UNIVERSITY OF LIVERPOOL

COMP 532
Machine Learning and BioInspired Optimization

Lecture 26: Artificial Immune System

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Tentative Schedule Task 2

30 April, 3pm

Group 1	**Jennifer Brown, Jessica Wimble, Andreea Perry-Gardner**	**– Article 1**
Group 2	**Ben Scotland, Callum Harris, Lauren Parker, Sam Broadhurst**	**– Article 2**
Group 3	**Michael Worthington, Jack Taylor, Robert Johnson, Michael Wright**	**– Article 3**
Group 4	**Shibao Yang, Ting Feng, Shengqiong Sun**	**– Article 4**

Tentative Schedule Task 2

11 May, 2pm

Group 5	**Orestis Katsanakis, Shaun Markham, Konstantinos Vatikiotis**	**– Article 5**
Group 6	**Mohamed Amine Ait Mansour, Cameron Hargreaves, James Wynne**	**– Article 6**
Group 7	**Ji Jia, FengRui Zhang, QingYing Zheng, Tianda Sun**	**– Article 7**
Group 8	**Matthew Oates, Jet Lee; Dominic Edwards, Gregory Madden**	**– Article 8**

Tentative Schedule Task 2

11 May, 4pm

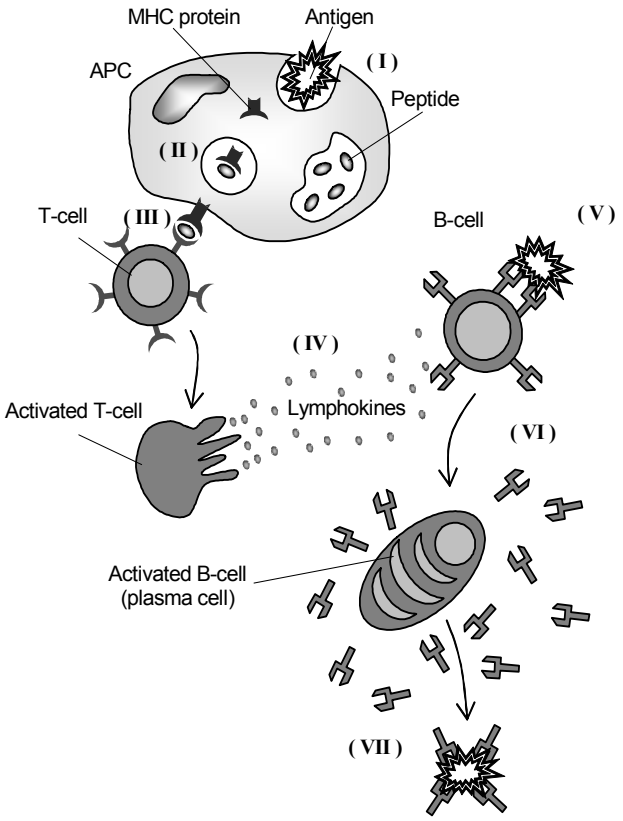
Group 9	**Alfredo Rodriguez Caballero, Daniel Shamaeli, Pablo Romero Salinas**	**– Article 9**
Group 10	**Lun Chen, Thomas Welsch, Haoxuan Chen**	**– Article 20**
Group 11	**Yifan Guan; Yanqing He; Zhaoye Wu**	**– Article 11**
Group 12	**Lu Chen, Keyan Li, Yuxiang Wang**	**– Article 12**
Group 13	**George Mostyn-Parry, Adrian Shannon, Robert Sherman**	**– Article 14**

Overview (2 Lectures)

- Part I: Introduction
  - Why artificial immune systems?
  - The immune system
- Part II: Artificial Immune Systems
  - The generic AIS framework
  - Negative Selection
  - Clonal Selection

Why Mimic the Immune System?

- Recognition
  - Anomaly detection
  - Noise tolerance
- Robustness
- Feature extraction
- Reinforcement learning
- Memory
- Distributed
- Multi-layered
- Adaptive



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.
- 1990 – Bersini first used immune algorithms to solve problems
- Forrest *et al.* – Computer Security mid 1990's
- Hunt et al, mid 1990's – Machine Learning
- 2000's Timmis *et al.*: data analysis

Has been applied in

- 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)

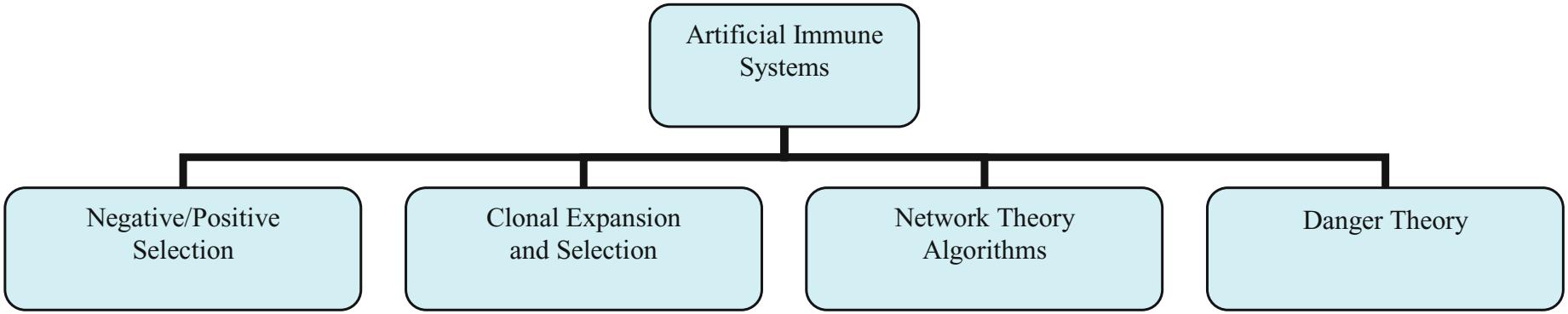
Has been applied in

- Job shop Scheduling (Hart 98,01,02)
- Chemical Pattern Recognition (Dasgupta 99)
- Robotics (Ishiguro 96,97; Singh 01)
- Optimization (DeCastro 99,02; Endo 98)
- 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 …

A Taxonomy of AIS

Four main groups of algorithms

(Brabazon chapter, see VITAL)



The immune system is:

- **Immune system**: a system that **protects** the body from foreign substances and pathogenic organisms by producing the immune response

- **Immunity**: state or quality of being resistant (immune), either by virtue of previous exposure (adaptive immunity) or as an inherited trait (innate immunity)

Role of the Immune System

- Protect our bodies from pathogen and viruses

- **Primary immune response**
  - Launch a response to invading pathogens

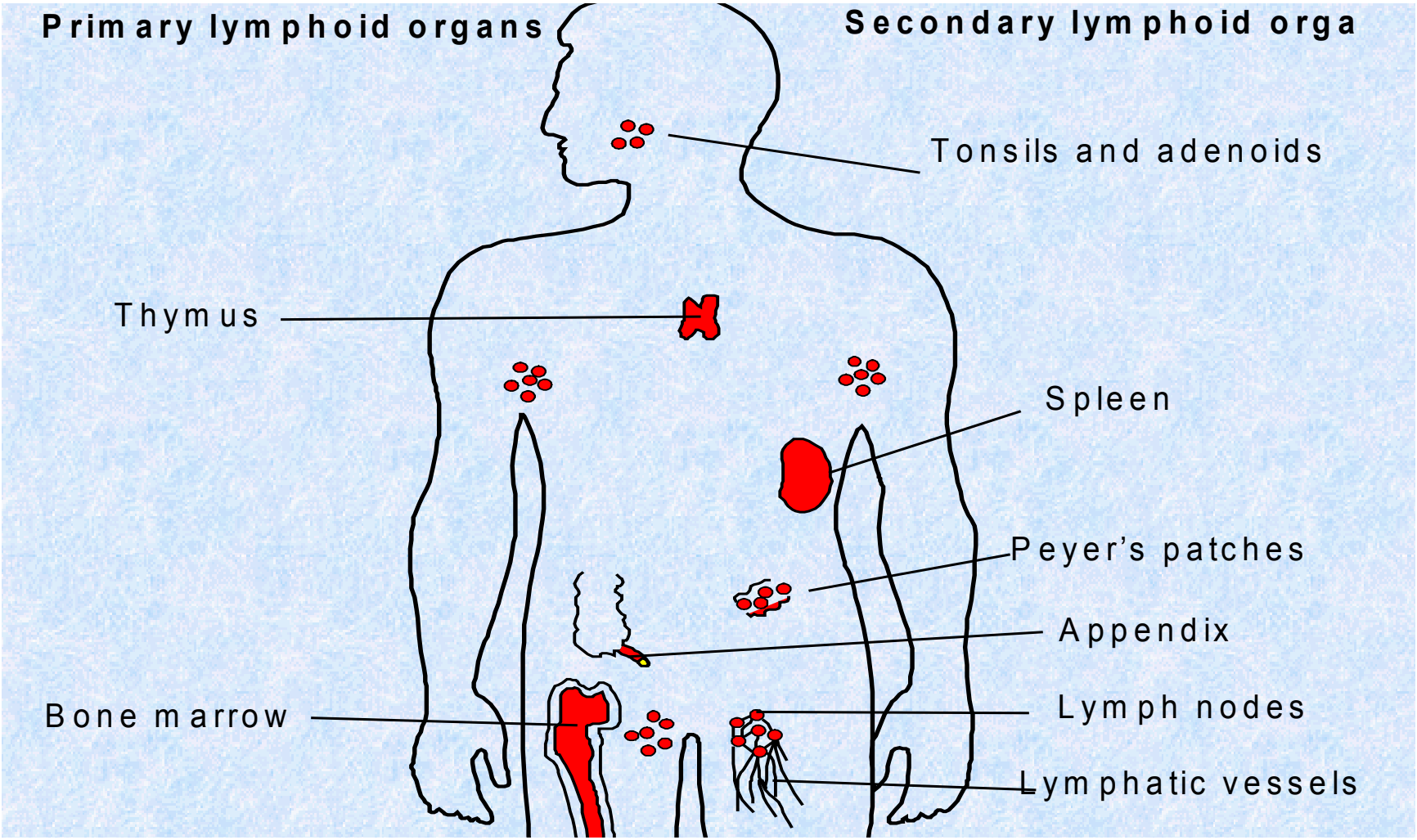
- **Secondary immune response**
  - Remember past encounters
  - Faster response the second time around

Immune cells

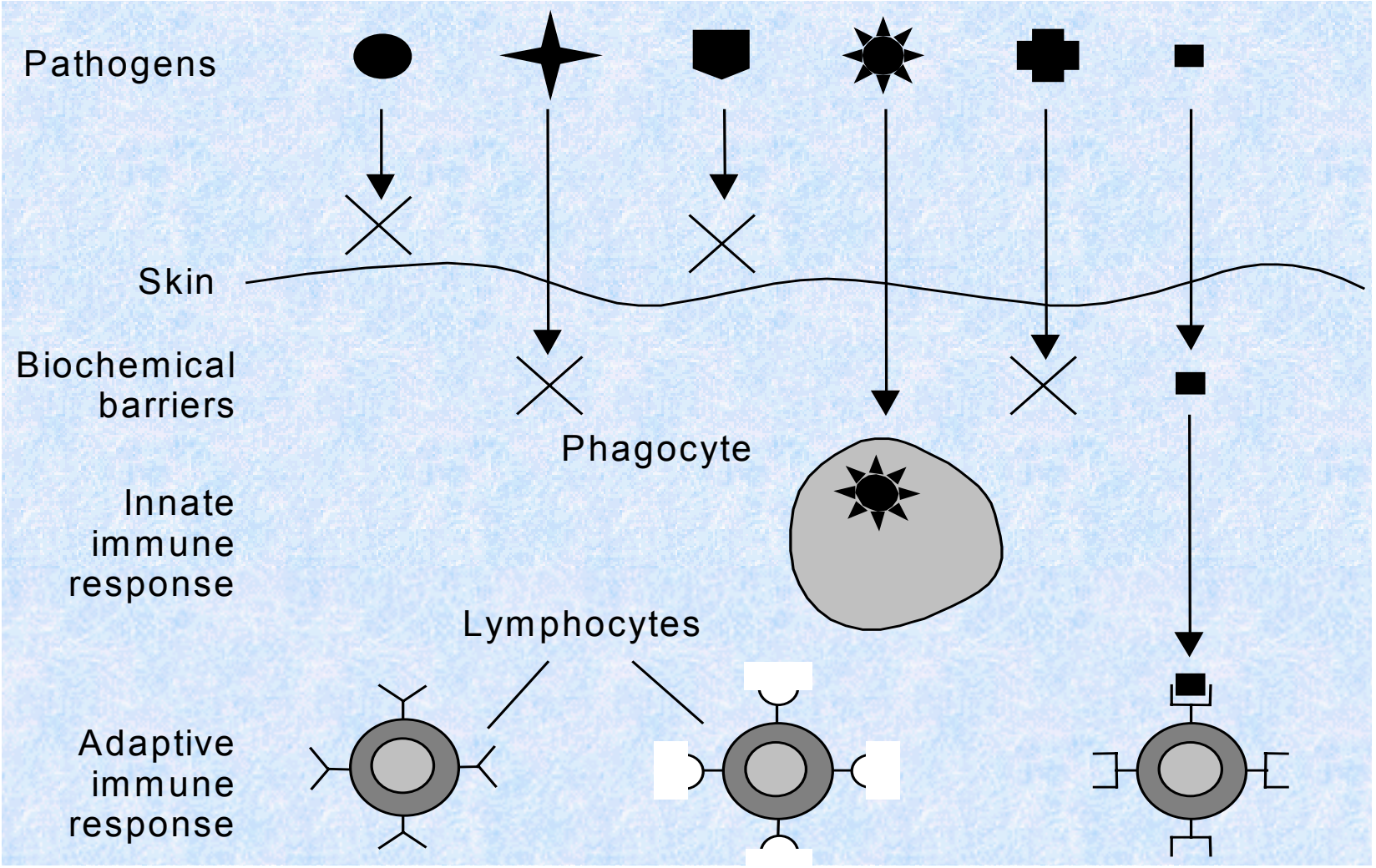
- There are two primarily types of lymphocytes:
  - B-lymphocytes (B cells)
  - T-lymphocytes (T cells)

- Others types include macrophages, phagocytic cells, cytokines, etc.

Where is it?


Primary lymphoid organs
Secondary lymphoid orga
Tonsils and adenoids
Thymus
Spleen
Peyer's patches
Appendix
Bone marrow
Lymph nodes
Lymphatic vessels

Multiple layers



Antigen

- Substances capable of starting a specific immune response commonly are referred to as **antigens**

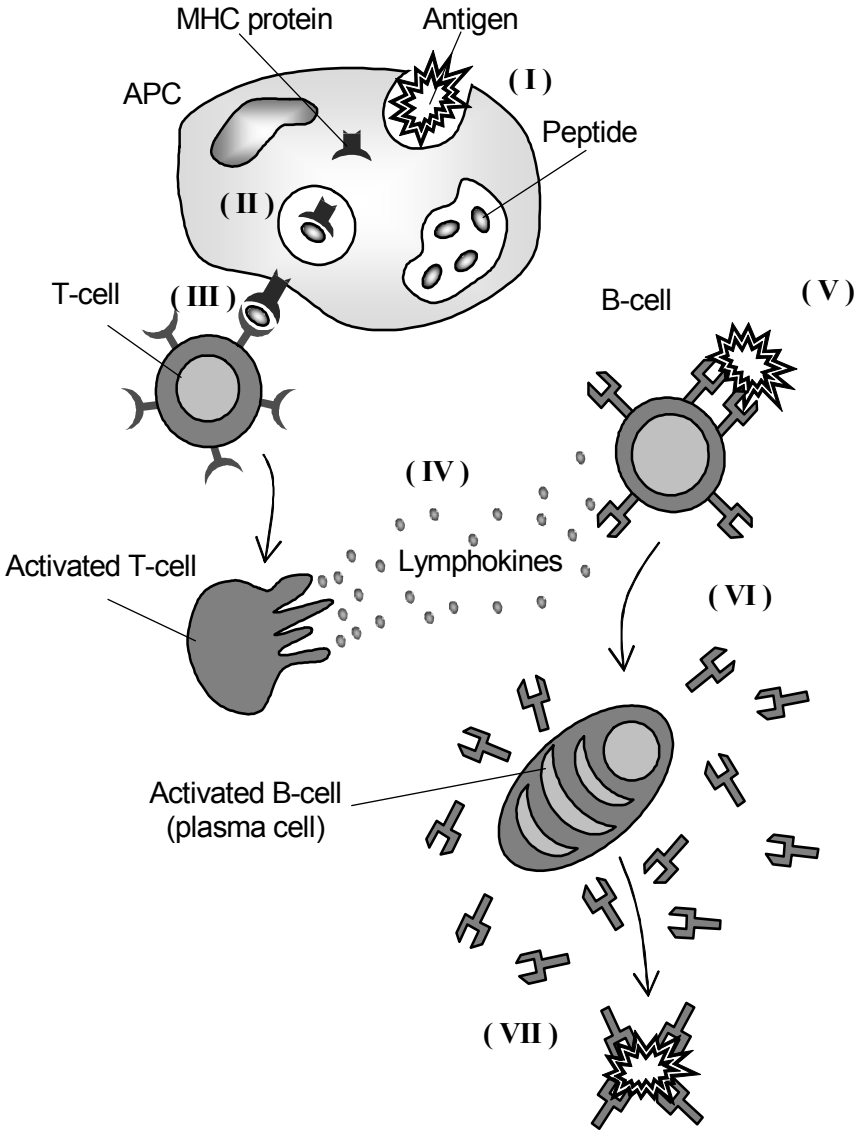
- This includes some pathogens such as viruses, bacteria, fungi etc.

Self/Non-Self Recognition

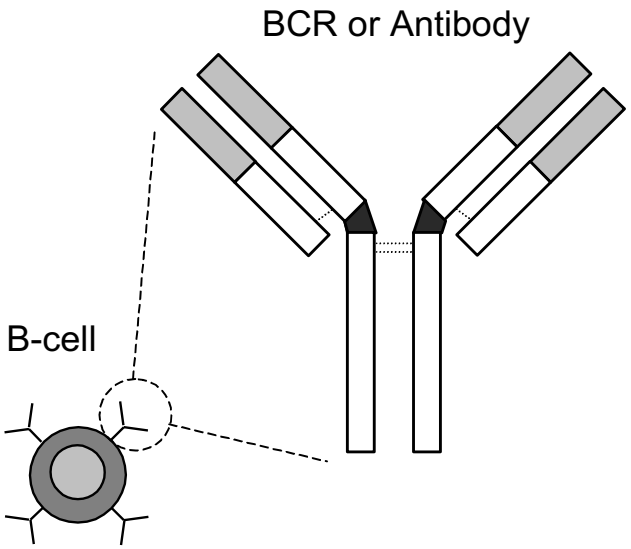
- Immune system needs to be able to differentiate between **self** and **non-self** cells

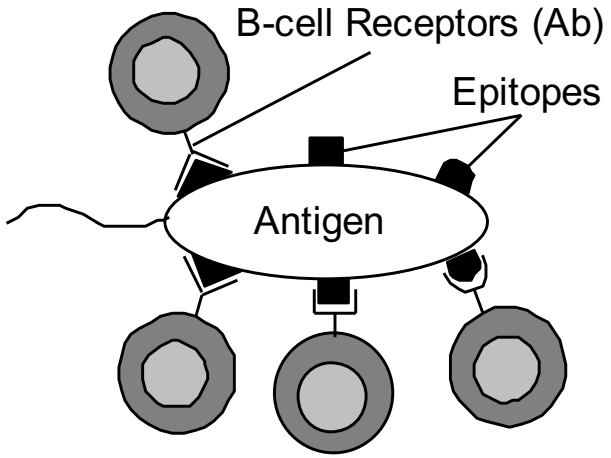
- Antigenic encounters may result in cell death, therefore
  - Some kind of *positive selection* (for non-self)
  - Some element of *negative selection* (for self)

How does it work: A simplistic view



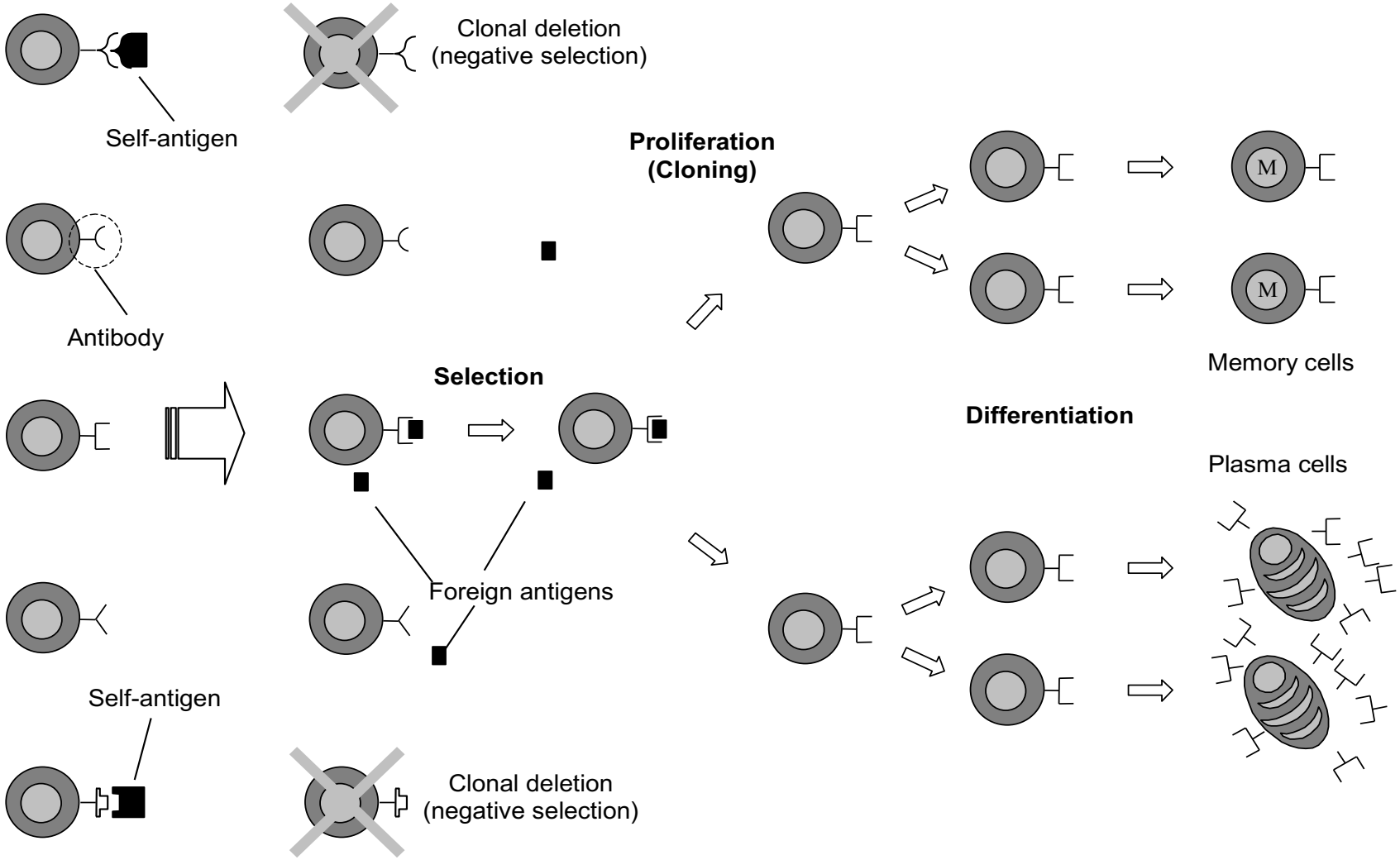
Immune Pattern Recognition





- 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

Clonal Selection

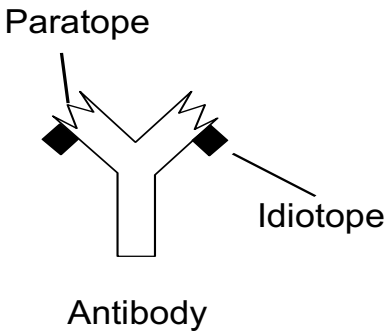


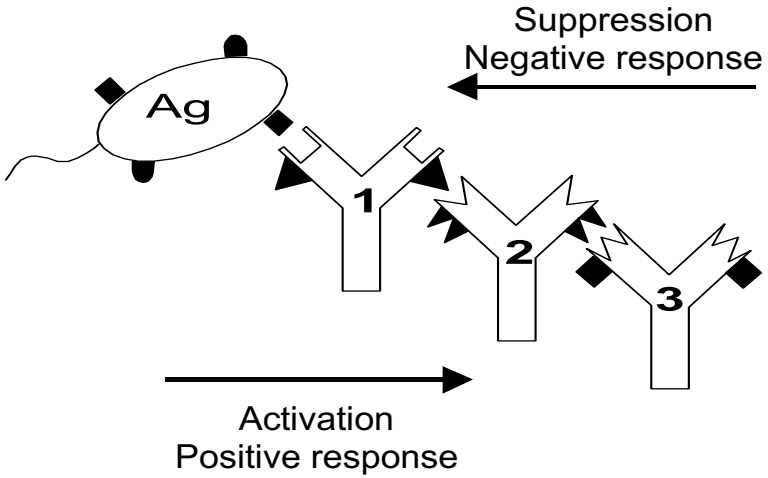
Main Properties of Clonal Selection

- Elimination of self antigens (negative selection)
- Proliferation and differentiation on contact of mature lymphocytes with antigen
- Restriction of one pattern to one differentiated cell and retention of that pattern by clonal descendants (memory cells)
- Generation of new random genetic changes, subsequently expressed as diverse antibody patterns by a form of accelerated somatic mutation

Immune Network Theory

- Idiotypic network
- B cells co-stimulate each other
  - Treat each other a bit like antigens
- Creates an immunological memory

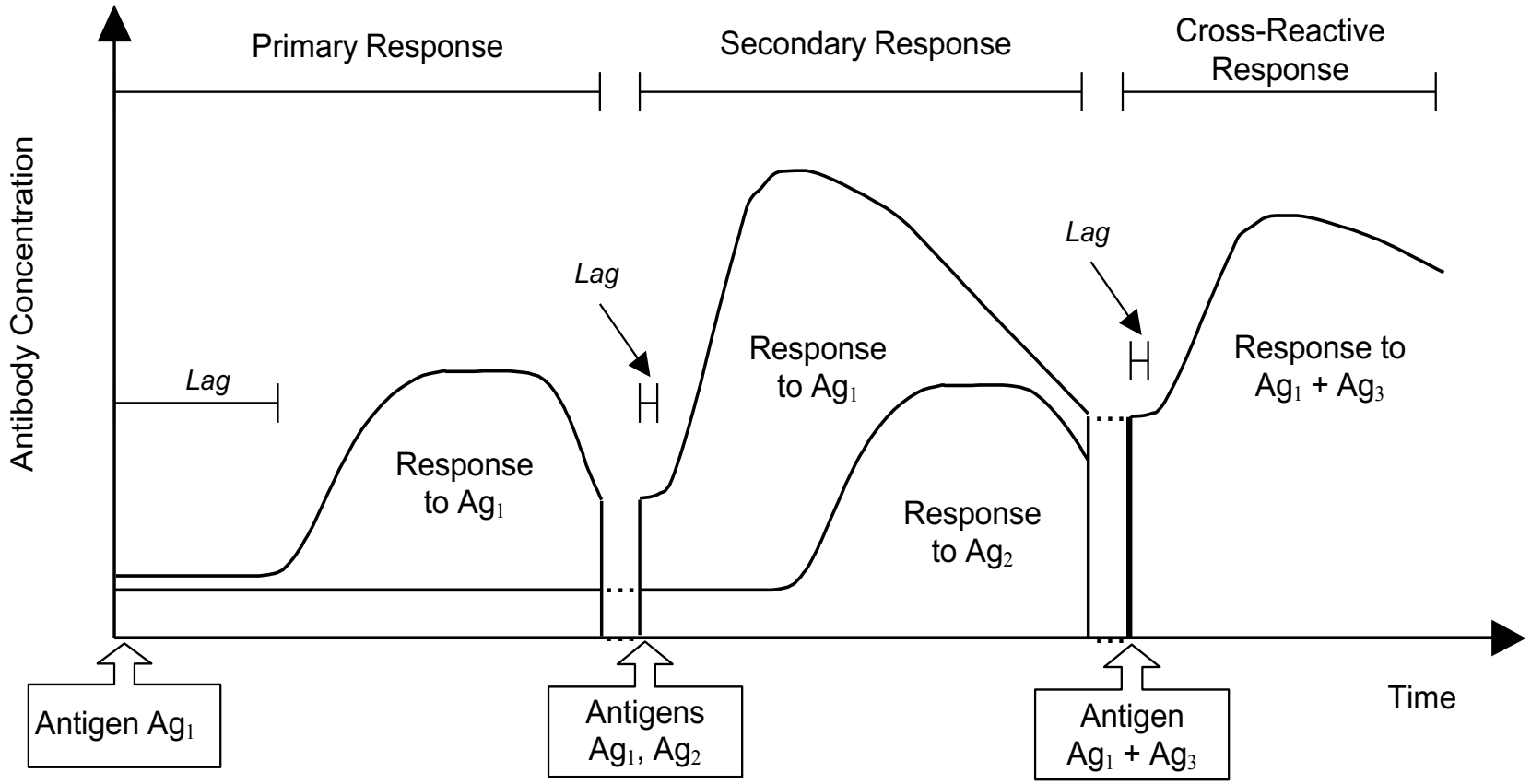




Reinforcement Learning and Immune Memory

- **Repeated exposure** to an antigen throughout a lifetime
- Primary, secondary immune responses
- **Remembers encounters**
  - No need to start from scratch
  - Memory cells
- **Continuous learning**

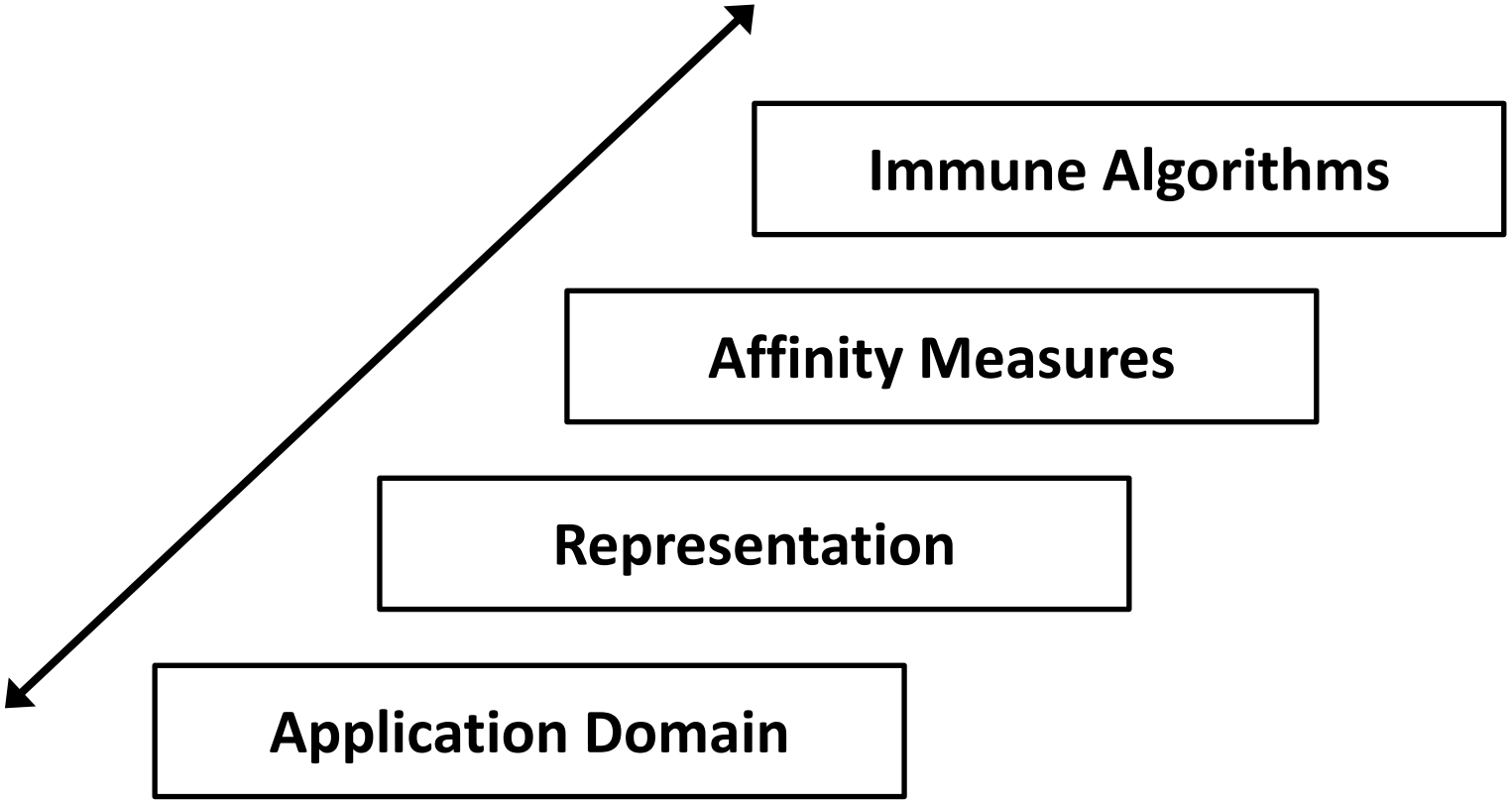
Reinforcement Learning and Immune Memory



Immune System: Summary

- Distinguish self (body cells) from non-self entities.
- When an entity is recognized as foreign (or dangerous) - activate several defense mechanisms leading to its neutralization.
- 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?

General Framework for AIS



Representation

- Vectors

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

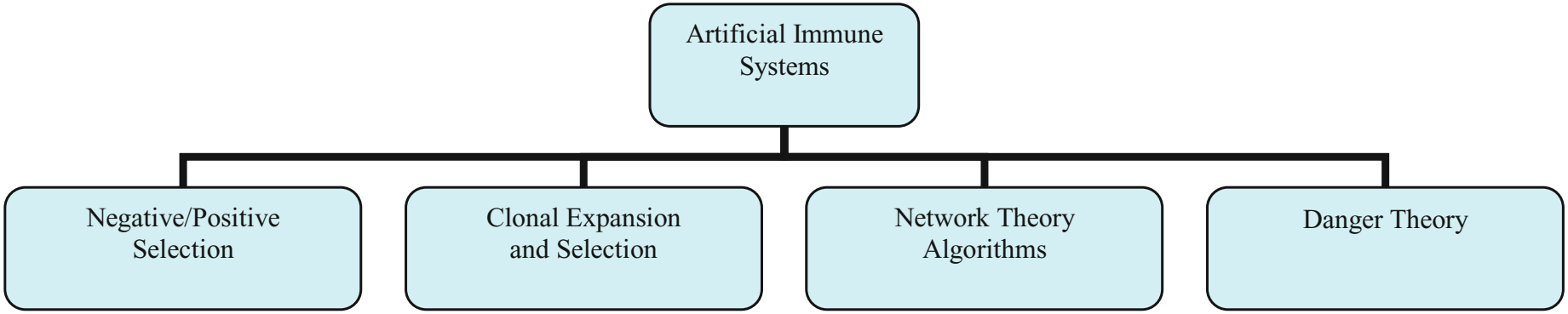
$$\mathbf{Ag} = \langle Ag_1, Ag_2, \ldots, Ag_L \rangle$$

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

Define their Interaction

- Define the term **Affinity**
- Typically: distance measures such as Hamming, Manhattan etc. etc.
- Affinity Threshold

Basic Immune Models and Algorithms

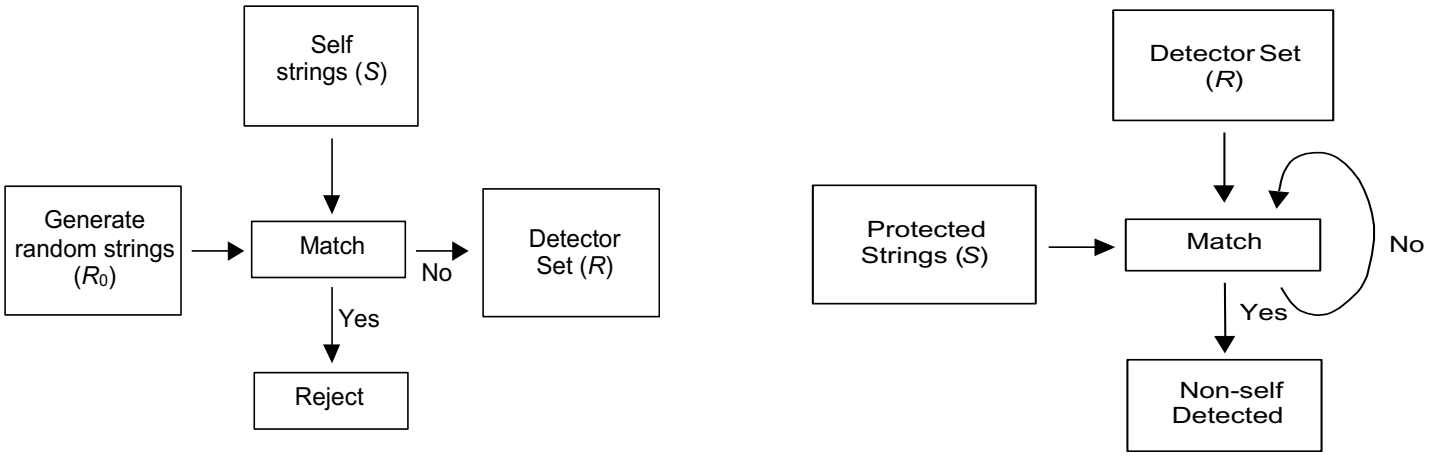


- Negative Selection Algorithms
- Clonal Selection Algorithm
- Immune Network Models
- Danger Theory

- Important building block: **somatic hypermutation**

Negative Selection Algorithms

- Idea taken from the negative selection of T-cells in the thymus
- Applied initially to computer security
- Split into two parts:
  - Censoring
  - Monitoring



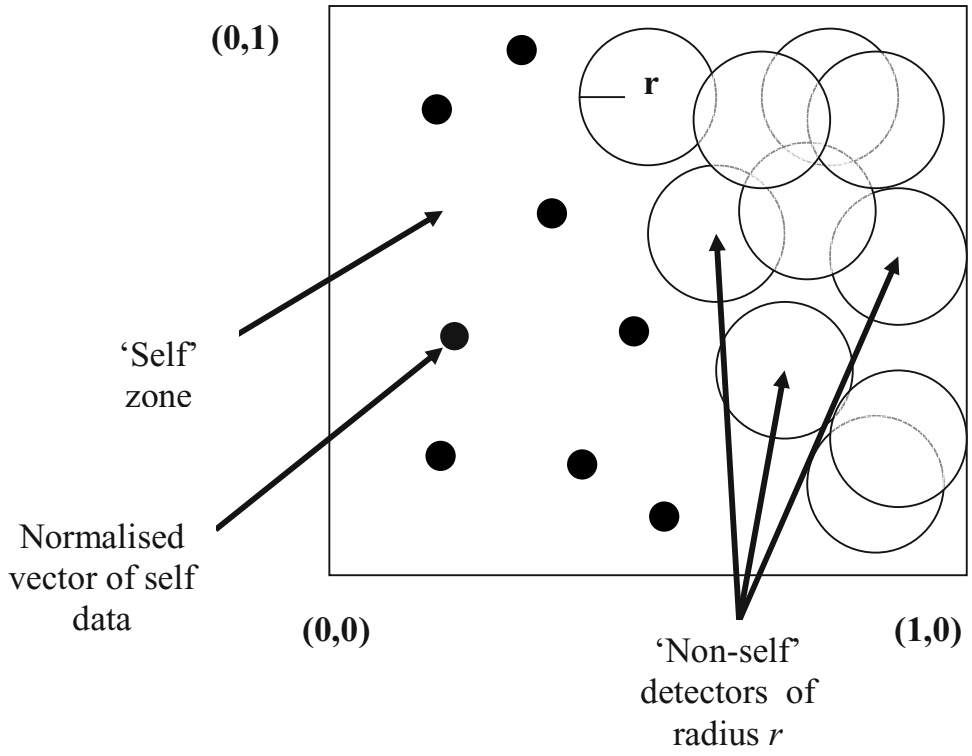
Negative Selection Algorithms

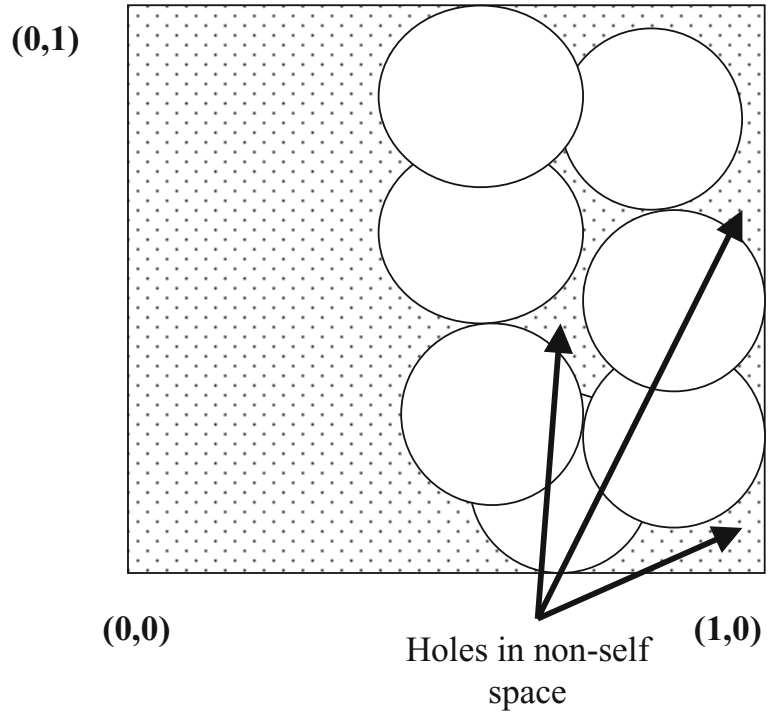
Algorithm 16.1: Negative Selection Algorithm

Initialise the detector set D to be the empty set;

repeat
  Create a random vector x, drawn from $[0,1]^n$;
  for *every* s_i *in* S, $i = 1, 2, ..., m$ **do**
    Calculate the Euclidean distance d_i between s_i and x;
  end
  if $d_i > r_s$ *for all* i **then**
    Add x (a valid nonself detector) to set D;
  end
until D *contains the required number* N *of valid detectors*;

Negative Selection Algorithm





Clonal Selection Algorithms

- Two populations:
  - Antigens = environment
  - Antibodies = current solutions

- **Affinity**: how well does an antibody “fit” with the population of antigens

- **Select** and **clone** antibodies proportional to affinity, and **mutate** inversely proportional to affinity

- Fitter antibodies are selected to form the next population

Clonal Selection Algorithms

Algorithm 16.3: CLONALG Algorithm

Create an initial random population P of solution vectors (antibodies);

repeat

  Select a set F of parents, $F \subseteq P$, biasing the selection process towards better solutions;

  for *each member of* F **do**

    Create a population P^{clone} of clones from F, with better members of F producing more clones (clonal expansion step);

    Mutate each of these clones, in inverse proportion to their parent's fitness (the hypermutation step), giving population P^{hyper};

    Select S, a subset of the better newly generated solutions P^{hyper};

    Create R, a set of new random solutions;

    Replace poorer members of P with better solutions from S and R;

  end

until *terminating condition*;

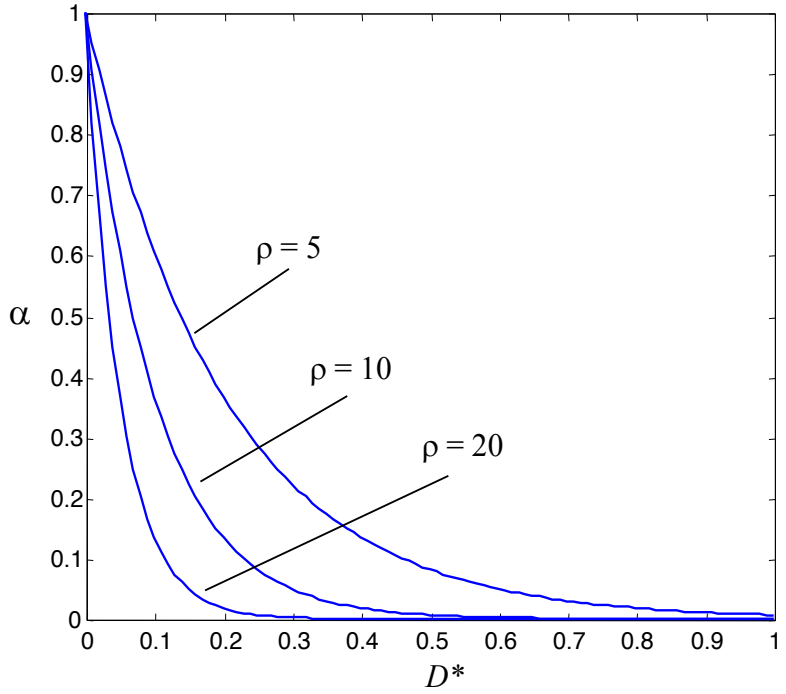
Clonal Selection Algorithms

- Resemblance to evolutionary algorithms
  - Both use populations that evolve based on fitness

- However, the way in which diversity is generated differs
  - Both use fitness proportionate selection
  - CS also uses fitness proportionate cloning and inverse proportionate mutation
  - CS does not use crossover

Somatic Hypermutation

- Mutation rate in proportion to affinity
- Highly controlled mutation in the natural immune system
- Trade-off between the normalized antibody affinity D^* and its mutation rate α, e.g. following $\alpha = e^{-\rho \cdot D^*}$



AIRS: Artificial Immune Recognition System

- One of the few examples where AIS are used for classification via supervised learning
  - Can be competitive to traditional classifiers
- Based on the way immune systems remember previously seen antigens
- However: difficult implementation and multiple user-defined parameters

AIRS Algorithm

High level overview:

1. present the training data (antigens) one at a time to the system
2. generate a candidate memory cell, and implement a cloning, mutation and affinity maturation process to refine memory cell candidates
3. determine whether the candidate memory cell is added into the final memory cell pool
4. repeat above steps until all training instances are presented
5. output is a population of memory cells, which can then be used, via a k nearest neighbour approach, to produce out-of-sample classifications

New Trends

- Danger Theory
  - Not self/non-self but danger/non-danger
  - Immune response is initiated by danger or alarm signals, such as molecules emitted by injured or dying cells
  - This makes it context dependant
  - Used as inspiration for the Dendritic Cell Algorithm

Summary

- Inspired by immune system metaphors
  - Antibodies and their interactions
  - Immune learning and memory
  - Self/non-self
  - Somatic hypermutation

- Artificial immune system algorithms
  - Negative Selection
  - Clonal Selection

IS as a Swarm System

The IS model has a number of characteristics in common with swarm systems:

- Large populations of independent agents of characterizable classes
- Each agent has at most a very few characteristic simple behaviors:
  - Bind with another appropriate agent and activate (B and T cells)
  - Kill something (killer T cell)
  - Clone myself (B cell)
  - Secrete a signaling chemical or an antibody (T and B cells)
  - Live for a long time (memory B and T cells)
- Simple interactions with the environment:
  - Special things that happen in lymphoid organs
  - Secreting signal chemicals which alter environmental properties (cytokines and inflammation)
- Self-organizing as an emergent property
- No centralized control over the system