2. **D. Dasgupta,** S. Yu, F. Nino, "Recent advances in artificial immune systems: Models and applications," *Applied Soft Computing, Elsevier*, vol. 11, pp. 1574-1587, 2011.

History of AIS

- **1990 – Bersini first use immune algorithms to solve problems**
- **Forrest et al – used for computer security**
  - S. Forest, S. Hofmeyr and A. Somayaji, "Computer Immunology ," In Communications of the ACM ,vol.40, issue 10, pp.88-96, 1997.
- **D. W. Bradley and A. M. Tyrrell - used for machine learning**
  - D. W. Bradley and A. M. Tyrrell , "Immuotronics – Novel Finite-State-Machine Architectures With Built-in Self-Test Using Self–Nonself Differentiation ," IEEE Trans on Evolutionary Computation, vol. 6, issue 3, pp.227-238, 2002.
- **Dasgupta et al – used for data analysis**
  - **D. Dasgupta**, "Advances in Artificial immune Systems," *IEEE Computational Intelligence Magazine*, vol. 1, issue 4, pp.40 – 49, 2006.
  - **D. Dasgupta,** S. Yu, F. Nino, "Recent advances in artificial immune systems: Models and applications," *Applied Soft Computing, Elsevier*, vol. 11, pp. 1574-1587, 2011.
- **L N de Charsto, J. Timmis, J. V. Zuben – used for optimization**
  - L N de Charsto and J. V. Zuben , "Learning and Optimization using Clonal Selection Principle ," *IEEE Trans. on Evolutionary Computation , Special issue on Artificial Immune Systems*, vol. 6, no. 3 , pp.239-251, 2002.
  - L. N. de Charsto, J. Timmis, An Introduction to Artificial Immune Systems: A New Computational Intelligence Paradigm, Springer-Verlag, 2002.

Steps to solve a problem using AIS



Theoretical Developments in AIS

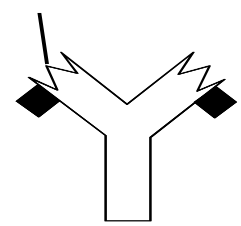
- Immune Network Model
- Negative Selection Algorithm
- Clonal Selection Algorithm (CLONALG)
- Danger Theory

S. J. Nanda, Artificial Immune Systems : Principle, Algorithms and Applications, M. Tech Research Thesis, National Institute of Technology Rourkela, India, 2009.

Immune Network Model

D. Dashgupta, 1999

- The *immune system* is composed of an enormous and complex network of paratopes that recognize sets of idiotopes, and of idiotopes that are recognized by sets of paratopes, thus each element can recognize as well as be recognized



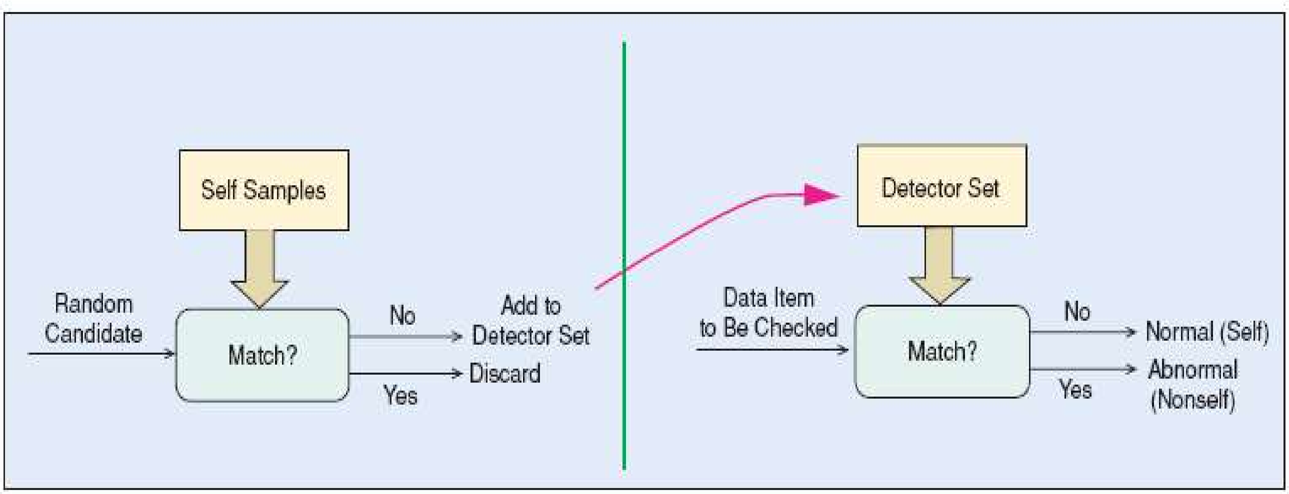
- The immune system maintains an idiotypic network of interconnected cells for antigen recognition. These cells both stimulate and suppress each other in certain ways that lead to the stabilization of the network.

- Two cells are connected if the affinities they share exceed a certain threshold, and the strength of the connection is directly proportional to the affinity they share.

L N de Charsto and J. V. Zuben , " Immune and Neural Network Models : Theoretical and Empirical Comparisons ," *Int. Journal of Comp. Intelligence and Applications* , pp.239-257, 2001.

Negative Selection Algorithm

S. Forrest *et al* (1994)



Censoring stage **Monitoring stage**

S. Forrest, A. S. Perelson, L. Allen, R. Cherukuri," Self-nonself discrimination in a computer," *Proceeding of IEEE Computer Society Symposium on Research in Security and Privacy*, pp. 202-212, 1994

M. Bereta, T. Burczynski, Immune K-means and negative selection algorithms for data analysis, *Information Sciences, Elsevier*, vol. 179, no. 10, 1407-1425, 2009.

Negative Selection Algorithm

- The main steps are
  - In generation stage, the detectors are generated by some random process and censored by trying to match self samples.
  - Those candidates that match are eliminated and the rest are kept as detectors.
  - In the detection stage, the collection of detectors (or detector set) is used to check whether an incoming data instance is self or non-self.
  - If it matches any detector, then it is claimed as non-self or anomaly.

D. Dasgupta, Artificial Immune Systems and their Applications, Springer-Verlag, 1999.

S. Forrest, A. S. Perelson, L. Allen, R. Cherukuri," Self-nonself discrimination in a computer," *Proceeding of IEEE Computer Society Symposium on Research in Security and Privacy*, pp. 202-212, 1994

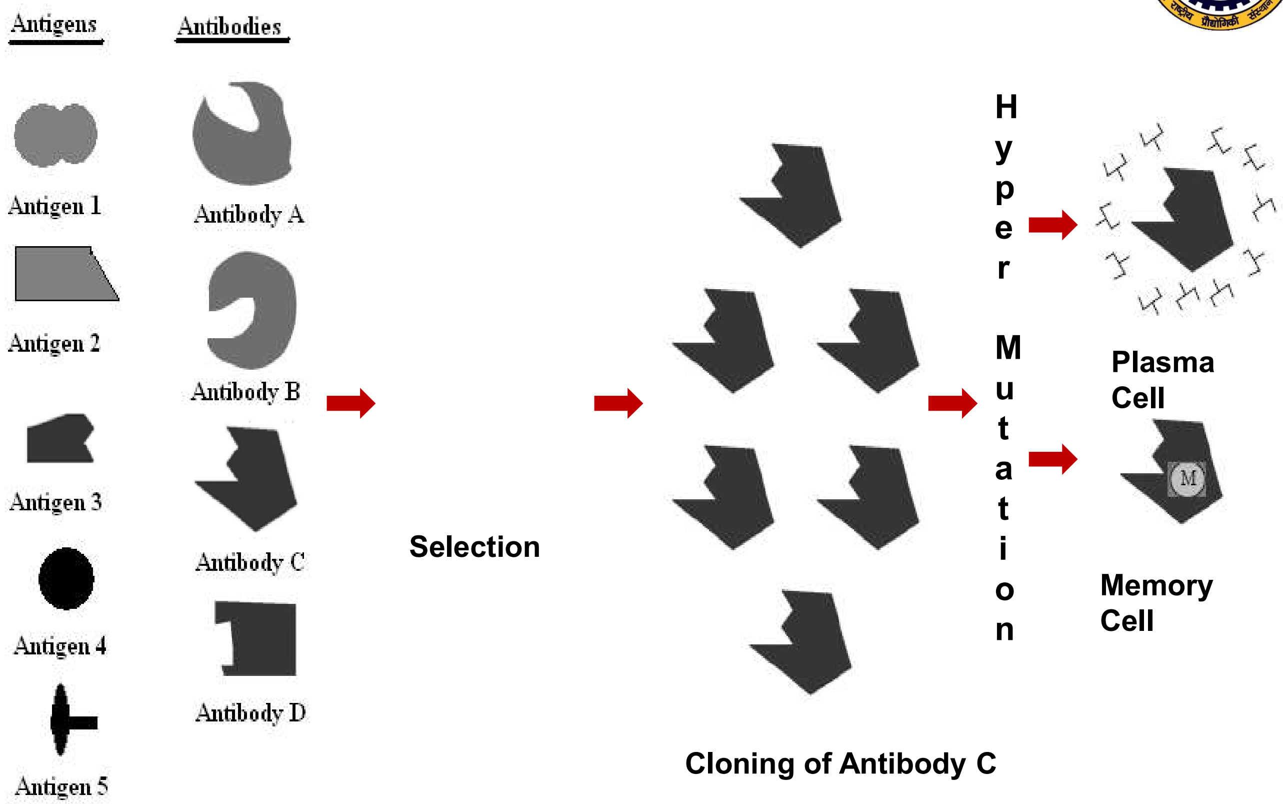
Clonal Selection Algorithm

L N de Charsto and J. V. Zuben, 2002

- When a pathogen (antigen) invades the organism ,only those immune cells that recognize the antigen undergo this process.
- During the cellular reproduction, the somatic cells reproduce in an asexual form, i.e. there is no crossover of genetic material during cell during cell mitosis. In this process new cells are formed which are copies of there parents (clone).
- Then they are subjected to go for a mutation mechanism.
- Among these cells some become effecter cells (plasma cells), while others act as memory cells.
- The effecter cells secrete antibodies.
- The memory cells having longer span of life so as to act faster or more effectively in future when the organism is exposed to same or similar pathogen .

L N de Charsto and J. V. Zuben , "Learning and Optimization using Clonal Selection Principle ," *IEEE Trans. on Evolutionary Computation , Special issue on Artificial Immune Systems*, vol. 6, no. 3 , pp.239-251, 2002.

Clonal Selection Algorithm

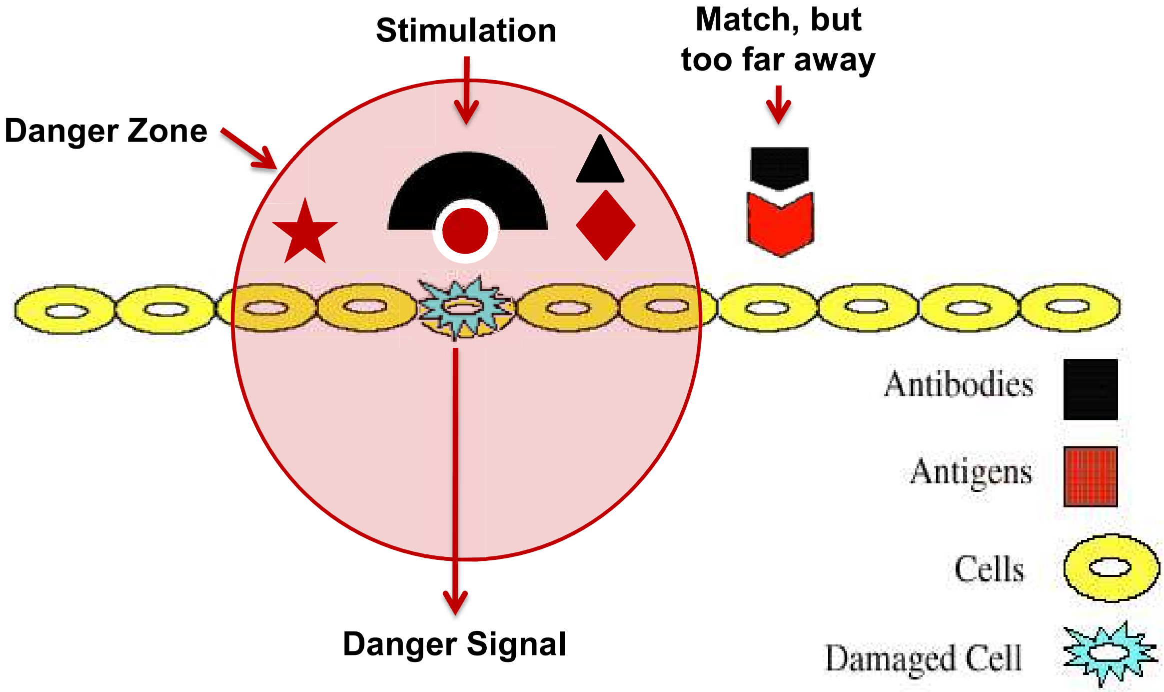


Clonal Selection Principle

The Danger Theory

- The theory is given by Matzinger
- According to this theory
  - The immune system does not respond to non-self but to danger
  - Danger is measured by damage to cells , indicated by distress signals that are sent out when cells die an unnatural death
  - Here we have to take care of “ Nonself but harmless” and “Self but harmful”.
- A cell that is distress sends out an danger signal
- The danger signal establishes a danger zone around itself
- B-cells producing antibodies that match within the danger zone get stimulated and undergo the clonal expansion.
- Those that do not match or are too far away do not get stimulated

The Danger Theory



The Danger Theory

Two signal model **(Bretscher and Chon)**

- **In this model two signals are**
  - **Signal One : Antigen recognition**
  - **Signal Two : Co-stimulation which means "this antigen really is foreign"**
    in Danger theory "this antigen is really is dangerous"

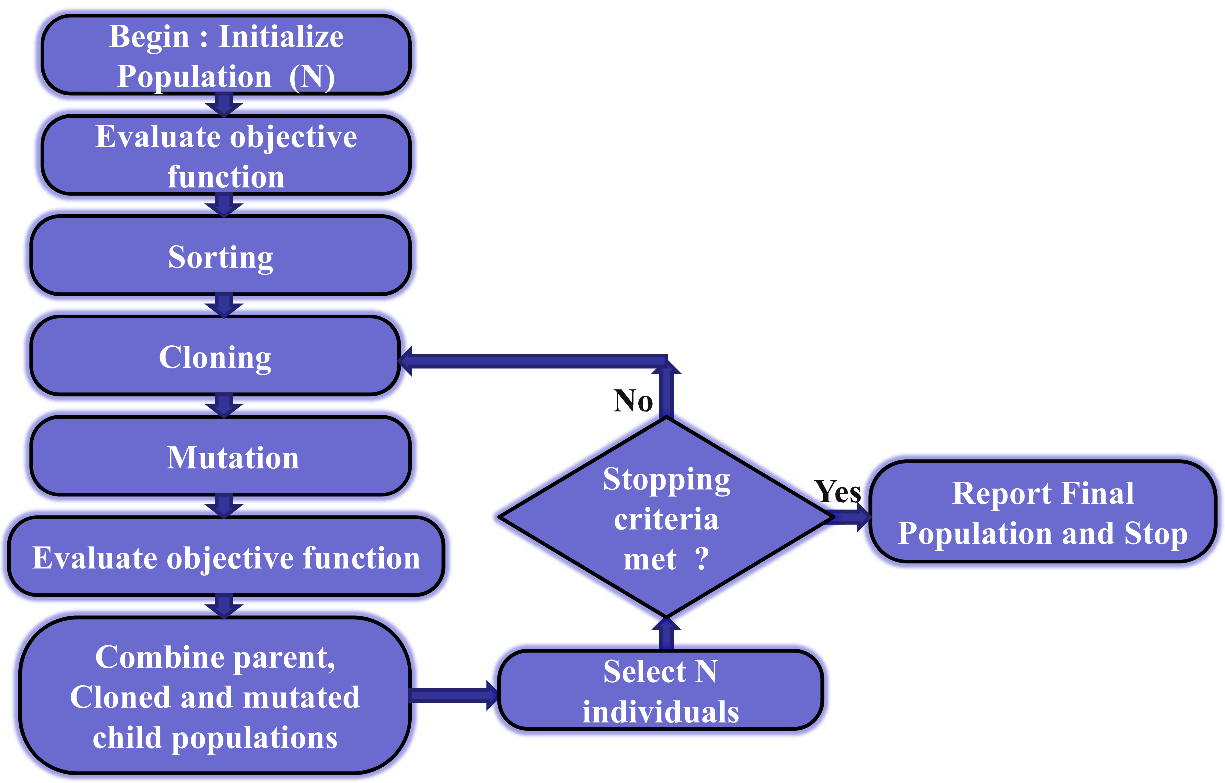
According to the two signal model the danger theory operates by 3 laws

- **Law 1 : Become activated if you receive signals one and two together.**
  Die if you receive signal one in the absence of signal two.
  Ignore signal two without signal one.
- **Law 2 : Accept signal two from antigen-presenting cells only.**
  Signal one may come from any cell.
- **Law 3 : After activation revert to resting state after a short time .**

Applications of AIS

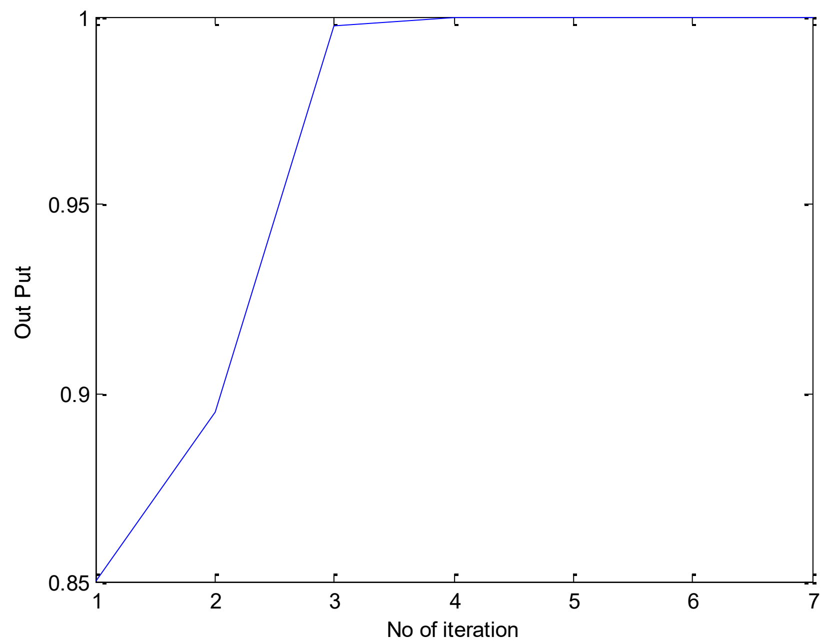
- Function Optimization
- Network Security

Function Optimization using AIS

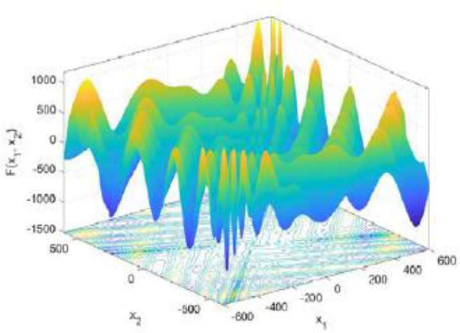


Function Optimization using AIS

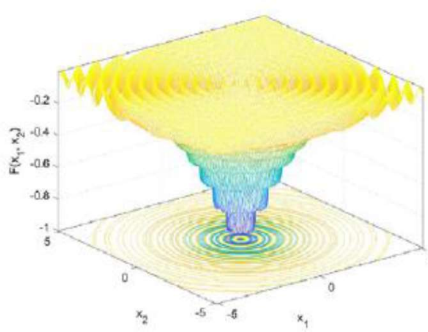
- AIS is very efficient for optimization and its probability of being trap into local minima is negligible.
- Here for **Maximization of Sin function** clonal selection algorithm is used. The initial population of cell is taken as 10.Weights are trained for 7 iteration.



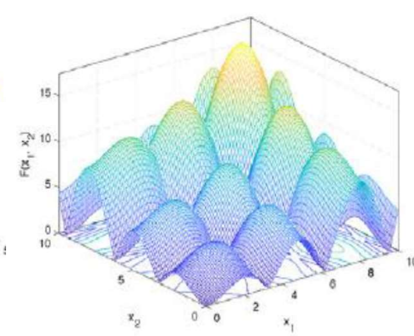
Function Optimization using AIS



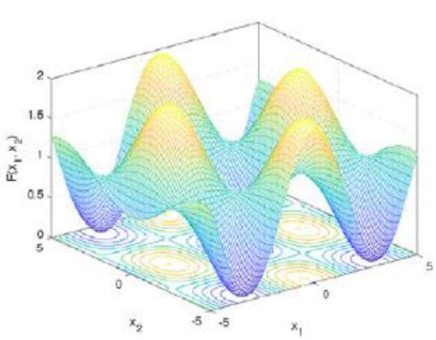
Egg holder



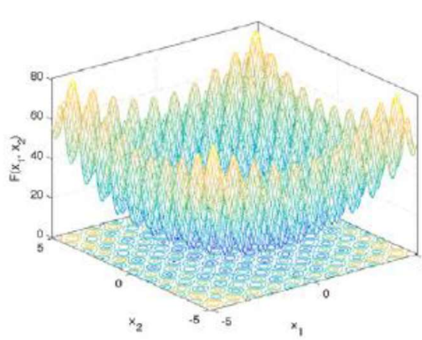
Drop Wave



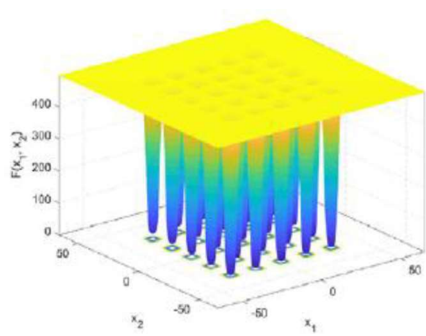
Alpine N.1



Griewank's



Rastrigin Func

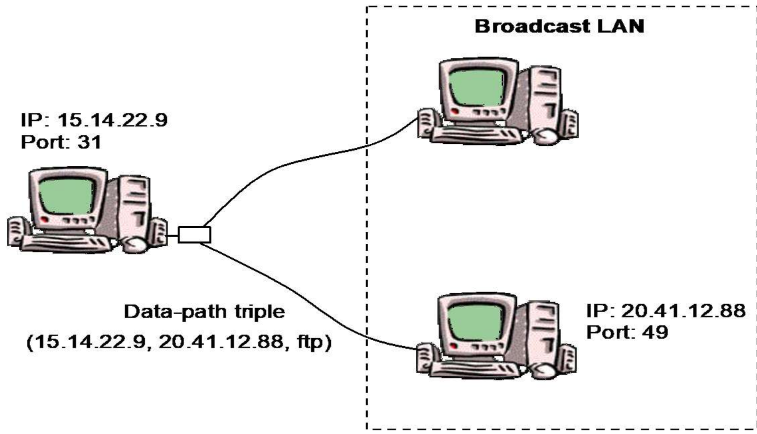


De-Jong Func

Network Security using AIS

AIM : Protecting a broadcast LAN from unwanted intrusions.

- A connection is defined in terms of "Data path triple"
  < Source IP address, Destination IP address, connection >
  The above information compressed to a single 49bit string .
- Self is the set of normally occurring connection observed over the time on LAN represented by 49bit string
- Non-self is also a set of connection same 49 bit representation but it is a enormous number that is not observed on LAN
- Detector is represented by bit string of length *L* =49



Network Security using AIS

- Each detector is a string d and detection of a string s occurs when there is match between d and s according to a matching rule.
- The matching rule(Fitness function) is of various type
  - r contiguous bit matching : Two strings match if they have r contiguous bits in common. The value of r is a threshold and determine specificity of the detector.

r = 4

Match	No match
0 $\boxed{1101}$ 00101	010 $\boxed{011}$ 0100
1 $\boxed{1101}$ 11101	111 $\boxed{011}$ 1101

  - Euclidian Distance $D = \sqrt{\sum_{i=1}^{L} (Ab_i - Ag_i)^2}$
  - Hamming Distance

Network Security using AIS

- The detectors are grouped into sets one set per machine on the LAN. Each detector set is constantly exposed to current set of connections in the LAN .

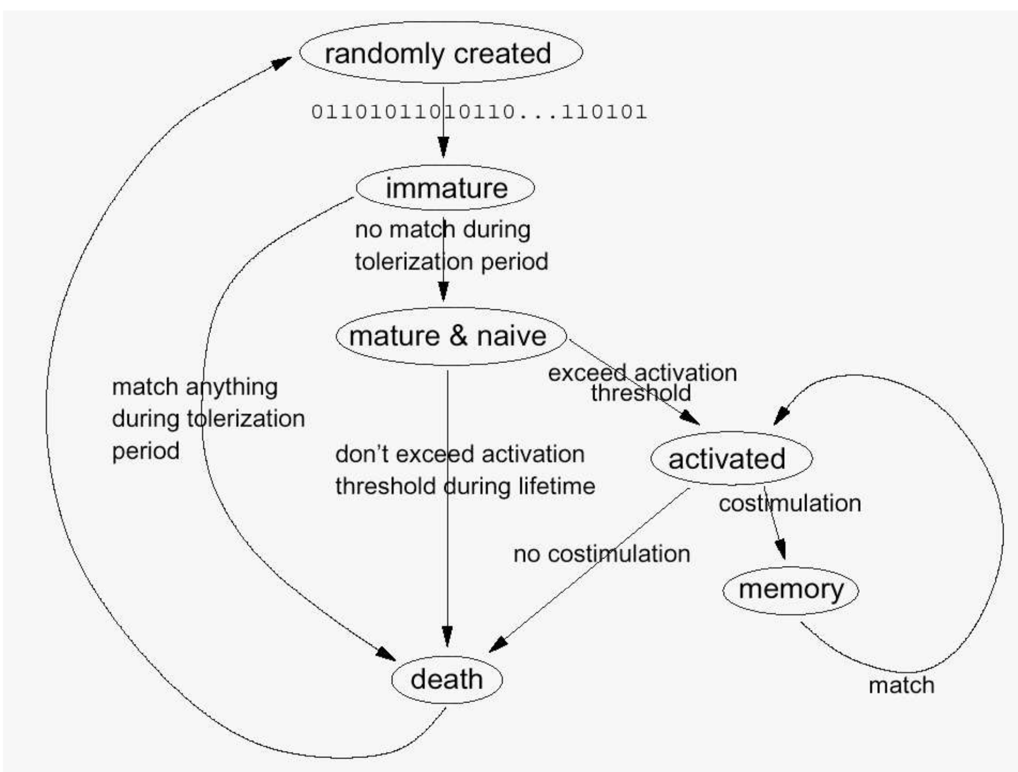
- Within each detector set new detectors are created randomly. These are passed through <u>negative selection</u> process, those survive promoted to <u>mature</u> detectors which act independently .

- If a mature detector matches sufficient no of packets(Exceed a threshold) an alarm is raised.

- The co-stimulation or second signal system prevents detectors reacting against self .It means antigen really is foreign. In this implementation it is a e-mail message .If it is received the detector becomes a <u>memory</u> detector with greatly extended lifetime.

Network Security using AIS

Life Cycle of a detector



Publications on AIS

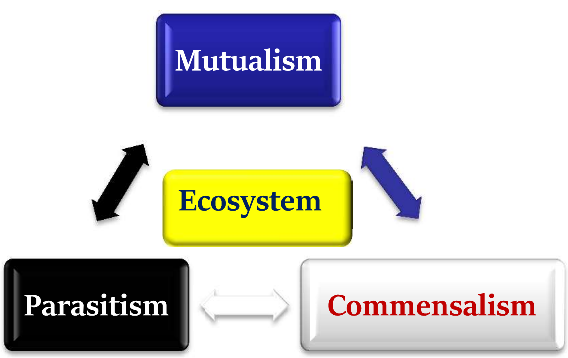
1. S. J. Nanda and **G. Panda**, "Automatic clustering algorithm based on multiobjective Immunized PSO to classify actions of 3D human models." in **Engineering Applications of Artificial Intelligence, Elsevier**, doi: 10.1016/j.engappai.2012.11.008, 2013.
2. S. J. Nanda, **G. Panda** and B. Majhi , "Improved identification of Hammerstein plants using new CPSO and IPSO algorithms" **Expert Systems with Applications, Elsevier**, no. 37, pp. 6868-6831, 2010.
3. S. J. Nanda and **G. Panda**, "Automatic clustering using MOCLONAL for classifying actions of 3D human models," IEEE Symposium on Humanities, Science and Engineering Research **(IEEE-SHUSER 12), Kualalumpur, Malaysia**, pp. 945-950, 2012.
4. S. J. Nanda and **G. Panda**, "Accurate partitional clustering algorithm based on Immunized PSO," IEEE Int. Conference on Advances in Engineering, Science and Management, **(IEEE-ICAESM 12), Tamilnadu, India**, pp. 524-528, 2012.

Reference Books

- D.Dasgupta, *Artificial Immune Systems and their Applications* ,Springer-Verlag, 1999.
- L.N. de Castro, J. Timmis ,*An Introduction to Artificial Immune Systems: A New Computational Intelligence Paradigm* ,Springer-Verlag, 2002.

Symbiotic Organism Search

M. Y. Cheng and D. Prayogo, "Symbiotic organisms search: a new metaheuristic optimization algorithm," Computers & Structures, Elsevier, vol. 139, pp. 98–112, 2014.



"In an Ecosystem several organisms live together and interact with each other for their survival and common growth. This process is termed as : Symbiosis"

M. Y. Cheng and D. Prayogo

Initialization

Initialize an ecosystem with 'p' number of organisms and each has dimension 'D'

$$\vec{O} = \begin{bmatrix} O_1 \\ O_2 \\ \vdots \\ O_p \end{bmatrix} = \begin{bmatrix} O_{1,1} & O_{1,2} \cdots & O_{1,D} \\ O_{2,1} & O_{2,2} \cdots & O_{2,D} \\ \vdots & \vdots & \vdots \\ O_{p,1} & O_{p,2} \cdots & O_{p,D} \end{bmatrix}$$

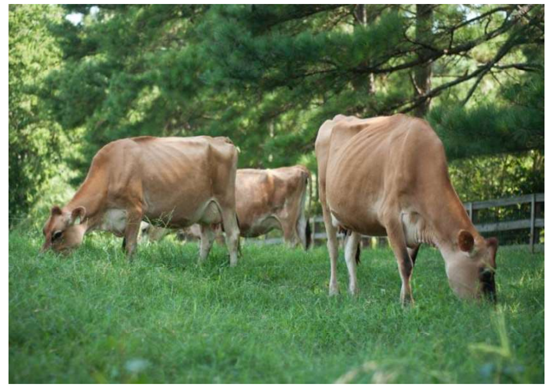
Fitness Evaluation

Evaluate the fitness of each organism & determine the best fit organism O_{best}

Symbiotic Organism Search

Mutualism Phase

- In this phase the interaction between two organisms of different spices result in benefiting both the organisms.
- Therefore it is also termed as ‘Phase of benefits’.
- Relation between Cow and Grass. Both Cow fill its stomach and Grass obtain growth.



The mutualism between two organisms O_i and O_j with i≠ j is given by

$$O_{i-new} = O_i + rand(0,1) * (O_{best} - MV * BF_1)$$

$$O_{j-new} = O_j + rand(0,1) * (O_{best} - MV * BF_2)$$

Where Mutual Vector $MV = \frac{O_i + O_j}{2}$

Benefit Factors BF1 and BF2 randomly takes value as 1 or 2.

Output of Mutualism $MO_{2p\times m} = \left[O_{i-new}, O_{j-new}\right]^T ; \forall i \in [1, p]$

Symbiotic Organism Search

Commensalism Phase

- In this phase the interaction between two organisms benefit one, the other one neither gets benefit nor suffers from the relationship.
- Ex : The interaction between Remora fish and Shark is commensalism. The Remora fish attach itself behind shark and eat the leftover thus get benefited.

The commensalism between two organisms O_i and O_j with i≠ j is

$$O_{i-new} = O_i + rand(-1,1) * (O_{best} - O_j)$$

The rand(-1,1) is a random number in range [-1, 1]

The $(O_{best} - O_j)$ reflect the benefits provided by O_j (Shark) to organism O_i (Remora fish) by enhancing its survivability in the ecosystem.

Output of Commensalism $CO_{p\times m} = \left[O_{i-new}\right]^T ; \forall i \in [1, p]$

Symbiotic Organism Search

Parasitism Phase

- In parasitism phase the interaction between two organisms eliminate a weaker organism from the ecosystem.
- The interaction between a mosquito and human is a phenomenon of parasitism.

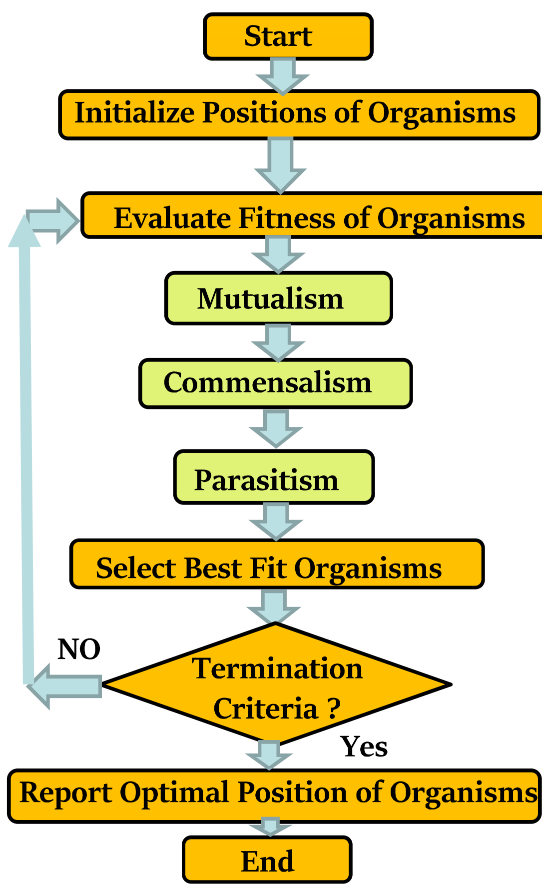
The parasitism between two organisms O_i and O_j with $i \neq j$ is given by

- Let O_i **be considered as a mosquito** which create a 'Parasite Vector (PV)' by copying the nature of parent organism O_i and randomly changing selected dimension values with random numbers. O_j **is given the role of human.**
- The fitness value of 'PV' and O_j are evaluated.
- If $f(PV)$ is better than $f(O_j)$, then O_j is eliminated. The 'PV' takes position of O_j
- Else $f(O_j)$ is better, then O_j has the power to protect and the 'PV' is eliminated.

After Parasitism the output is given by $PO_{p\times m} = [A_i]^T ; \forall i \in [1, p]$

Where $A_i = \begin{cases} O_j & if \ \ f(O_j) \prec f(PV) \\ PV & Otherwise \end{cases} ; \forall j \in [1, p] \ and \ j \neq i$

Flow Chart of Symbiotic Organism Search



Applications of Symbiotic Organism Search

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THANK YOU