Artificial Immune System

Course Title: Computational Intelligence
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Intended Outcomes of this Session

At the end of this session, the student will be able to:

1. Relate the concepts of biological immune systems to artificial immune systems
2. Develop the artificial immune system algorithm
3. Develop Negative Selection Algorithm
4. Develop Clonal Selection Algorithm
5. Develop the multi-layered immune system algorithm
6. Apply danger theory for applications, such as Intrusion detection

Recommended Resources for this Session

1. Engelbrecht, A. P. (2007). *Computational intelligence: An introduction*. Chichester, England, John Wiley & Sons.

2. De Jong, K. A. (2012). *Evolutionary Computation: A Unified Approach*. New York, USA, Bradford Books.

3. Konar, A. (2005). *Computational Intelligence: Principles, Techniques and Applications*. Secaucus, NJ, USA, Springer-Verlag New York, Inc.

4. Zhou, Dasgupta. *Revisiting Negative Selection Algorithms*

5. Burnet F.M. (1959). *The Clonal Selection Theory of Acquired Immunity*. Cambridge University Press.

Introduction

- Human body's immune system is a learning system that distinguishes between good cells and potentially harmful ones
- Artificial Immune System (AIS) is a intelligent and adaptive system inspired by the human immune system to solve problems in mathematics, engineering and information technology
- AIS was developed in the mid 1980s on theoretical immune networks. In 1990s AIS algorithm was used to solve problems in engineering and in mid 90s AIS was experimented on computer security and in machine learning
- AISs have been used to solve a wide variety of problems including computer Security, pattern recognition, data analysis, data mining, search and optimization methods, autonomous navigation and control, fault and anomaly detection etc

Natural Immune System (NIS)

AIS has been inspired by the modelling of the NIS structure which comprises of the cells and mechanisms that defend the person from infection by other organisms. Some frequently used terms in NIS:

Term	Meaning
Cell	Basic biological unit of all known living organisms
Self cell	Normally present in the human body
Non-self cell	Foreign or antigen cell (to be destroyed)
B cells	Connect to antigens on the surface of the infection
T cells	Connect to antigens on the outside of infected cells
White Cells	Fight infections by attacking antigens
Lymphocyte	Subtypes of white cell that detect any antigens
Antigen	a Specific foreign body material
Antibodies	Chemical proteins to de-activate the antigen

Natural Immune Systems (NIS)

NIS concepts used in AIS are:

- Understand the structure of self or normal cells
- Ability to distinguish between self and foreign/non-self cells
- Ability to sense a dangerous or non-dangerous foreign cell
- Cloning and mutation of Lymphocytes to learn and adapt to the structure of the encountered foreign cells
- Building a memory to store the learned structures of the foreign cells to encounter foreign cells
- Ability to formulate the lymphocyte networks with the cooperation and co-stimulation among lymphocytes. This helps in learning and reacting against encountered foreign cells

AIS Concepts based on NIS

- Artificial lymphocytes (ACLs) or trained detectors are used to detect a foreign patterns with a certain affinity
- Antigen affinity is the measurement of similarity or dissimilarity between an ALC and an antigen pattern. It is the degree to which an ALC detects a pattern
- Measures of affinity in existing AIS models are the Euclidean distance, hamming distance, r-continuous matching rule, and cosine similarity
- In following figure there are 7 continuous matches between the ALC and the pattern. Thus, if $r = 4$, the ALC matches the pattern since $7 > r$

ALC	A	A	B	C	D	G	U	W	J	S	W	E	H	U	T	S	D	F	E	S	S	T	R
Pattern	A	H	F	H	E	H	U	D	U	S	W	E	H	U	T	S	E	F	J	F	J	E	T

7 continuous matches

AIS Concepts based on NIS

- Network affinity is the measurement of affinity between two ALCs. Network affinity threshold determines whether two or more ALCs are linked to form a network
- In some of the AIS models, the selection of highest affinity ALCs is based on a preset affinity threshold H. Thus, the selected subset H can be the entire set S, depending on the preset affinity threshold
- A repository or AIS memory of self patterns or self and non-self patterns is maintained to detect non-self or foreign patterns and train the ACLs to be self-tolerant
- When an ALC detects non-self patterns, it can be cloned and the clones can be mutated to have more diversity in the search space

The AIS Algorithm - Outline

- Initialize a set of ALCs as C, antigen pattern as z_p and a set of antigen pattern as D_T
- Set the stopping condition or convergence state
- Select a subset, S, of ALCs
- Calculate the antigen affinity
- Select a subset, H, of ALCs as a preset threshold
- Calculate the network affinity
- Adapt the ALCs in subset H
- Update the stimulation of an ALC and create a memory set contains the ALCs that most frequently match z_p

Pseudocode of AIS algorithm

Algorithm 10.1. Pseudocode of AIS algorithm

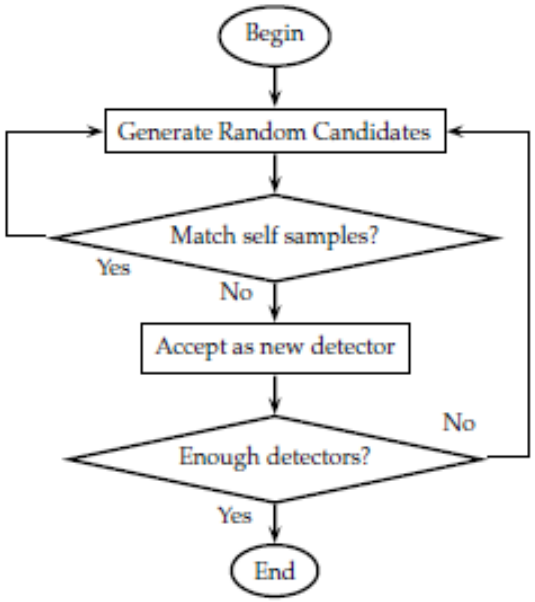
Initialize population C;
Determine antigen pattern as a training set D_T ;
while some stopping condition not true **do**
  for each antigen pattern $z_p \in D_T$ **do**
    Select a subset of ALCs for exposure to z_p
    for each ALC, $x_i \in S$ **do**
      Calculate antigen affinity between z_p and x_i;
    end for
    Select a subset of ALCs with the highest calculated antigen affinity as population $H \subseteq S$;
    Adapt the ALCs in H with some selection method, based on the calculated antigen affinity and or the network affinity among ALCs in H;
    Update the stimulation level of each ALC in H;
  end for
end while

Classic Models

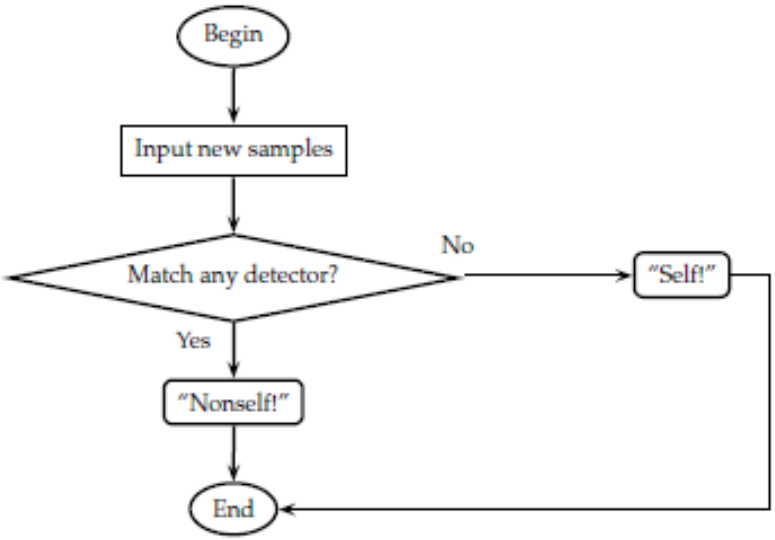
1. Negative selection models
2. Evolutionary approach-based models
3. Clonal Selection Models

Negative Selection Algorithm (NSA)

NSA is inspired by the change detection performed by T-cells based on the principle of self/non-self discrimination in the immune system. The first NSA was proposed by Forrest et al (1994) to detect data manipulation caused by a virus in a computer system



(a) Generation of detector set



(b) Detection of new instances

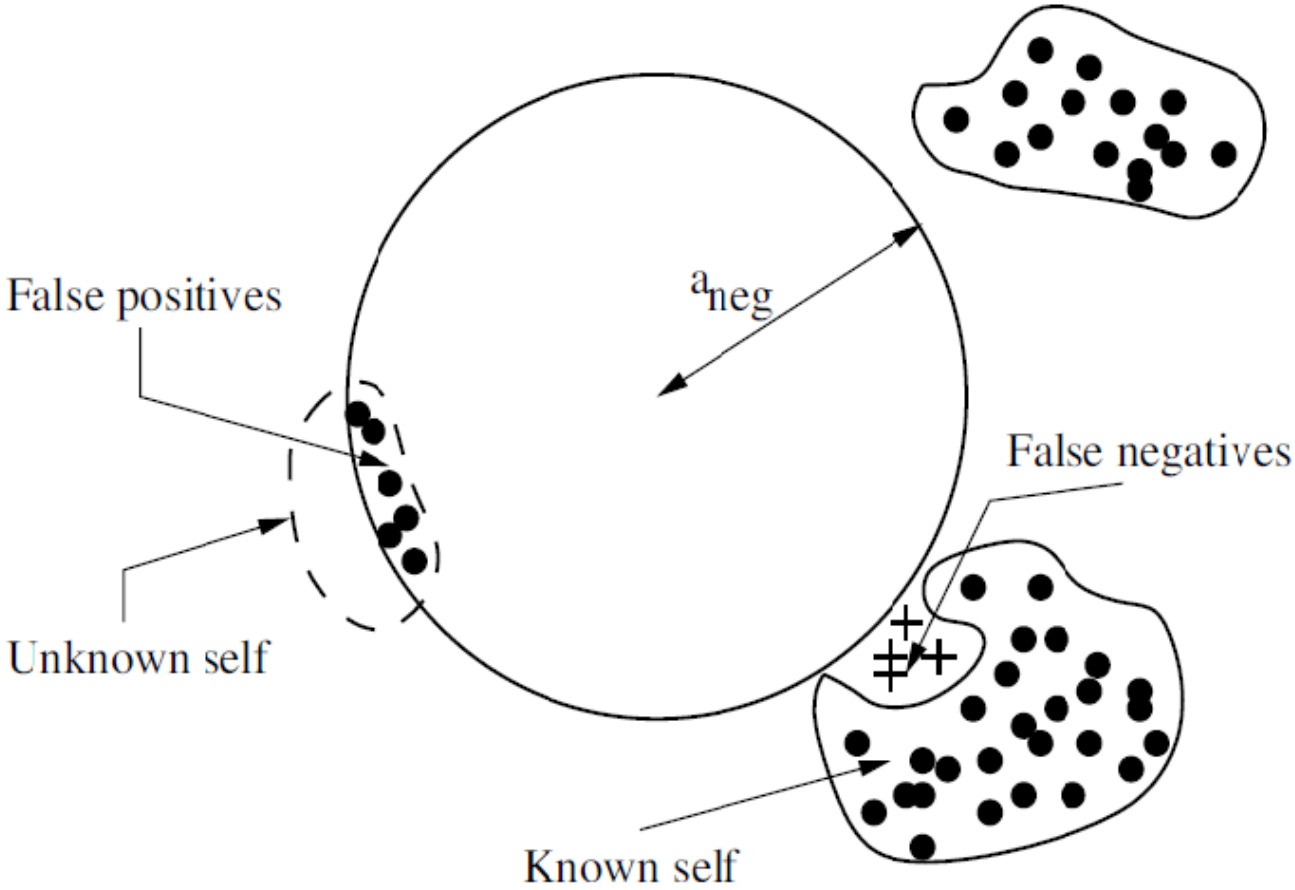
Features of NSA

- A set of ALCs and self pattern in the model represent the mature T-Cells and normal pattern of activity in the natural immune system respectively
- In the generation stage, the detectors or ALCs 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 detector set is used to check whether an incoming data instance is self or non-self. If it matches any detector, it is claimed as or an anomaly
- A drawback of the negative selection model is that the training set needs to have a good representation of self patterns
- Another drawback is the exhaustive replacement of an ALC during the monitoring of the training set until the randomly generated ALC is self-tolerant

Evolutionary Approach in NSA

- Instead of randomly generating ALCs, evolutionary process is used to evolve ALCs towards non-self and to maintain diversity
- Here a evolutionary technique converges to a point where all the non-self patterns and none of the self patterns are detected. The ALCs at this point represent a description of the concept
- In the model of Graaff and Engelbrecht, all patterns are represented as binary strings and the Hamming distance is used as affinity measure
- A genetic algorithm is used to evolve ALCs away from the training set of self patterns towards convergence
- Adapted Negative selection method is another example of evolutionary approach in NSA

Adapted Negative Selection

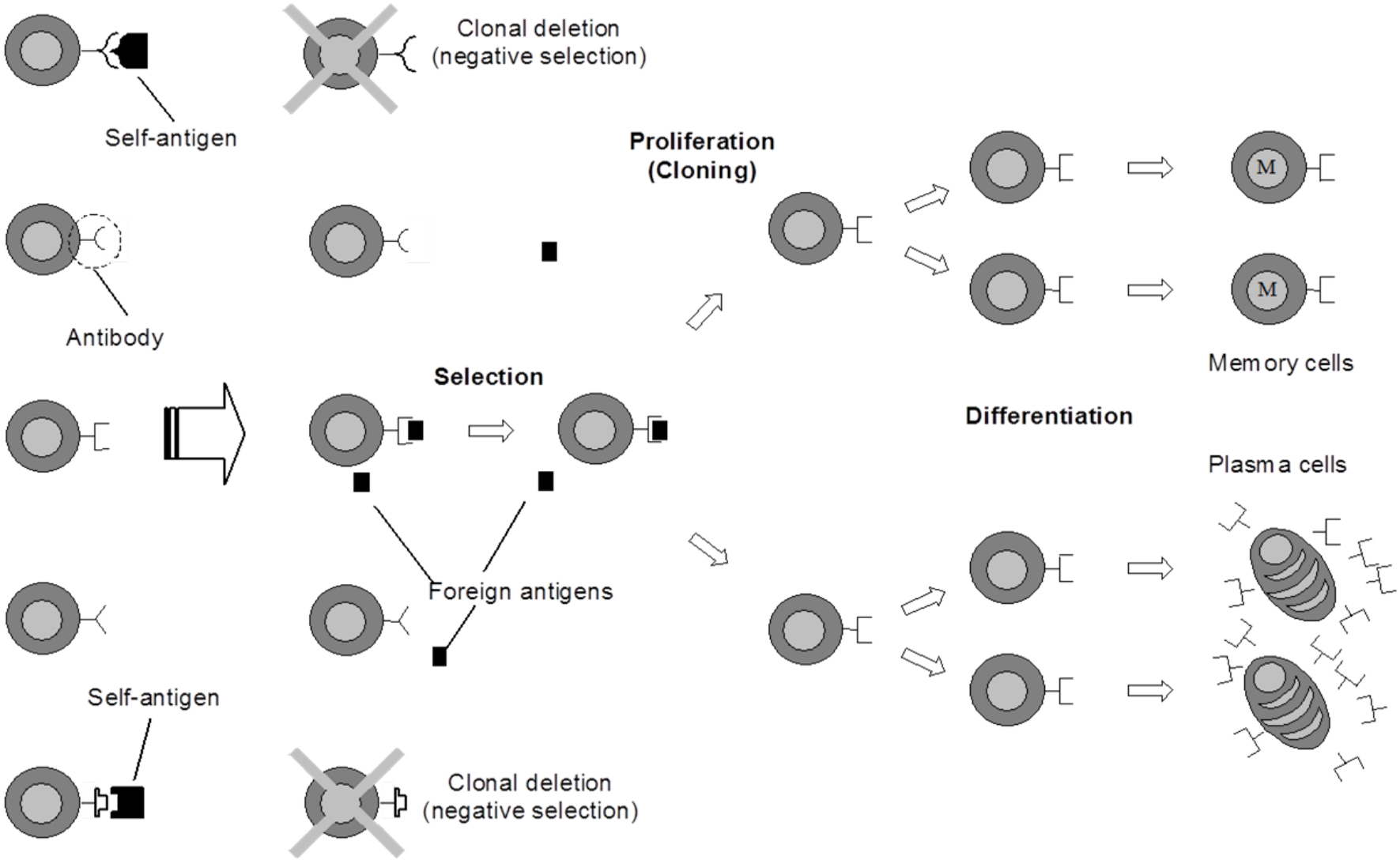


a_{neg} = Affinity threshold

Clonal Selection (NIS)

- Clonal selection helps the immune system to learn and increase the population of lymphocytes that frequently recognize antigens
- When an antigen stimulates a lymphocyte, the lymphocyte not only secretes antibodies to bind to the antigen but also generates mutated clones of itself in an attempt to have a higher binding affinity with the detected antigen. The latter process is known as somatic hyper-mutation
- Since antigens determine or select the lymphocytes that need to be cloned, the process is called clonal selection
- The total number of lymphocytes in the immune system is regulated by discarding those lymphocytes that seldom or never detect any antigens. The immune repository is kept complete and diverse as possible to recognize any foreign shape

Clonal Selection



Clonal Selection (AIS)

- Clonal selection in AIS is the selection of a set of ALCs with the highest calculated affinity with a non-self pattern
- The selected ALCs are then cloned and mutated in an attempt to have a higher binding affinity with the presented non-self pattern
- The mutated clones compete with the existing set of ALCs, based on the calculated affinity between the mutated clones and the non-self pattern, for survival to be exposed to the next non-self pattern
- De Castro and Von Zuben [186, 190] presented CLONALG as an algorithm that performs machine-learning and pattern recognition tasks

Multi-layered AIS

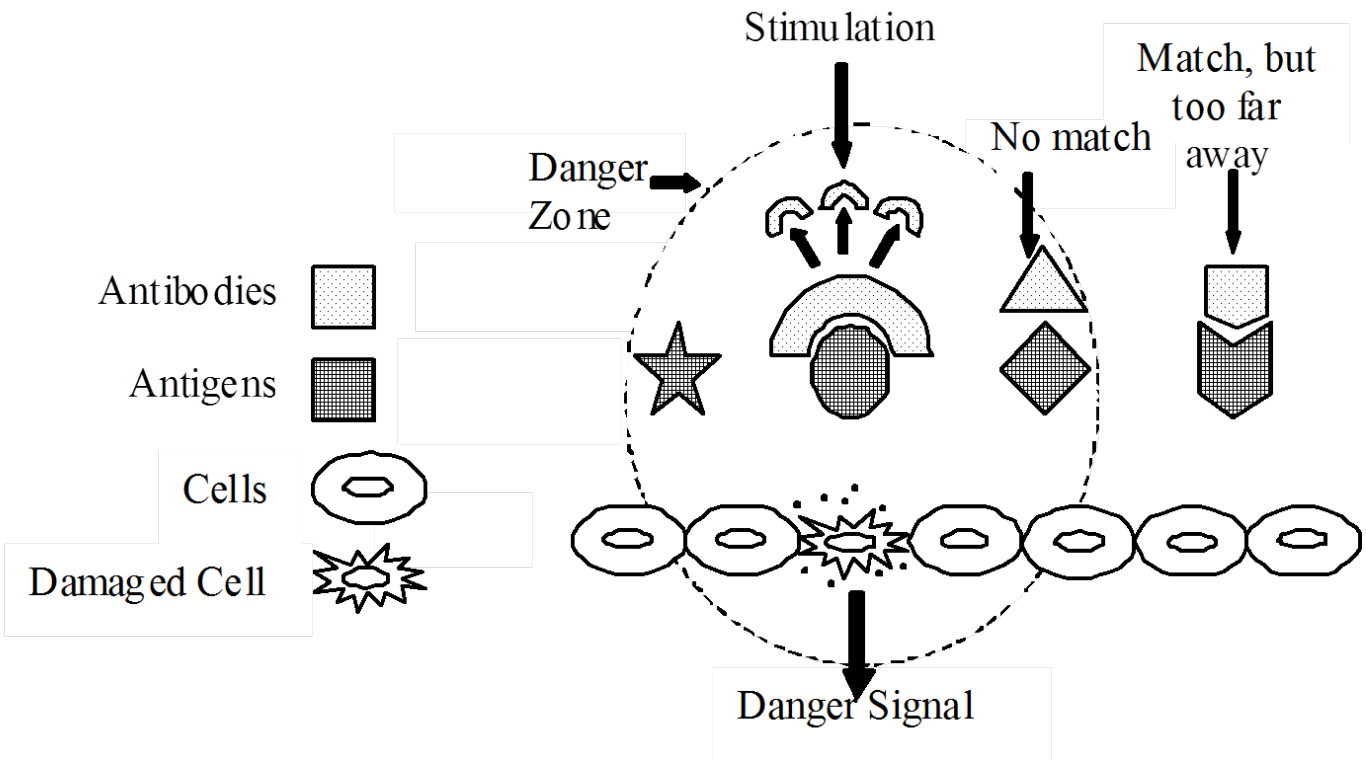
- Multi-layered AIS follows a layered approach to adopt and interact with structure of the presented antigen patterns in a dynamic environment
- The multi-layered AIS consists of the following layers: the free-antibody layer (F), B-Cell layer (B) and the memory layer (M)
- Each layer has an affinity threshold (a_F, a_B, a_M), and a death threshold (ϵ_F, ϵ_B, ϵ_M)
- The affinity threshold determines whether an antigen binds to an entity within a specific layer
- The death threshold is measured against the length of time since a cell was last stimulated within a specific layer

Description of Layers in AIS

- The free-antibody layer stores antigen patterns and performs the binding when a new antigen z_p enters. The bindings is stored in the variable n_b
- The number of free antibodies produced by a B-Cell is as follows:
- $f_F(z_p, u_k) = (a_{max} - c)\alpha$
- Here f_F = number of antibodies that are added to the free-antibody layer, a_{max} is maximum possible distance between a B-Cell and an antigen pattern in the data space, $fa(zp, uk)$ is affinity between antigen, z_p, and B-Cell, u_k, and positive constant α
- The B-Cell layer binds antigen to one of the B cells in random manner. This layer performs need-based cloning and mutation
- The final layer, M, consists only of memory cells and only responds to new memory cells

Danger Theory

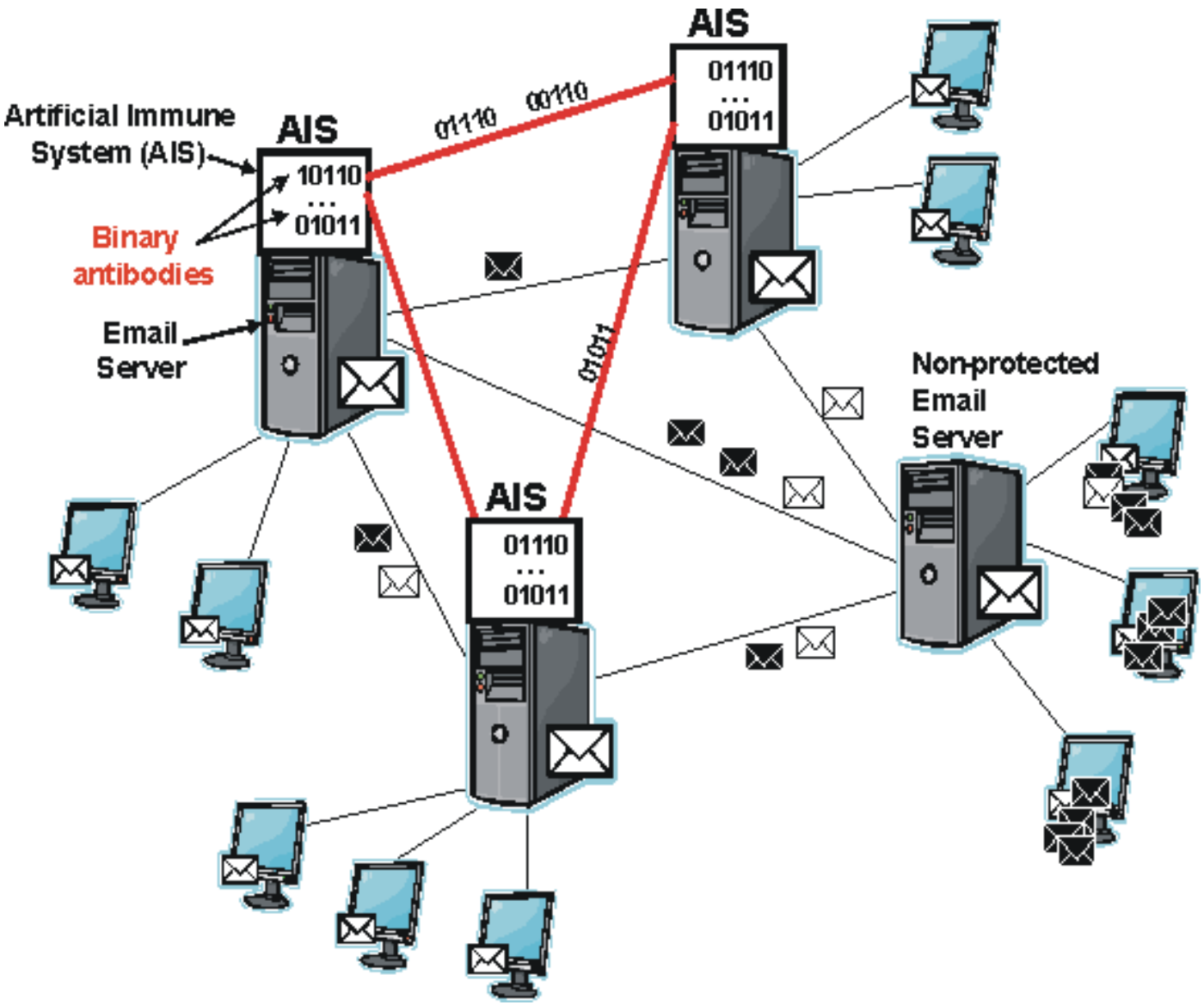
In the danger model, the idea is to recognise **danger** rather than **non-self**. In the danger-based AIS models, an additional signal is included to determine whether a non-self pattern is dangerous or not



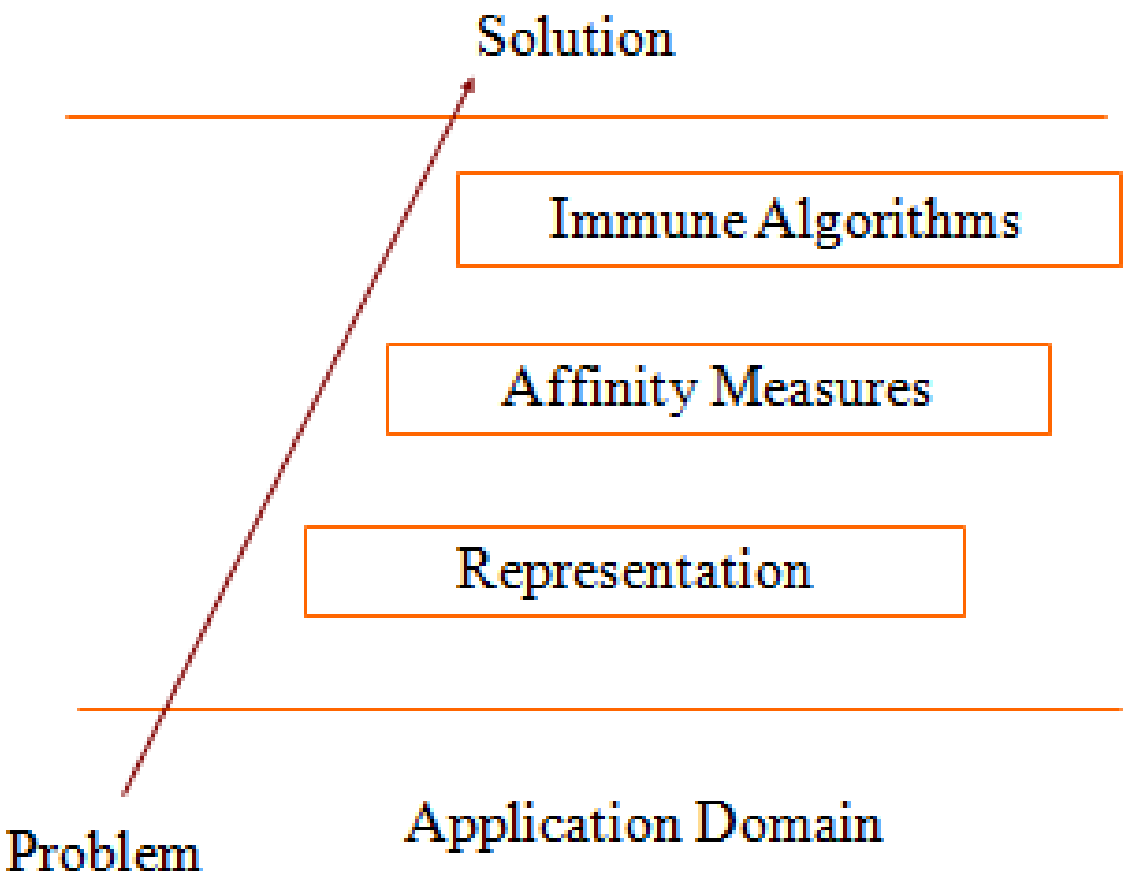
Danger Theory Application - Adaptable Intrusion Detection Service (IDS)

- IDS monitors incoming traffic at a specific host connected to a network
- The IDS creates a profile of normal user traffic and signals an alarm of intrusion for any detected abnormal traffic
- The normal traffic changes with the time with which the profile gets outdated
- The danger signal inspired by danger theory is defined as a signal generated by the host if any incoming traffic resulted in abnormal CPU usage, memory usage or security attacks
- If no danger signal is received from the host, the profile is adapted to accommodate the new detected normal traffic

IDS



General Framework of AIS



Session Summary

- AIS has been inspired by the modelling of the NIS structure which comprises of the cells and mechanisms that defend the person from infection by other organisms
- Classic models of AIS include:
  - Negative selection models
  - Evolutionary approach-based models
  - Clonal Selection Models
- NSA is inspired by the change detection performed by T-cells based on the principle of self/non-self discrimination in the immune system
- Clonal selection helps the immune system to learn and increase the population of lymphocytes that frequently recognize antigens
- Multi-layered AIS follows a layered approach to adopt and interact with structure of the presented antigen patterns in a dynamic environment
- In the danger-based AIS models, an additional signal is included to determine whether a non-self pattern is dangerous or not

Any Questions?

Thank You