Nature-Inspired Computing

Artificial Immune Systems*

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Introduction

- biological immune system (BIS) defends body from foreign pathogens
- able to categorize all cells/molecules as self or non-self
- artificial immune system (AIS) inspired from BIS

Biological Immune System

- depending on type of pathogen and its way of entry, different response mechanisms used:
  - neutralize pathogenic effect
  - destroy infected cells
- immune system:
  - innate immune system: present at birth
  - adaptive immune system: learning, adaptability and memory

Biological Immune System

- immune system features relevant to AIS
  - matching: binding between antigen and antibody
  - diversity: in order to achieve optimal antign space coverage, antibody diversity encouraged
  - distributed control: immune system governed by local interactions between immune cells and antigens

Immune Network Theory

- immune system maintains idiotypic network of interconnected B-cells for antigen recognition
  - B-cells responsible for antibody (proteins that bind to antigens) production
- suppress and stimulate each other in such a way as to lead to stabilization of network

Immune Network Theory

- two B-cells are connected if the affinities they share exceed a threshold
- strength of the connection directly proportional to affinity they share

Negative Selection Mechanism

- aim is to provide tolerance for self-cells
- deals with immune system's ability to:
  - detect unknown antigens
  - not react to self-cells

Negative Selection Mechanism

- when immune system cells are created they undergo negative selection in thymus
- those that react against self-cells are destroyed
- those that do not are released from thymus

Clonal Selection

- describes basic features of an immune response to an antigen
- only those that recognize an antigen proliferate (increase in no.s)
  - selection against those that do not match

Clonal Selection

- main features of clonal selection theory:
  - new cells which are copies (clones) of parents are subject to a high mutation (somatic hypermutation)
  - elimination of newly differentiated lymphocytes carrying self-reactive receptors.
  - proliferation and differentiation of mature cells

Illustrative Problems

- intrusion detection
- data mining – collaborative filtering and clustering

Intrusion Detection

- to identify potential attacks and to react by generating an alert or by blocking the possible attack
- main goal is to detect misuse, unauthorized use and abuse of computer systems by both insiders and external intruders

Intrusion Detection

- current IDS define suspicious signatures based on known intrusions and probes
  - limitation: failure to detect previously unknown attacks

Data Mining – Collaborative Filtering (CF) and Clustering

- broad range of algorithms that use a similarity measure to obtain recommendations
  - e.g. "people who bought this also bought these"
- any problem domain where users are required to rate items is suitable for CF
  - recommender systems
- related problem: clustering of similar preferences or types

Artificial Immune Systems

- decisions when implementing AIS:
  - encoding
  - similarity measure
  - selection
  - mutation

Encoding

- in an application domain
  - antigen = target solution
    - data item to check if it is an intrusion
    - the user which is being clustered or is being made a recommendation for
  - antibodies: remainder of data
    - other users in database
    - network traffic which has already been identified

Encoding

- there can be more than one antigen and usually many antibodies
- antigens and antibodies are repesented in the same way
- efficient encoding / representation is chosen similar to in EAs

Encoding – Data Mining Example

- movie recomender
- user profile should be represented
  - movies seen
  - how much liked
- possible encoding:

$\{\{id_1, score_1\}, \{id_2, score_2\}, \ldots, \{id_n, score_n\}\}$

Encoding – Intrusion Detection Example

- for each data packet transferred:

```
[<protocol><source ip><source
  port><destination ip><destination port>]
```

- example:

```
[<tcp><113.112.255.254><any><108.100.111.12>
  <25>]
```

Similarity / Affinity Measure

- similarity measure = matching rule
  - related to encoding
    - e.g. for binary encoding may use Hamming distance or the length of the longest of the continuous no. of matching bits
    - e.g. for real encoding, may use Euclidean distances

Similarity / Affinity Measure

- for data mining applications similarity usually means correlation
  - e.g. use Pearson correlation coefficient between users
    - -1 means strong disagreement, 1 means strong agreement, 0 means no correlation

Artificial Immune Systems

1. initially AIS is empty
2. target user is set as antigen, all others as antibodies
3. add antigen to AIS
4. add one candidate antibody at a time
5. antibodies start with an initial concentration which decreases over time (death rate)
   1. low concentration antibodies removed
   2. high concentration antibodies may go to saturation
   3. matching antibodies increase in amount (better matching ones increase more) ⇒ stimulation

Artificial Immune Systems

$$\frac{dx_i}{dt} = \left[\begin{pmatrix} antigens \\ recognized \end{pmatrix} - (death\ rate)\right]$$
$$= \left[k_2\left(\sum_{j=1}^{N} m_{ji} x_i y_j\right) - (k_3 x_i)\right]$$

N: no of antigens
k_2: stimulation effect
k_3: death rate
x_i, y_j: concentrations of antibodies i and j
m_{ji}: matching function between antibodies i and j (antibodies or antigens)

Pseudocode of AIS for the Movie Recommender System

```
initialize AIS;
encode user to make predictions for as Ag;
while (AIS not full) and (more antibodies) do
{
  add next user as antibody Ab;
  calculate match score between Ag and Ab;
  while (AIS at full size) and (AIS not stabilized) do
   {
     reduce concentration of all Abs by a fixed amount;
     match each Ab against Ag; stimulate as necessary;
   }
}
use final set of antibodies for recommendations;
```

Result of AIS for the Movie Recommender

- in the final set of antibodies, use concentrations as weights and take a weighted average to determine recommendation
- AIS is called stabilized if (for e.g.) for 10 iterations no size change occurs
- stabiliztion means that sufficient no of good neighbors have been found
  - a good prediction can be made using it

Somatic Hypermutation

- similar to EAs
  - but mutation is less distruptive for better matches
- mutation may not make sense for some types of data
  - mutating user to be more similar to target works but basing a recommendation on the artificial users is not meaningful

Somatic Hypermutation

- mutation may make sense for some types of data
  - meaningful in IDS: for example mutating those that match self rather than dscarding them directly
  - in clustering, cluster centers can be artificial users, so mutating cluster centers is meaningful

Idiotypic Networks – Network Interactions (Suppression)

- antibodies can match other antibodies as well as antigens
- antibody matches others which also match others too
  - can explain memory of past infections
- this could result in suppression of similar antibodies to increase diversity

Idiotypic Networks – Network Interactions (Suppression)

$$\frac{dx_i}{dt} = c\left[\begin{pmatrix}antibodies\\recognized\end{pmatrix} - \begin{pmatrix}I\ am\\recognized\end{pmatrix} + \begin{pmatrix}antigens\\recognized\end{pmatrix}\right] - (death\ rate)$$

$$= c\left[k_2\left(\sum_{j=1}^{N} m_{ji}x_i x_j\right) - k_1\left(\sum_{j=1}^{N} m_{ij}x_i x_j\right) + \left(\sum_{j=1}^{n} m_{ji}x_i y_j\right)\right] - (k2x_i)$$

N: no of antigens
n: no of antibodies
c: rate constant
k_1: suppressive effect
k_2: death rate
x_i, x_j: concentrations of antibodies i and j
y_j: concentration of antigen j
m_{ji}: matching function between antibody i and antibody/antigen j

Pseudocode of AIS for the Movie Recommender System with Idiotypic Networks

```
initialize AIS;
encode user to make predictions for as Ag;
while (AIS not full) and (more antibodies) do
{
  add next user as antibody Ab;
  calculate match score between (Ag and Ab) and (Ab and other Abs);
  while (AIS at full size) and (AIS not stabilized) do
   {
     reduce concentration of all Abs by a fixed amount;
     match each Ab against Ag; stimulate as necessary;
     match each Ab against each other and execute idiotypic effect;
   }
}
use final set of antibodies for recommendations;
```

Standard Negative Selection Algorithm

1. initialize random detectors;
2. censoring:
   1. match evaluation: determine affinity between every self and detector;
   2. selection: if a detector matches a self then discard it else add to detector set;
3. monitoring: monitor neew set of self for possible changes / variations;

Standard Clonal Selection Algorithm

1. initialize random detectors;
2. for each antigen do:
   1. selection: select antibodies which have a higher affinity to antigen;
   2. reproduction and genetic variation:
      1. produce copies (clones) of selected cells(no. depends on how good the match is);
      2. mutate each inversely proportional to its affinity to antigen;
   3. affinity evaluation;
3. cycle: repeat step 2 until stopping criteria are met;