Artificial Immune Systems Tutorial

By

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Overview

- **Biological Immune System.**
- Artificial Immune System (AIS).
- Comparison to other Algorithms.
- Applications of AIS:
  - Data Mining.
  - Security (Build Your Own).
  - Others.
- The Future.

Antigens

- Substances capable of starting a specific immune response are referred to as **antigens.**
- This includes some pathogens such as viruses, bacteria, fungi etc .

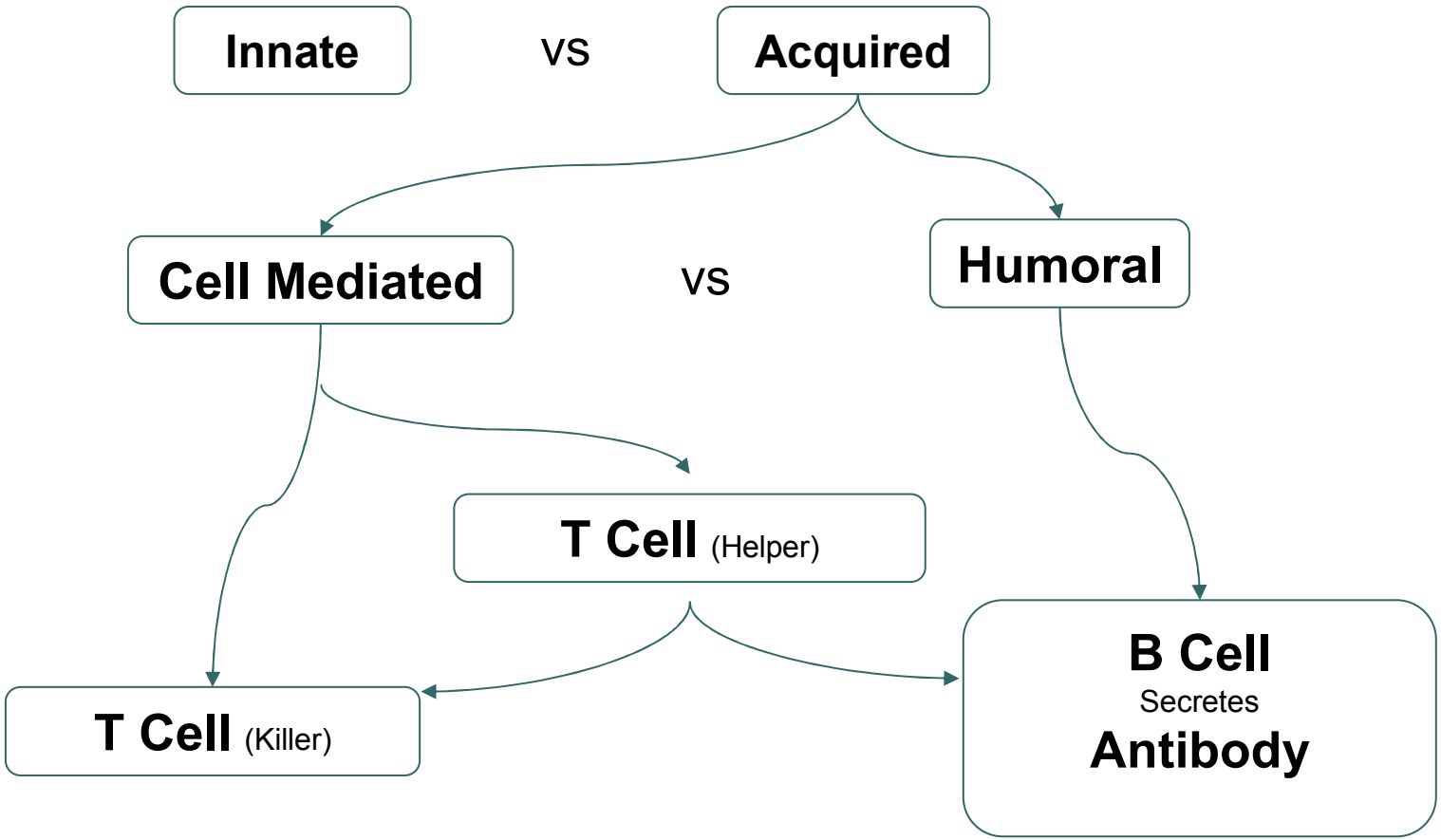
Why the Immune System?

- Robust.
- Autonomous.
- Effective Memory.
- Distributed.
- Adaptive.
- Very Successful.

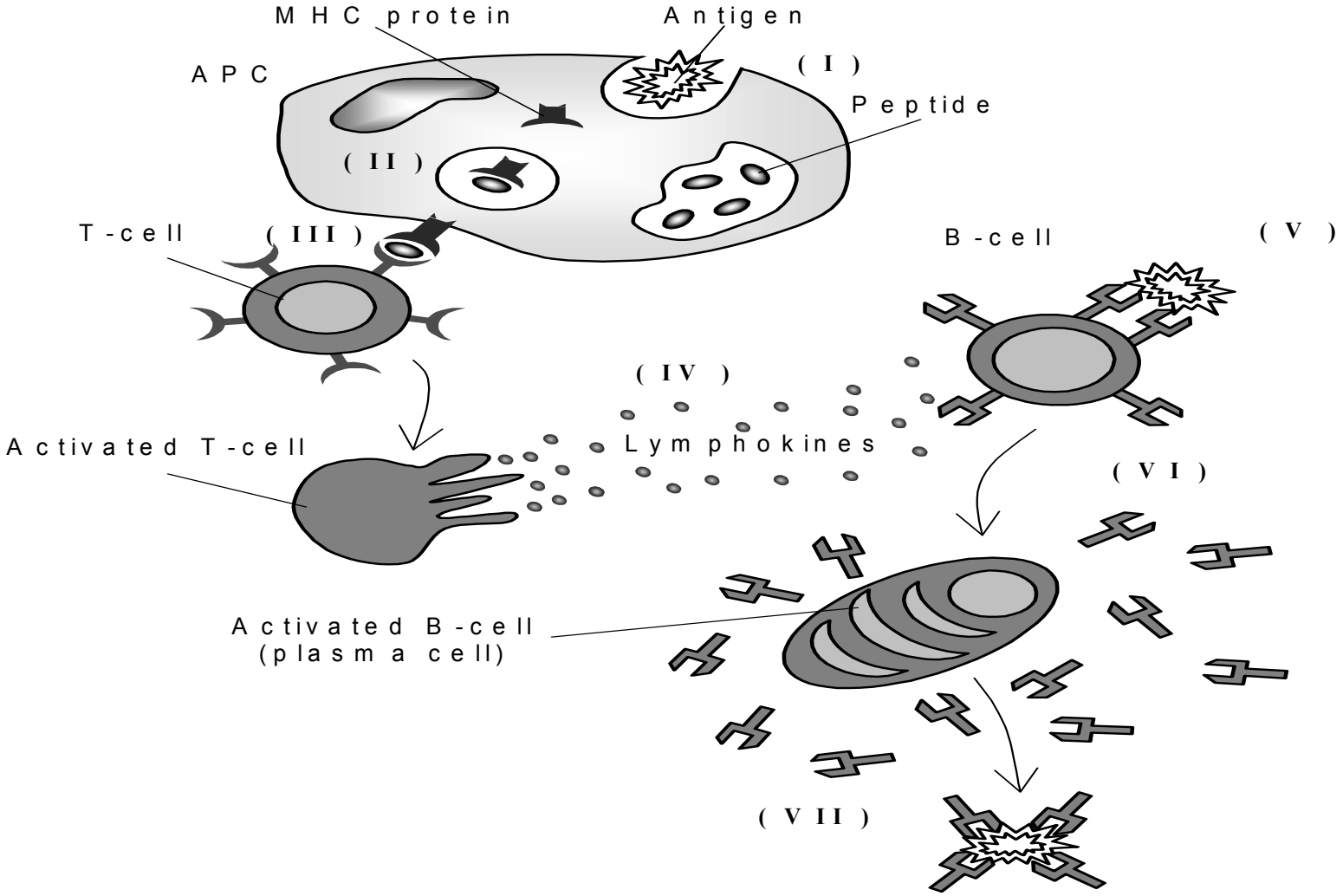
Biological Immune System

- Protect our bodies from pathogens.
- Primary immune response:
  - Launch a response against invaders.
- Secondary immune response:
  - Remember past encounters.
  - Faster response the second time.

Biological Immune System



Immune System Overview

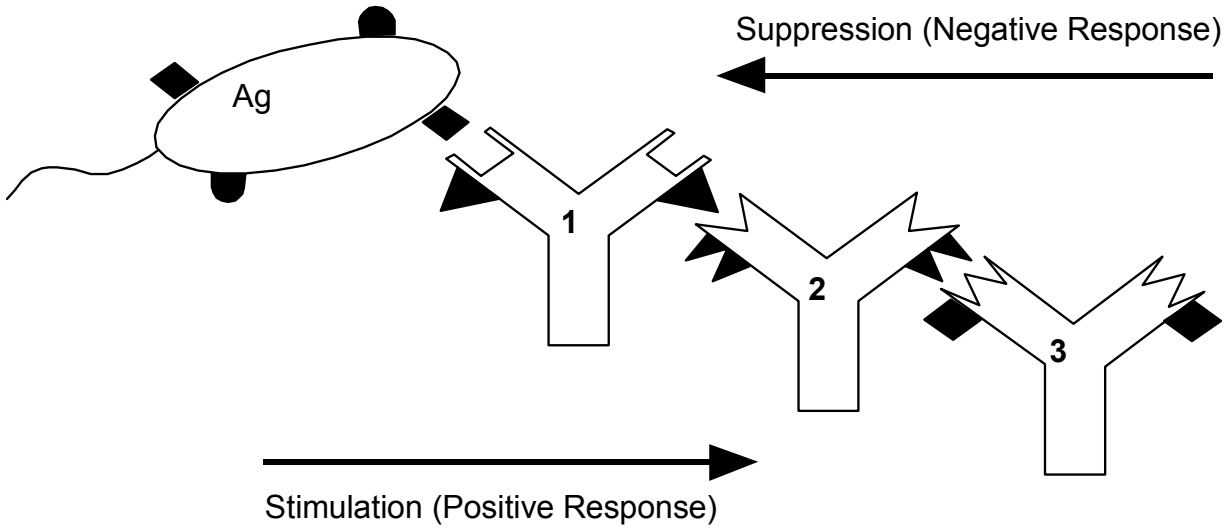


Self-Nonself Discrimination

- Immune system differentiates between self and nonself cells.
- Antigenic encounters may result in cell death.
- Therefore:
  - Some kind of **positive selection**.
  - Some element of **negative selection**.

Immune Network Theory

- Idiotypic network (Jerne, 1974):
- B cells stimulate each other.
- Creates an immunological memory.



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Film Recommender

- Prediction:
  - What rating would I give a specific film?
- Recommendation:
  - Give me a ‘top 10’ list of films I might like.

Film Recommender

- **EachMovie database** (70k users).
- **User Profile**: set of tuples {movie, rating}.
- **Me**: My user profile.
- **Neighbour**: User profile of others.
- **Similarity metric**: Correlation score.
- **Neighbourhood**: Group of similar users.
- **Recommendations**: From neighbourhood.

Film Recommender

- **User Profile**: set of tuples {movie, rating}
- **Me**: My user profile.
- **Neighbour**: User profile of others.
- **Affinity metric**: Correlation score.

Antigen

Antibody

Stimulation

Suppression

Antibody – Antigen Binding

Antibody – Antibody Binding

- **Neighbourhood**: Group of similar users.

Group of antibodies similar to antigen and dissimilar to other antibodies

- **Recommendations**: From neighbourhood

Weighted Score based on Similarities.

Film Recommender

- Start with empty AIS.
- Encode target user as an antigen **Ag.**
- **WHILE** (AIS not full) && (More Users):
  - Add next user as antibody **Ab.**
  - **IF** (AIS at full size) Iterate AIS.
- Generate recommendations from AIS.

Film Recommender

Suppose we have 5 users and 4 movies:

- u1={(m1,v11),(m2,v12),(m3,v13)}.
- u2={(m1,v21),(m2,v22),(m3,v23),(m4,v24)}.
- u3={(m1,v31),(m2,v32),(m4,v34)}.
- u4={(m1,v41),(m4,v44)}.
- u5={(m1,v51),(m2,v52),(m3,v53), (m4,v54)}.

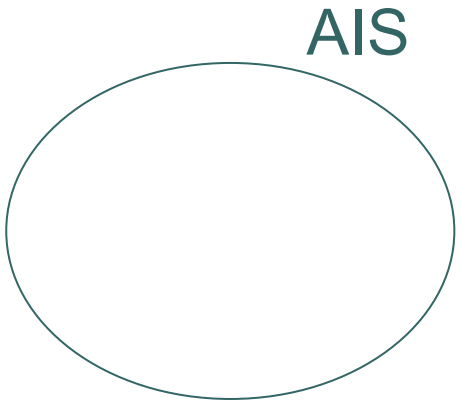
- We do not have users' votes for every film.
- We want to predict the vote of user u4 on movie m3.

Algorithm walkthrough (1)

Start with empty AIS:

DATABASE

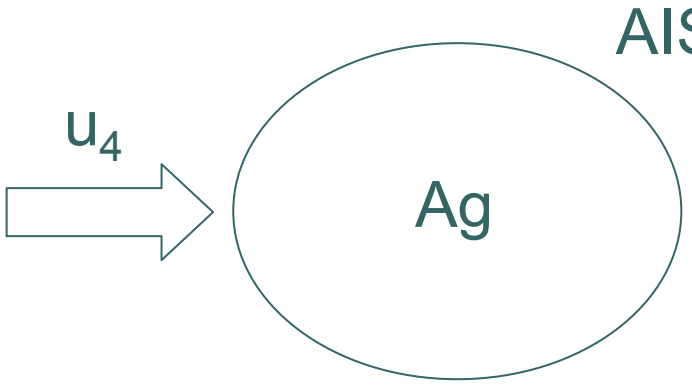
u_1, u_2, u_3, u_4, u_5



User for whom to predict becomes antigen:

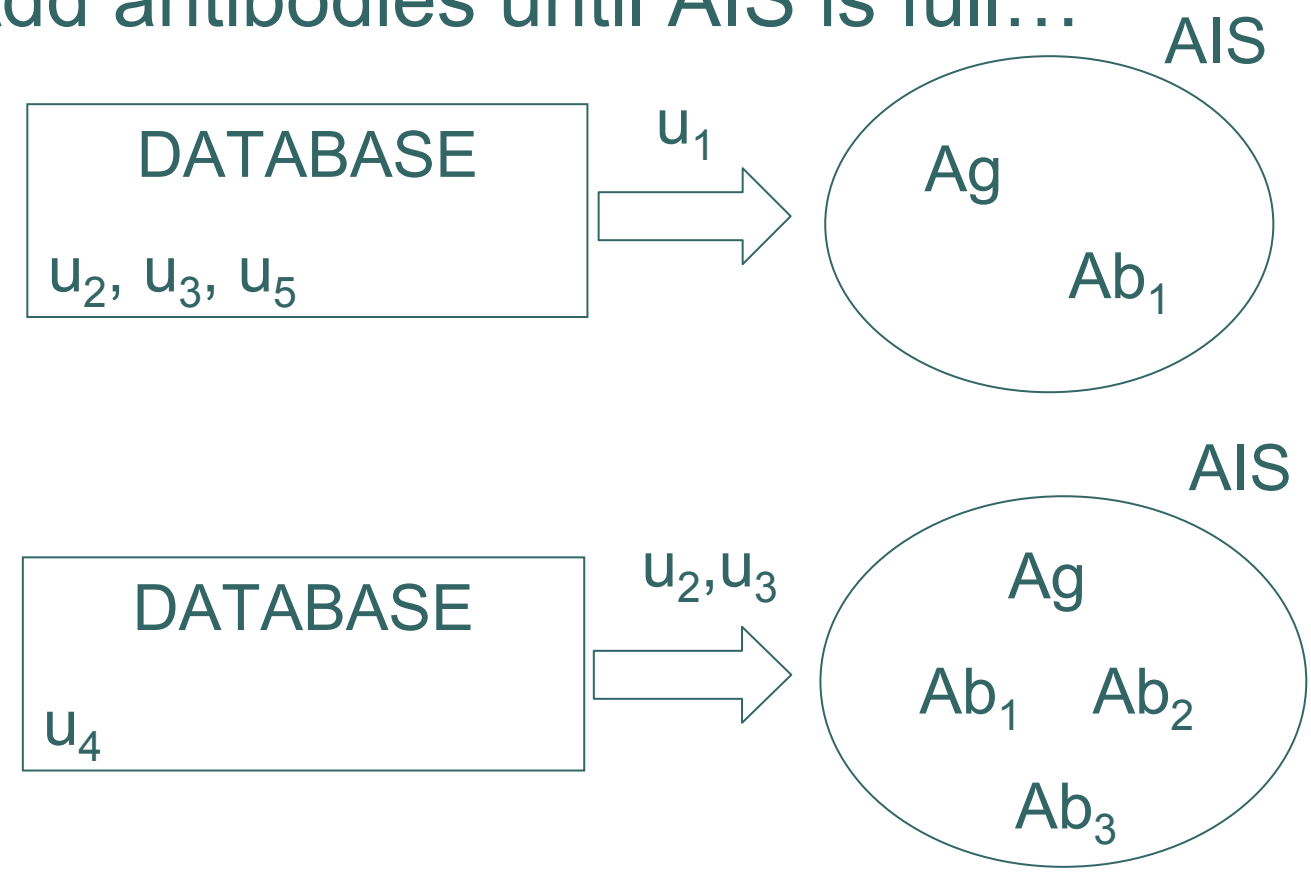
DATABASE

u_1, u_2, u_3, u_5

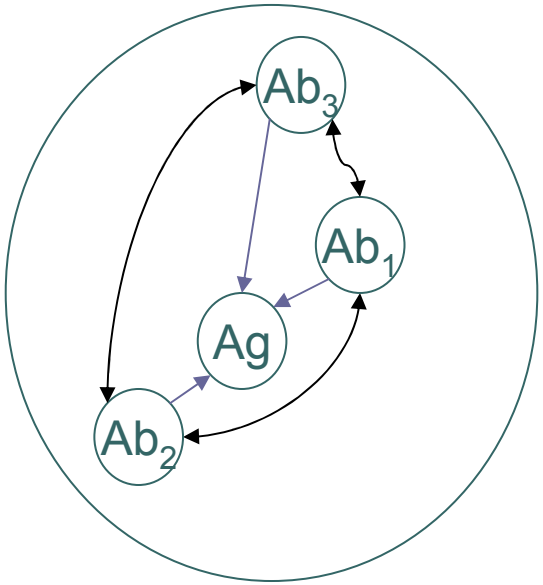


Algorithm walkthrough (2)

Add antibodies until AIS is full…



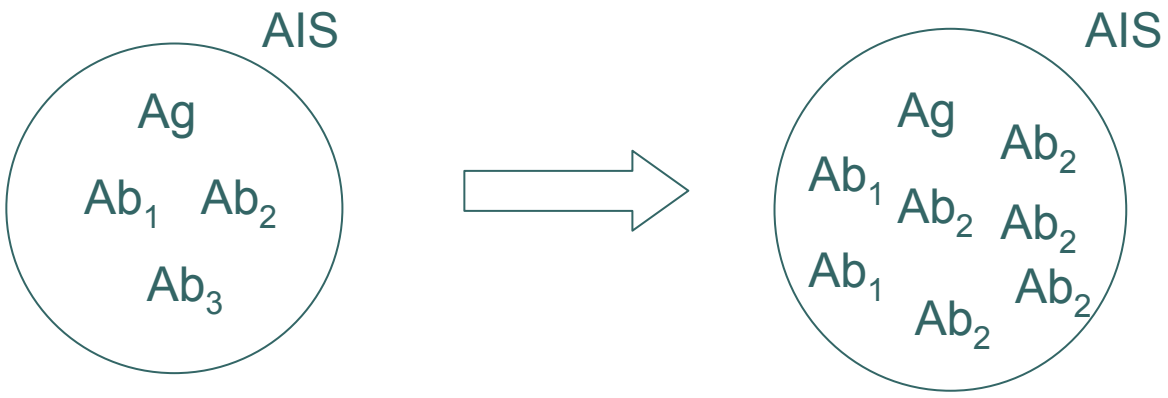
Algorithm walkthrough (3)



- Table of Correlation between Ab and Ag:
  - MS14, MS24, MS34.
- Table of Correlation between Antibodies:
  - MS12 = CorrelCoef(Ab1, Ab2)
  - MS13 = CorrelCoef(Ab1, Ab3)
  - MS23 = CorrelCoef(Ab2, Ab3)

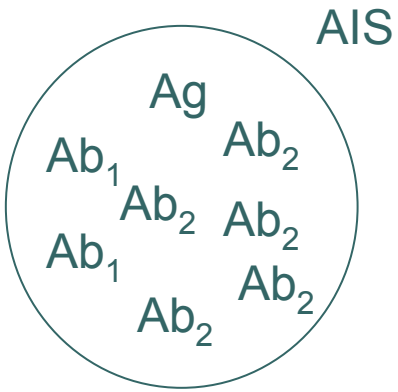
Algorithm walkthrough (4)

- Calculate Concentration of each Ab:
  - Interaction with Ag (Stimulation).
  - Interaction with other Ab (Suppression).



Algorithm walkthrough (5)

- Generate Recommendation based on Antibody Concentration.



Recommendation for user u_4 on movie m_3 will be highly based on vote on m_3 of user u_2

Film Recommender Results

- Tested against standard method (Pearson *k*-nearest neighbours).
- Prediction:
  - Results of same quality.
- Recommendation:
  - 4 out of 5 films correct (AIS).
  - 3 out of 5 films correct (Pearson).

Evaluation

- AIS is good for Collaborative Filtering:
  - Idiotypic effect for more varied population.
  - Potential for distribution.
  - Smaller neighbourhoods.
- General recommendation tool:
  - Webmining (URL Recommender).

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Comparison of Algorithms

	GA (Optimisation)	NN (Classification)	AIS
Components	Chromosome Strings	Artificial Neurons	
Location of Components	Dynamic	Pre-Defined	
Structure	Discrete Components	Networked Components	
Knowledge Storage	Chromosome Strings	Connection Strengths	
Dynamics	Evolution	Learning	
Meta-Dynamics	Recruitment / Elimination of Components	Construction / Pruning of Connections	
Interaction between Components	Crossover	Network Connections	
Interaction with Environment	Fitness Function	External Stimuli	
Threshold Activity	Crowding / Sharing	Neuron Activation	

Comparison of Algorithms

	GA (Optimisation)	NN (Classification)	AIS
Components	Chromosome Strings	Artificial Neurons	Attribute Strings
Location of Components	Dynamic	Pre-Defined	Dynamic
Structure	Discrete Components	Networked Components	Discrete components / Networked Components
Knowledge Storage	Chromosome Strings	Connection Strengths	Component Concentration / Network Connections
Dynamics	Evolution	Learning	Evolution / Learning
Meta-Dynamics	Recruitment / Elimination of Components	Construction / Pruning of Connections	Recruitment / Elimination of Components
Interaction between Components	Crossover	Network Connections	Recognition / Network Connections
Interaction with Environment	Fitness Function	External Stimuli	Recognition / Objective Function
Threshold Activity	Crowding / Sharing	Neuron Activation	Component Affinity

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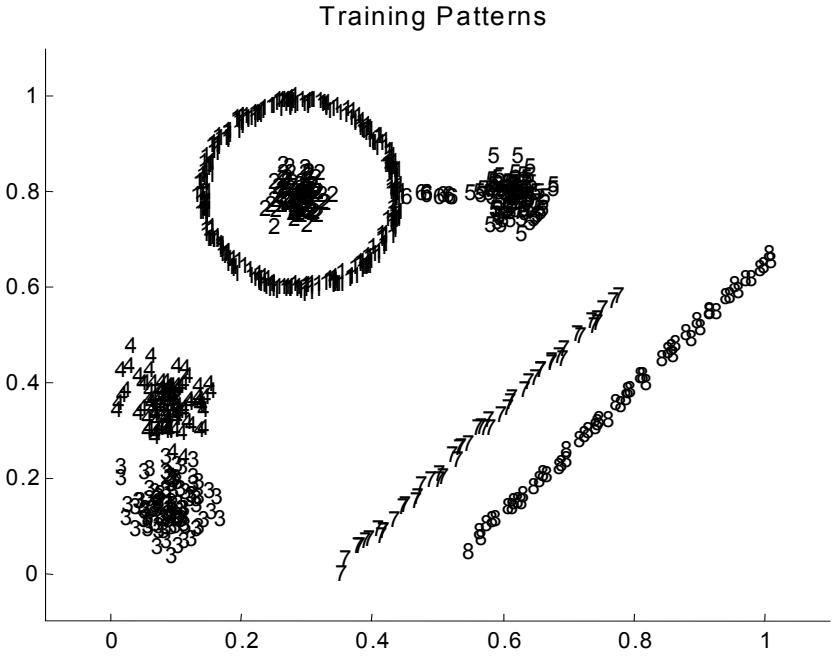
Clustering (aiNet)

Immune System	aiNET
Antibody	Internal data vector
Antigen	Training data vector
Affinity	Euclidean distance
Cell cloning	Duplication of internal data vectors
Somatic hypermutation	Affinity proportional mutation
Immune network	Network of internal data vectors
Metadynamics	Removal / creation of internal data vectors

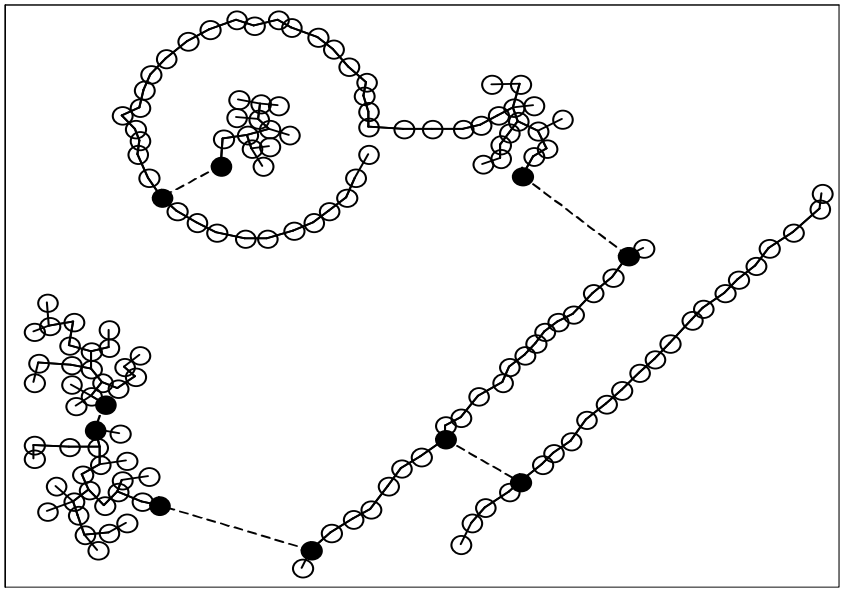
Clustering (aiNet)

- Initialization (Create a random population of antibodies).
- For each antigen do:
  - Clonal selection and Hypermutation.
  - Metadynamics (Removal).
- Network interactions (Suppression).
- Cycle (Repeat for a number of iterations).

Clustering (aiNet)



Training Pattern



Immune network

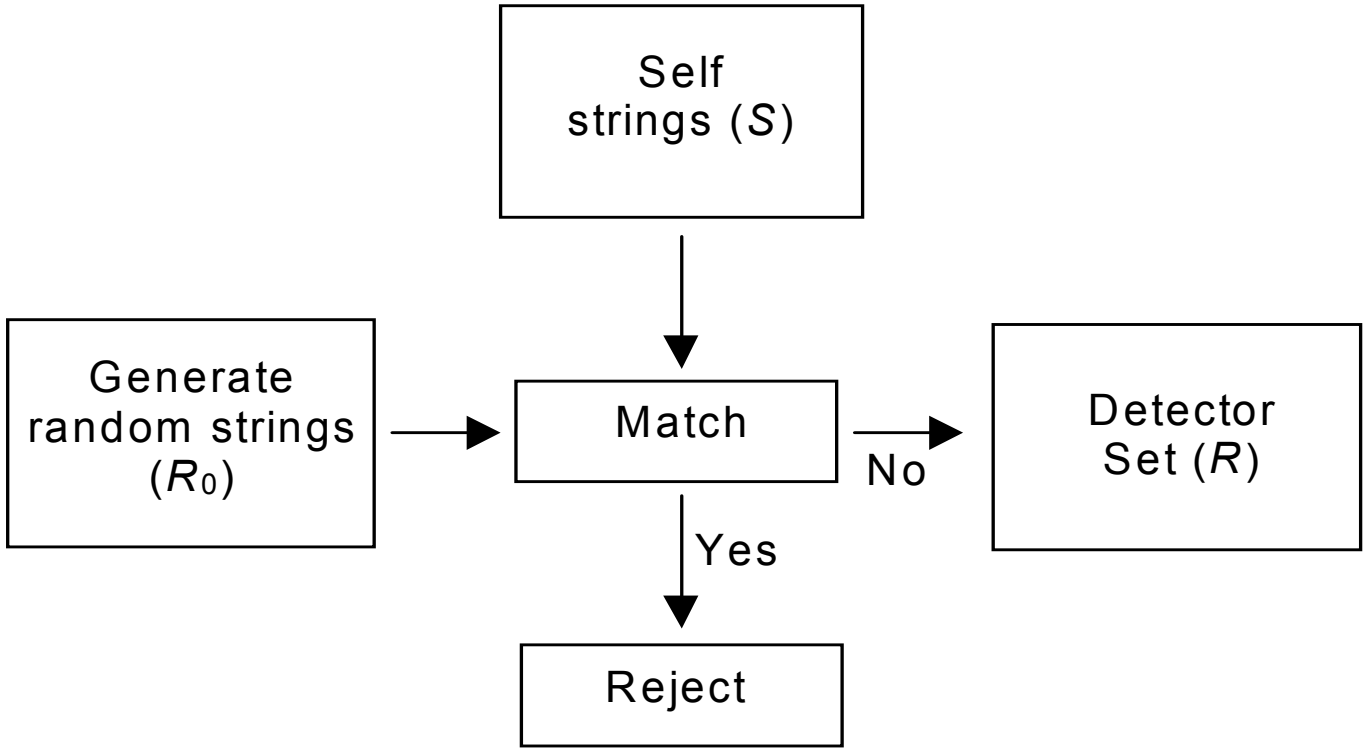
AIS for Security

- ‘Self’: files, network traffic, system calls.
- Antibody creation: positive vs. negative.
- Change detection (Checksums).
- Advanced Features:
  - Binary strings or symbolic rules.
  - Activation thresholds (vs false positives).
  - Co-stimulation (vs false positives).
  - Memory detectors (secondary response).

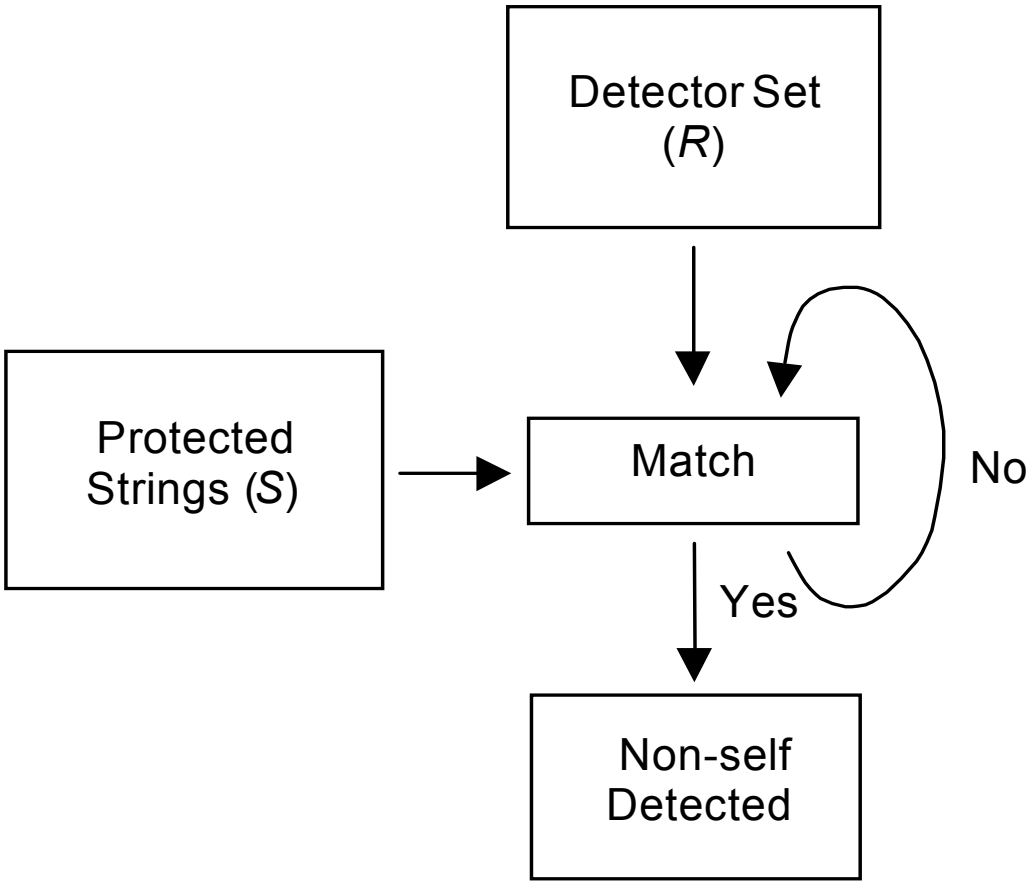
Design a Simple AIS IDS

Feature	**AIS IDS**
Positive or Negative Selection?	
Antibody	
Antigen	
Affinity Measure	
Cloning	
Somatic Hypermutation	
Immune Network	
Metadynamics	

Forrest's Censoring



Forrest's Monitoring



AIS Security Evaluation

- Applied to network intrusion, virus detection…
- Good results on test systems.

BUT…

- Definition of Self ambiguous.
- Inefficient to map entire nonself universe.
- Self / Nonself changes over time.

AIS for Optimisation

- Applied to TSP (of course), job shop scheduling, time series prediction…
- Some good results on test problems.

BUT…

- Often little ‘added value’ to GA.
- AIS metaphor somewhat strained?

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Traditional Self-Nonself

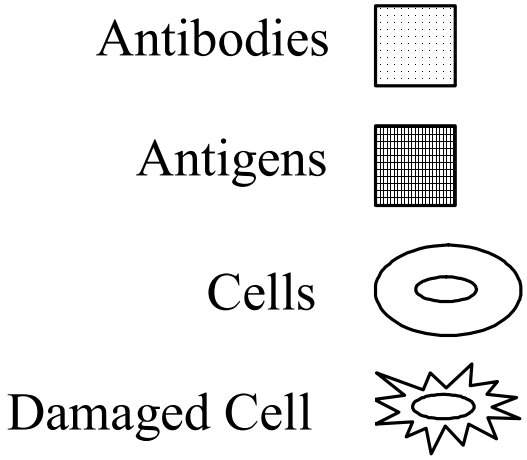
Traditional Self-Nonself Problems:

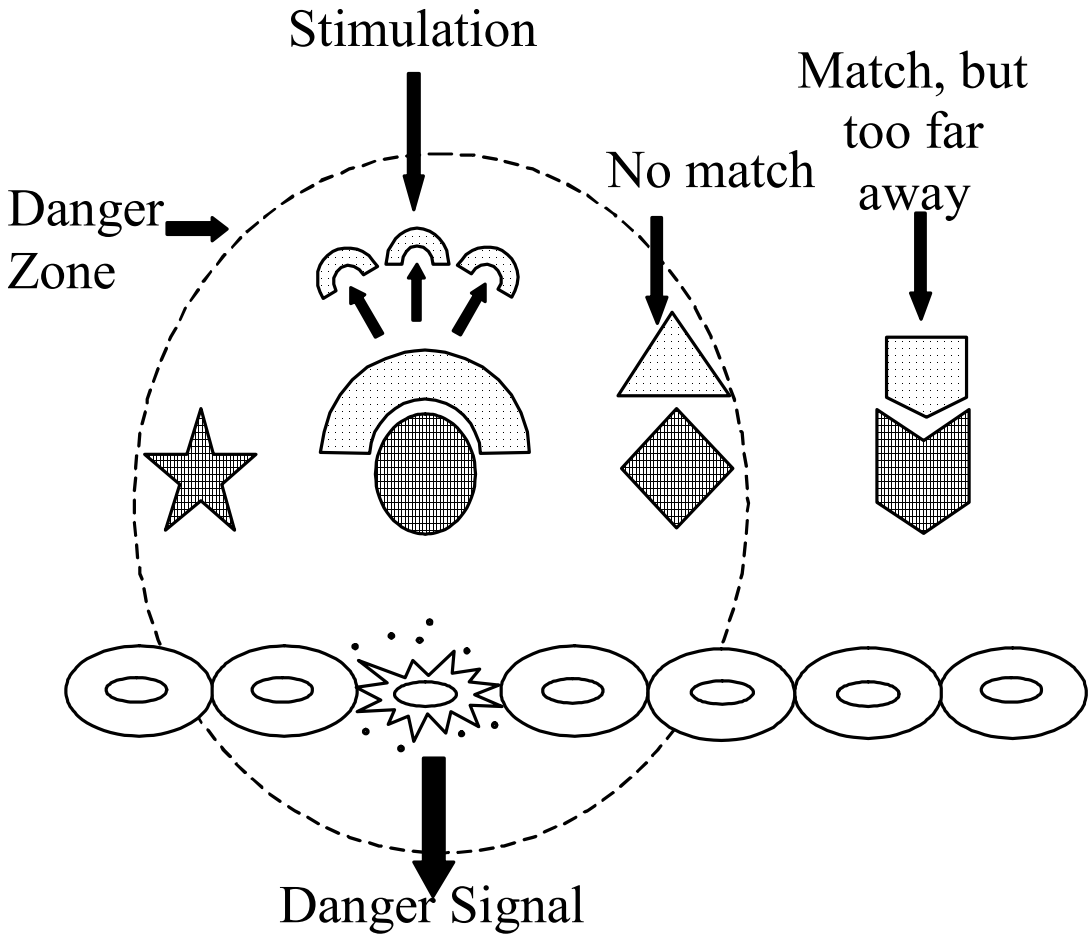
- No reaction to foreign bacteria in gut.
- No reaction to food / air / etc.
- The human body changes over its life.
- Auto-immune diseases.
- Tumours / Transplants.

Danger Theory

- Need for discrimination: What should be responded to?
- Self-Nonself discrimination useful.
- Respond to Danger not to “foreignness”.
- Danger is measured by damage / distress signals.
- What would be ‘danger signals’?

Danger Zone


Antibodies
Antigens
Cells
Damaged Cell


Stimulation
Match, but too far away
No match
Danger Zone
Danger Signal

The Future

- Much work is very diverse:
  - More formal approach required?
- Wide possible application domains.
- What makes the immune system unique?
- More work with immunologists:
  - Danger theory.
  - Idiotypic Networks.
  - Self-Assertion.

The Future (2)

- Use Latest Immunological ‘Danger Theory’ for Intrusion Detetcion.
- Investigate the Correlation between ‘Good’ and ‘Bad’ Cell Deaths.
- Overcome Self-Nonself Limitations.

➢ Supported by £659k EPSRC Adventure Grant (+ £33k Industry).

The Future (3)

- ARTIST: A Network for Artificial Immune Systems (EPSRC funded network).
- Work towards:
  - A theoretical foundation for AIS.
  - Extraction of accurate metaphors.
  - Application of AIS.
- Train PhD students.
- Fund workshops/meetings.
- Coordinate and Disseminate UK based AIS research.

AIS Resources

- Artificial Immune Systems and Their Applications by D Dasgupta (Editor), Springer Verlag, 1999.
- Artificial Immune Systems: A New Computational Intelligence Approach by L de Castro, J Timmis, Springer Verlag, 2002.
- Immunocomputing: Principles and Applications by A Tarakanov et al, Springer Verlag, 2003.

- Second International Conference on Artificial Immune Systems (ICARIS), September 1-3, 2003, Napier University, Edinburgh, UK.