An Introduction to Artificial Immune Systems

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Novel paradigms are proposed and accepted not necessarily for being faithful to their sources of inspiration, but for being useful and feasible

What do I want to achieve?

- Give you a taster of what AIS is all about
  - Why do we find the immune system useful?
  - Explain what AIS are
  - Show you where they are being used
  - Comments for the future
- I won't:
  - Talk about all areas of AIS and applications
  - Talk too much about how AIS relate to other bioinspired ideas (although I will mention it)
  - Go into too much detail: this is an introduction

Outline

- **What are AIS?**
- Useful immunology
- Thinking about AIS
- Application Areas
- The Future

Why the Immune System?

- Recognition
  - Anomaly detection
  - Noise tolerance
- Robustness
- Changing nature of self
- Diversity, Adaptive
- Reinforcement learning
- Memory; Dynamically changing coverage
- Distributed
- Multi-layered

A Definition

AIS are adaptive systems inspired by theoretical immunology and observed immune functions, principles and models, which are applied to complex problem domains

Some History

- Developed from the field of theoretical immunology in the mid 1980's.
  - Suggested we 'might look' at the IS
- 1990 – Bersini first use of immune algos to solve problems
- Forrest et al – Computer Security mid 1990's
- Hunt et al, mid 1990's – Machine learning

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Scope of AIS:

- Computer Security *(Forrest'94'96'98, Kephart'94, Lamont'98'01,02, Dasgupta'99'01, Bentley'00'01,02)*
- Anomaly Detection *(Dasgupta'96'01'02)*
- Fault Diagnosis *(Ishida'92'93, Ishiguro'94)*
- Data Mining & Retrieval *(Hunt'95'96, Timmis'99' 01, '02)*
- Pattern Recognition *(Forrest'93, Gibert'94, de Castro '02)*
- Adaptive Control *(Bersini'91)*

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Scope of AIS (Cont……):

- Job shop Scheduling *(Hart'98, '01, '02)*
- Chemical Pattern Recognition *(Dasgupta'99)*
- Robotics *(Ishiguro'96'97,Singh'01)*
- Optimization *(DeCastro'99,Endo'98, de Castro '02)*
- Web Mining *(Nasaroui'02)*
- Fault Tolerance *(Tyrrell, '01, '02, Timmis '02)*
- Autonomous Systems *(Varela'92,Ishiguro'96)*
- Engineering Design Optimization *(Hajela'96 '98, Nunes'00)*
- And so on …

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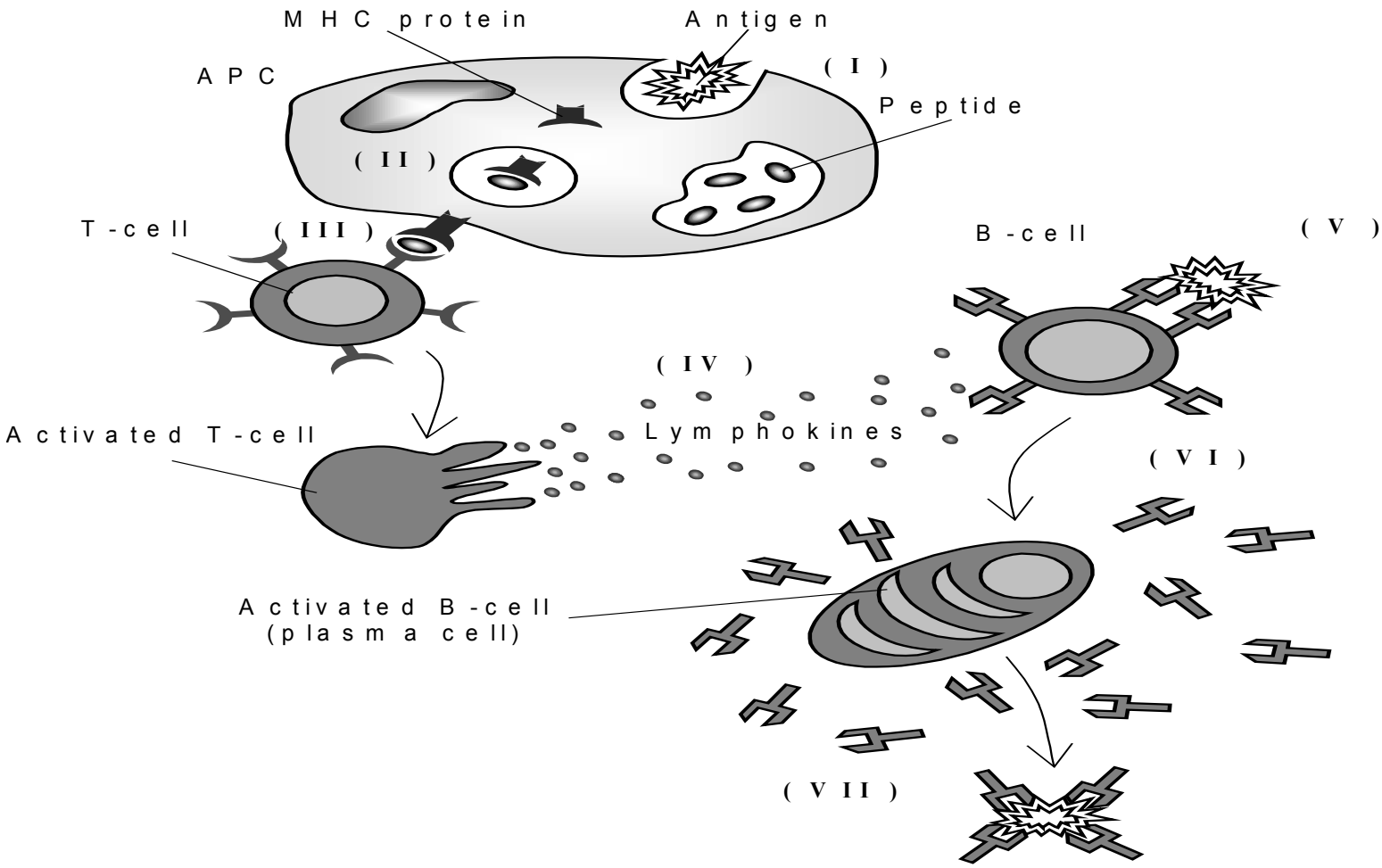
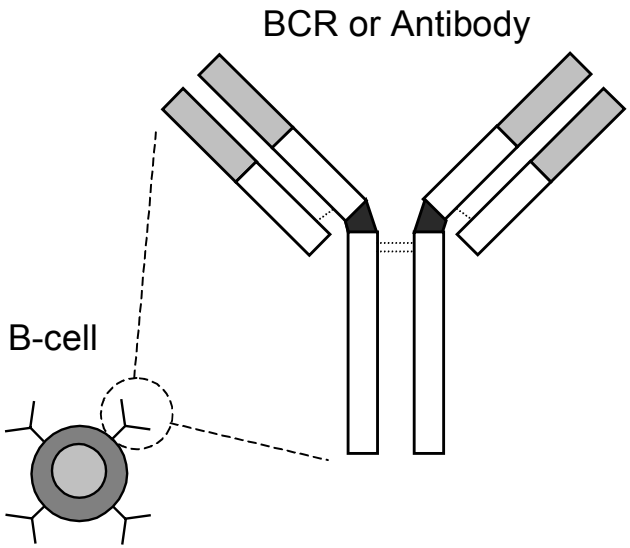
How does it work: A simplistic view

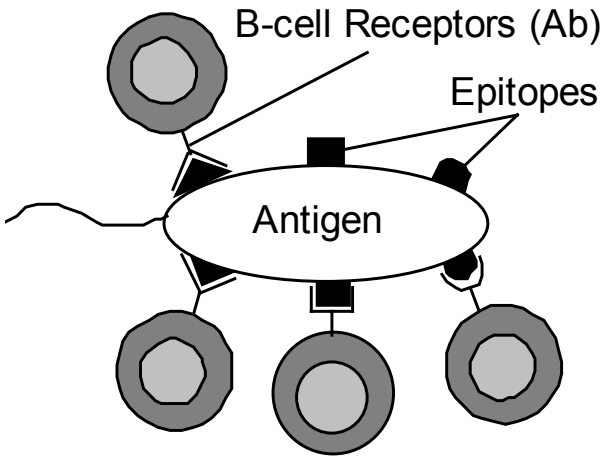


Self/Non-Self Recognition

- Immune system needs to be able to differentiate between self and non-self cells
- Antigenic encounters may result in cell death, therefore
  - Some kind of *positive selection*
  - Some kind of *negative selection*

Immune Pattern Recognition

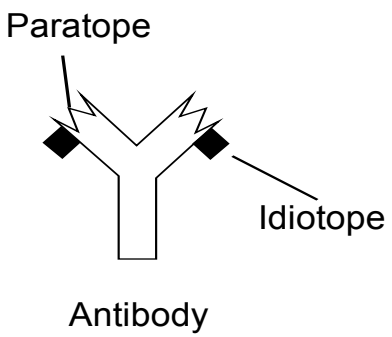


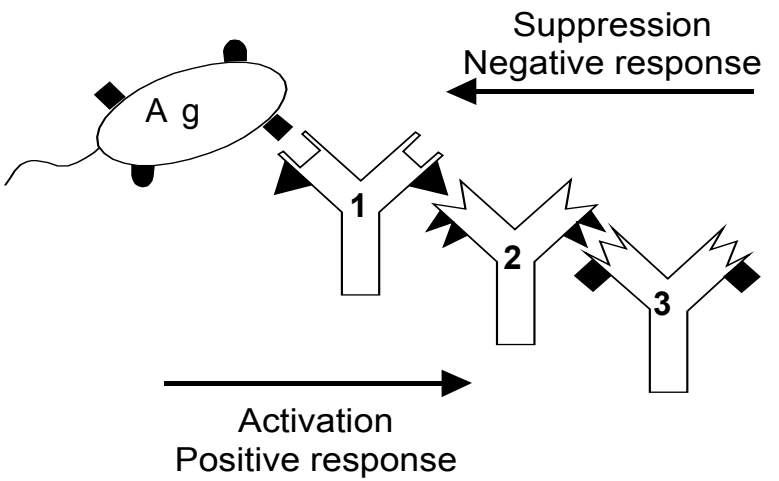


- The immune recognition is based on the *complementarity* between the binding region of the receptor and a portion of the antigen called *epitope*.
- Antibodies present a single type of receptor, antigens might present several epitopes.
  - This means that each antibody can recognize a single antigen

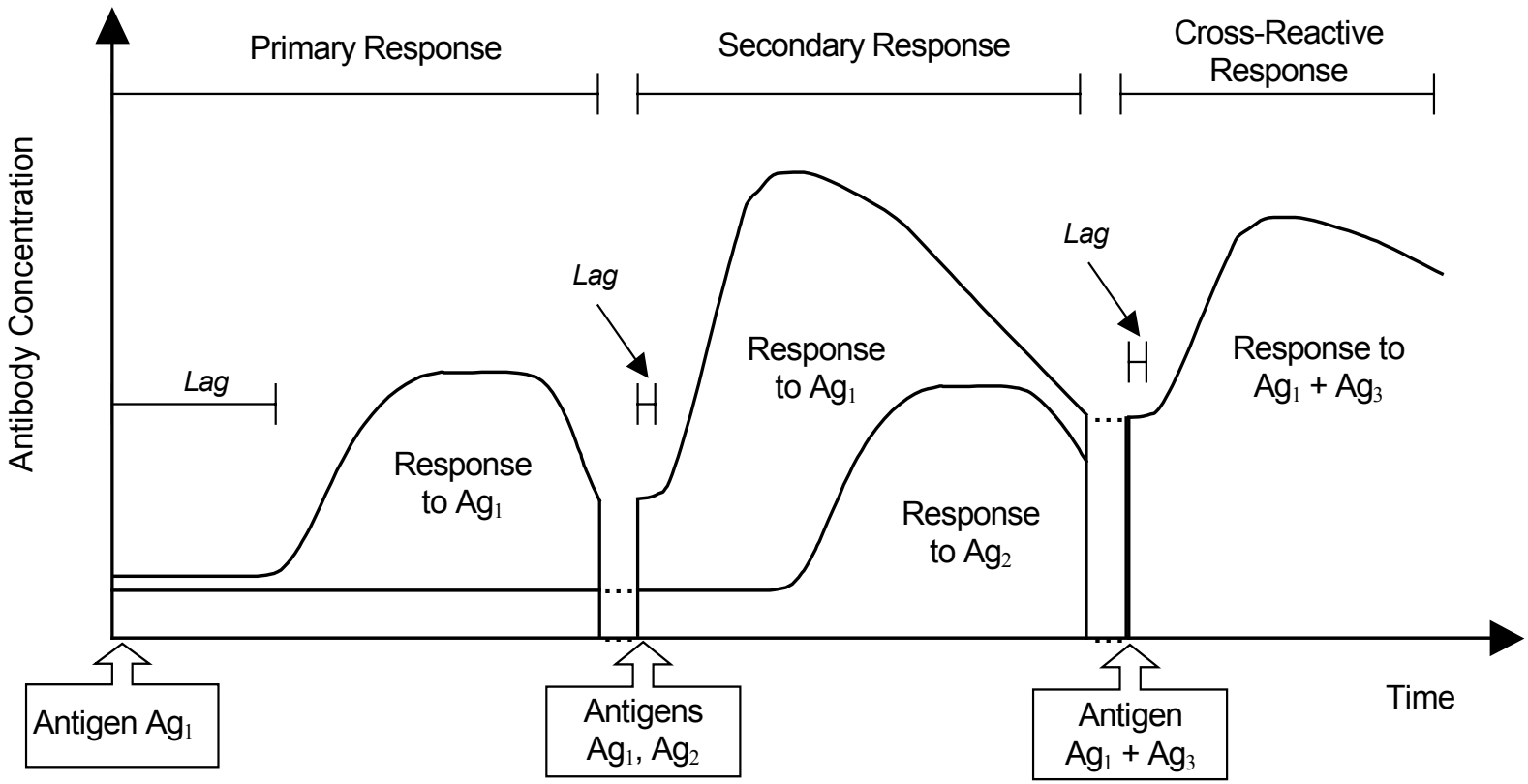
Immune Network Theory

- Idiotypic network (Jerne, 1974)
- B cells co-stimulate each other
  - Treat each other a bit like antigens
- Creates an immunological memory





Learning


Primary Response
Secondary Response
Cross-Reactive Response
Antibody Concentration
Lag
Lag
Lag
Response to Ag_1
Response to Ag_1
Response to Ag_2
Response to $Ag_1 + Ag_3$
Antigen Ag_1
Antigens Ag_1, Ag_2
Antigen $Ag_1 + Ag_3$
Time

Danger Theory (1)

- Proposed by Polly Matzinger, around 1995
- Problem: Traditional self/non-self theory doesn't always match observations
  - Immune system always responds to non-self
    - …apart from the nonself it doesn't respond to (harmless foreign)
  - Immune system always tolerates self
    - …apart from the self it doesn't tolerate (dangerous self)
- T-cell activation by APCs
  - Janeway's infectious nonself model

Danger Theory (2)

- Danger theory relates innate and adaptive immune systems:
  - Tissues induce tolerance towards *themselves*
  - Tissues protect *themselves* and select class of response

1. Tissues induce tolerance by:
   - Lymphocytes receive 2 signals
     - Signal 1 – antigen/lymphocyte binding
     - Signal 2 – antigen is properly presented by APC
   - Signal 1 WITHOUT signal 2 = lymphocyte death

Danger Theory (3)

2. Tissues protect themselves
   - Alarm Signals activate APCs
     - Alarm signals come from
       - Cells that die unnaturally
       - Cells under stress
   - APCs activate lymphocytes
3. Tissues dictate response type
   - Alarm signals may convey information

Immune System: Summary

- The host has to distinguish either between self/non-self or dangerous/non-dangerous
- When an entity is recognised as foreign (or dangerous)- activate several defense mechanisms leading to its destruction (or neutralisation).
- Subsequent exposure to similar entity results in rapid immune response.
- Overall behavior of the immune system is an emergent property of many local interactions.
- So it is useful?

Outline

- What are AIS?
- Useful immunology
- **Thinking about AIS**
- Application Areas
- The Future

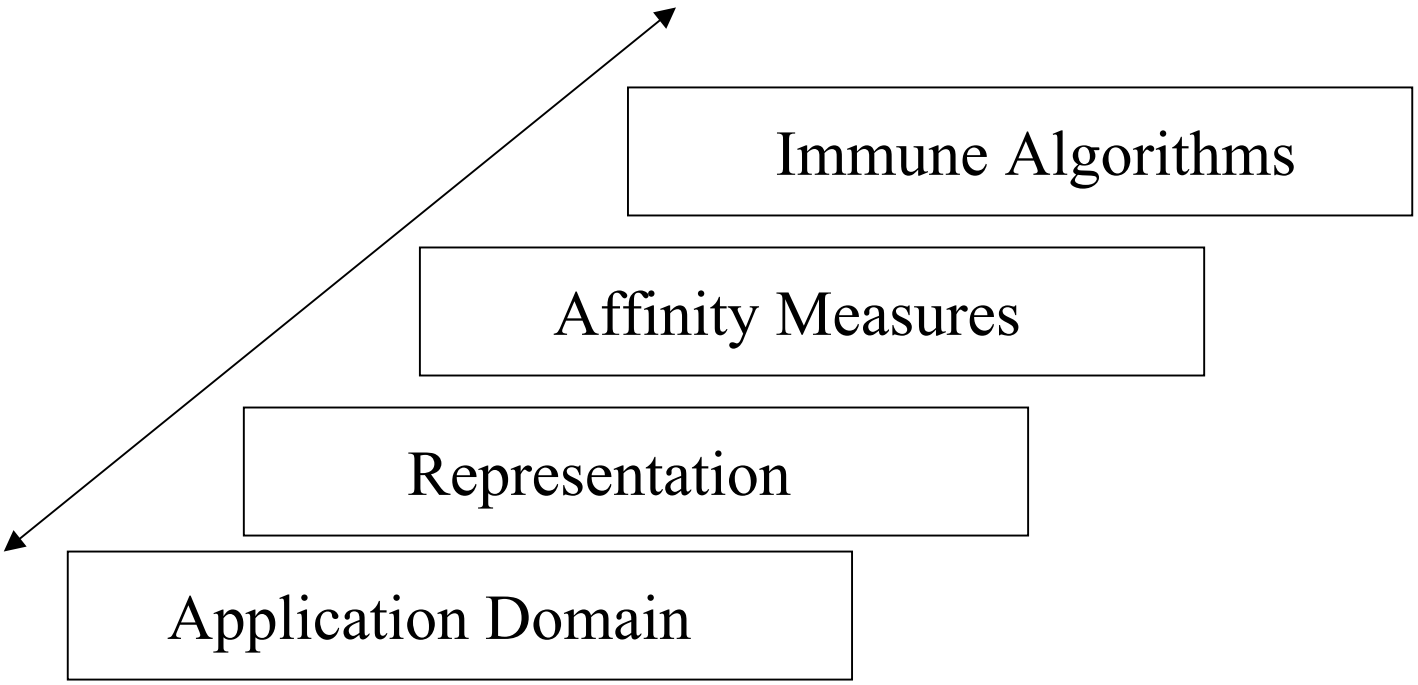
This Section

- General Framework for describing and constructing AIS models
- Provide a few examples of applications
  - Data Mining
  - Optimisation
  - Other areas from the labs research

What do want from a Framework?

- In a computational world we work with representations and processes. Therefore, we need:
  - To be able to describe immune system components
  - Be able to describe their interactions
  - Quite high level abstractions
  - Capture *general purpose* processes that can be applied to various areas

General Framework for AIS



The Framework ..

- Think about the use of AIS in terms of:
  - Representation;
  - Affinity Measures;
  - Immune Algorithms;
- …and **how** we apply them and to **what** we apply them
- Think about the *bias* of all of the above and what affect that may have on the result (if any).

Representation

- Vectors

$$\mathbf{Ab} = \langle Ab_1, Ab_2, \ldots, Ab_L \rangle$$

$$\mathbf{Ag} = \langle Ag_1, Ag_2, \ldots, Ag_L \rangle$$

- Real-valued shape-space
- Integer shape-space
- Binary shape-space
- Symbolic shape-space

Define their Interaction

- Define the term **Affinity**
- Affinity is related to distance
  - Euclidian

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

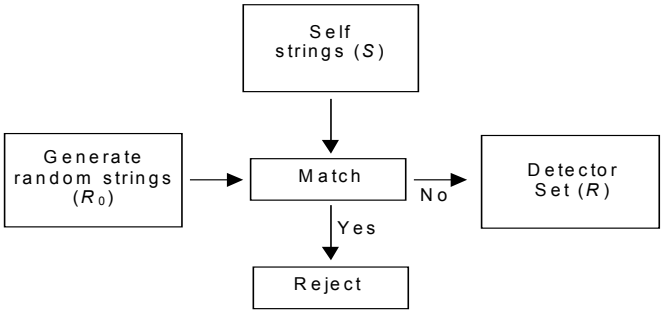
  - Other distance measures such as Hamming, Manhattan etc. etc.
  - Affinity Threshold

Basic Immune Algorithms

- Negative Selection Algorithms
- Clonal Selection Algorithm
- Immune Network Algorithms
- Bone Marrow Algorithms

Negative Selection (NS) Algorithms

- Define *Self* as a normal pattern of activity or stable behavior of a system/process
  - A collection of logically split segments (equal-size) of pattern sequence.
  - Represent the collection as a multiset S of strings of length *l* over a finite alphabet.
- Generate a set R of *detectors*, each of which fails to match any string in S.
- Monitor new observations (of S) for changes by continually testing the detectors matching against representatives of S. If any detector ever matches, a change (or deviation) must have occurred in system behavior.



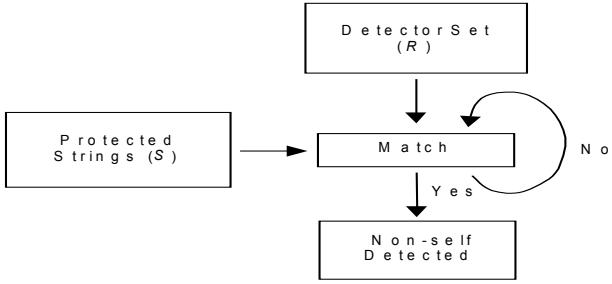
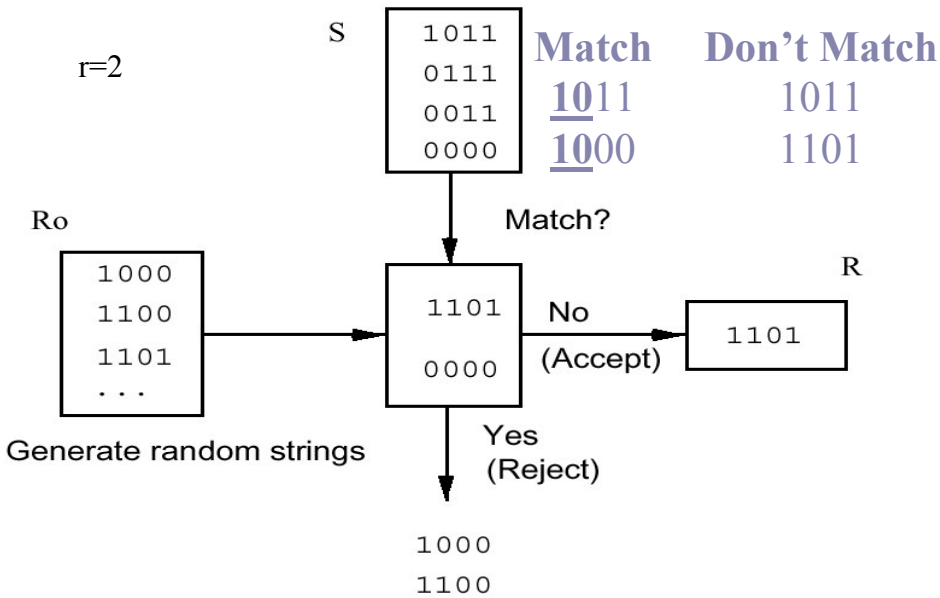
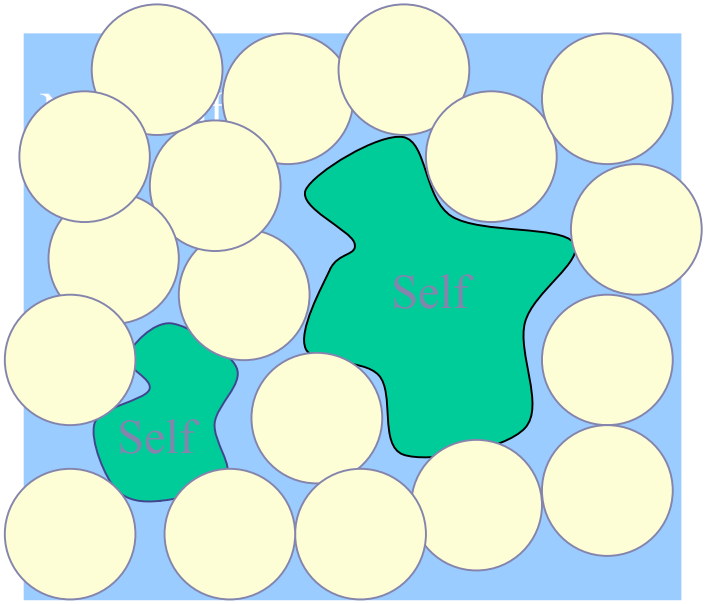


Illustration of NS Algorithm:





Clonal Selection Algorithm

1. *Initialisation*: Randomly initialise a population (P)
2. *Antigenic Presentation*: for each pattern in Ag, do:
   - 2.1 *Antigenic binding*: determine affinity to each P'
   - 2.2 *Affinity maturation*: select *n* highest affinity from P and clone and mutate prop. to affinity with Ag, then add new mutants to P
3. *Metadynamics*:
   - 3.1 select highest affinity P to form part of M
   - 3.2 replace *n* number of random new ones
4. *Cycle*: repeat 2 and 3 until stopping criteria

Immune Network Algorithm

- *Initialisation*: create an initial network from a sub-section of the antigens
- *Antigenic presentation*: for each antigenic pattern, do:

  2.1 Clonal selection and network interactions: for each network cell, determine its stimulation level (based on antigenic and network interaction

  2.2 Metadynamics: eliminate network cells with a low stimulation

  2.3 Clonal Expansion: select the most stimulated network cells and reproduce them proportionally to their stimulation

  2.4 Somatic hypermutation: mutate each clone

  2.5 Network construction: select mutated clones and integrate

3. Cycle: Repeat step 2 until termination condition is met

Outline

- What are AIS?
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- The Future

Data mining

- More benchmark problem in this case
- Assume a set of labelled vectors
- Classification

AIRS: (Artificial Immune Recognition System)

- Clonal Selection
- Based initially on immune networks, though found this did not work
- Resource allocation
- Somatic hypermutation
- Antibody/antigen binding

AIRS: Mapping from IS to AIS

Antibody	→	Feature Vector
Recognition	→	Combination of feature Ball vector and vector class
Antigens	→	Training Data
Immune Memory	→	Memory cells—set of mutated ARBs

AIRS Algorithm

- Data normalisation and initialization
- Memory cell identification and ARB generation
- Competition for resources in the development of a candidate memory cell
- Potential introduction of the candidate memory cell into the set of established memory cells

Classification Accuracy

- Important to maintain accuracy

	AIRS1: Accuracy	AIRS2: Accuracy
Iris	96.7	96.0
Ionosphere	94.9	95.6
Diabetes	74.1	74.2
Sonar	84.0	84.9

Features

- No need to know best architecture to get good results
- Default settings within a few percent of the best it can get
- User-adjustable parameters optimize performance for a given problem set
- Generalization and data reduction

Unsupervised Learning

- Again, a benchmark problem in this case
- Assume a set of unlabelled vectors
- We can ask the questions:
  - Is there a large amount of redundancy?
  - Are there any groups or subgroups intrinsic to the data?
  - What is the structural or spatial distribution?

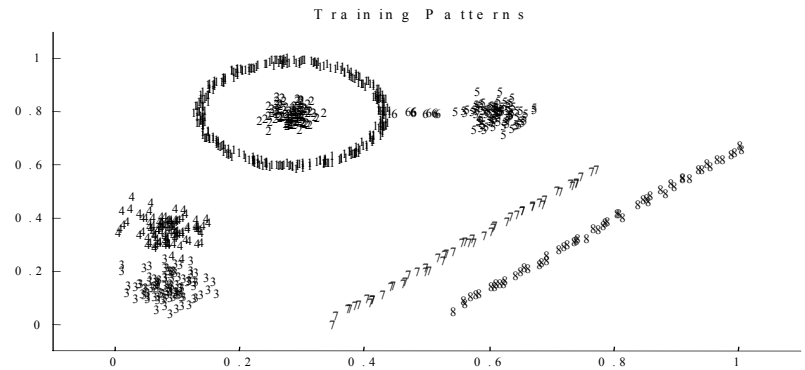
aiNET: Immune principles employed

- B-cells (antibodies)
- Antigens
- Antibody/antigen binding
- Clonal selection process
- Immune network theory
- Combined with statistical analysis tools

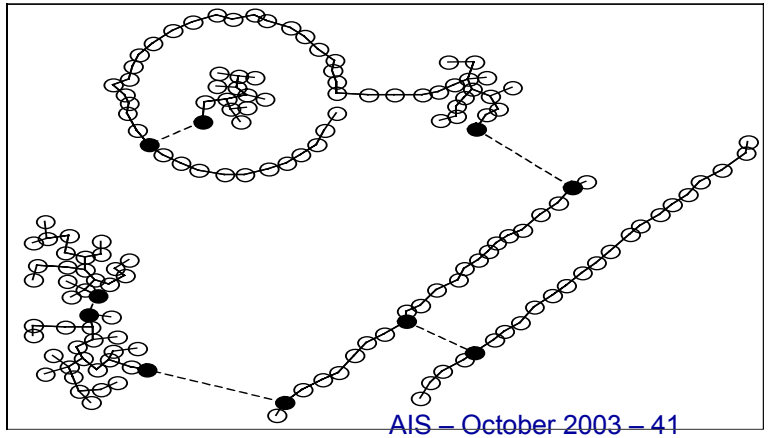
Data mining: Clustering (aiNet)

- Limited visualisation
- Interpret via MST or dendrogram
- Compression rate of 81%
- Successfully identifies the clusters

Training Pattern



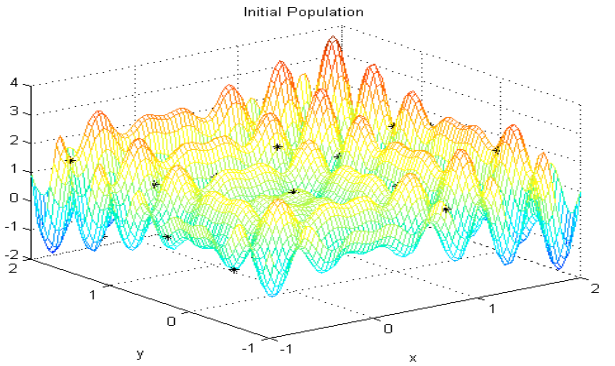
Result immune network



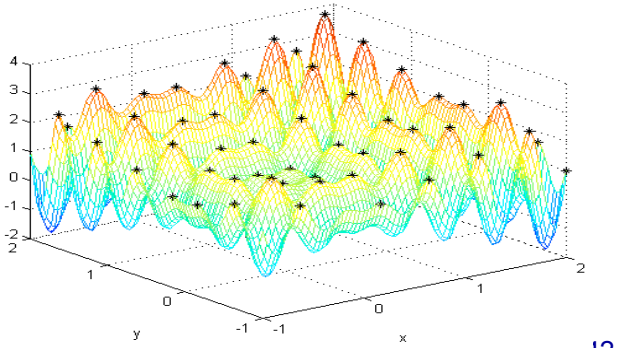
Data mining: Adaptation to multimodal optimisation

- Supports the idea of general purpose algorithms
- Slight modification of network algorithm
- Combines local and global search

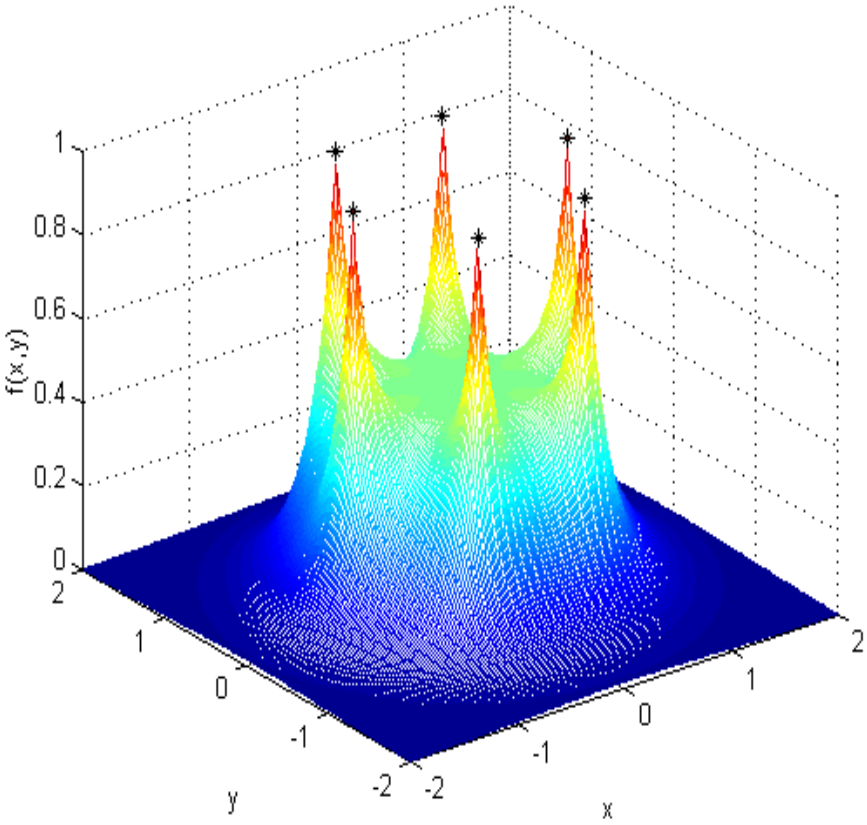
Initial population



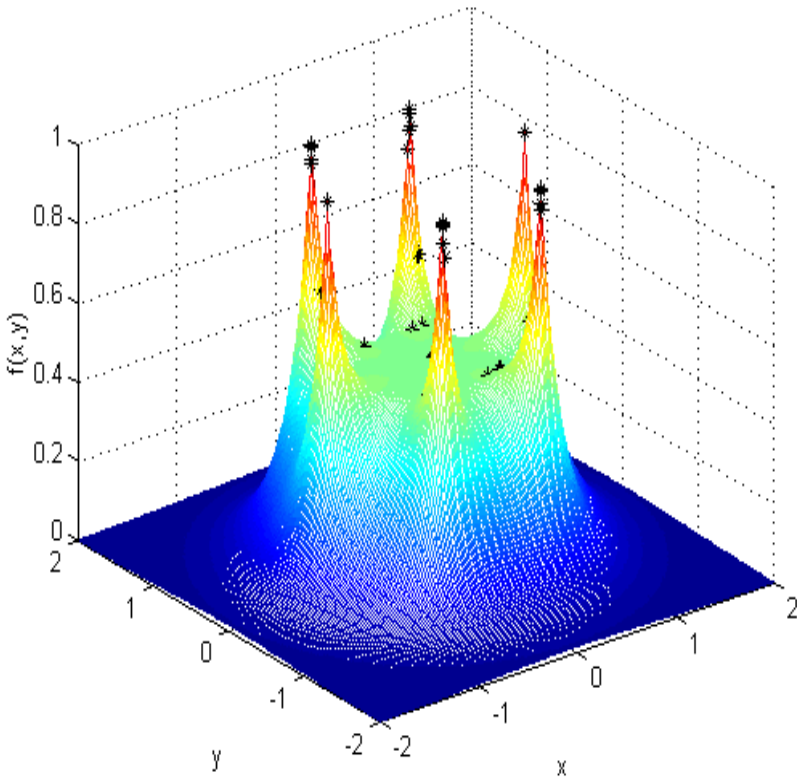
Final population



Results – Roots Function



aiNET



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Fun Immune Inspired Ideas

- Immunised Fault Tolerance for Mechatronic devices
  - Exploratory industrial sponsored work
  - Increase availability of machines
  - Prediction of machine states
- Software Mutation Testing
  - Find a *vaccine* for the software development process
  - Coevolution of programme and test data to identify common errors in the software development lifecycle of a particular team

More fun …

- Danger theory and Web content mining
  - Extracting information from the content of web pages.
  - Little AIS research in this area.
  - A very large and very dynamic data set.
- Domain characteristics include:
  - Highly volatile data.
  - High volume of data.
  - Ever-changing content.
  - Need for continuous adaptation.

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The Future

- Rapidly emerging field
- Much work is very diverse
  - Framework helps a little
  - More formal approach required?
- Wide possible application domains
- What is it that makes the immune system unique?
- More work with immunologists
  - Theories such as Danger theory, Self-Assertion may have something to say to AIS

Danger Theory and AIS

- Advantages
  - More scalable (activation in danger area only)
  - More dynamic
- Both do not have to be explicitly coded for

- Characteristics
  - Context dependent activation
    - via danger signal
  - Notion of danger area
  - Localised response within danger area

Integrating: Homeostasis

Ability of an organism to achieve a steady state of internal body function in a varying environment

- Lots of complex interactions
  - Nervous system
  - Endocrine system
  - Immune System
- Developed a simple neural network and endocrine controller for a mobile robot

The Future (2)

- ARTIST: A Network for Artificial Immune Systems (EPSRC funded network)
- Work towards:
  - A theoretical foundation for AIS as a new CI
  - Extraction of accurate metaphors
  - Immune System Modelling
  - Application of AIS
- Train PhD students
- Fund workshops/meetings
- Coordinate and Disseminate UK based AIS research (links to Europe)

AIS Resources: Books

- Artificial Immune Systems and Their Applications by Dipankar Dasgupta (Editor) Springer Verlag, January 1999.
- Artificial Immune Systems: A New Computational Intelligence Approach by Leandro N. de Castro, Jonathan Timmis, Springer Verlag, November 2002.
- Immunocomputing: Principles and Applications by Alexander O. Tarakanov, Victor A. Skormin, Svetlana P. Sokolova, Springer Verlag, April 2003.