

# Profile Adaptation in Adaptive Information Filtering: An Immune Inspired Approach

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**Abstract**— Within the context of information filtering, learning and adaptation of user profiles is a challenging research area and is, in part, addressed by work in Adaptive Information Filtering (AIF). In order to be effective in a dynamic context, maintaining filtering performance, information filtering systems need to adapt to changes. We argue that artificial immune systems (AIS) exhibit the properties required by AIF, and have the potential to be exploited in the context of AIF. In this paper, we extract general features of immune systems and AIF, based on a principled meta-probe approach. We then propose an architecture for AIF incorporating ideas from AIS. Having such characteristics as adaptability, diversity and self-organised, we argue that AIS have suitable characteristics that are amenable to the task of AIF.

**Keywords**-Adaptive Information Filtering, Artificial Immune Systems, Profile Adaptation, Clonal Selection Algorithm

## I. INTRODUCTION

Information filtering (IF) is the process of filtering incoming data streams based on a description (profile) of a single user, or a group of users, where the user reacts to the stream of information in such a way that only relevant data (information) is preserved. An IF application poses challenging research problems, relating to the uncertain nature of a user's information need and the associated formulation process, the ambiguity in representing a document, and the matching of an uncertain query to an inaccurate document representation [1]. Our study focuses on the challenges of profile adaptation. The profile appears to adapt to a variety of changes ranging from frequent variations in a user's short-term needs, to occasional radical changes like the emergence of a new topic of interest or the loss of interest in a current topic. The profile can learn interesting topics, or to forget topics that are no longer interesting. Through profile adaptation, the profile becomes open to its environment with the addition and removal of 'terms'. This results in the profile constantly changing in response to changes in user response to the stream of documents.

In this paper, we propose an immune inspired approach to profile adaptation. This is motivated by the ability of the natural immune system to maintain sufficient diversity, adaptability and self-organisation. Artificial immune systems (AIS) have been described as: "adaptive systems inspired

by theoretical immunology and observed immune functions, principles and models" [2]; they have the potential to support adaptability and diversity. There is a range of computer algorithms and applications in the area of information filtering [3], [4], [5].

The remainder of this paper is structured as follows. Section II briefly introduces a principled meta-probe approach to identifying relevant properties of the immune system and our target AIF application domain, using the *ODISS meta-probes* [6]. Section III describe a proposal for an immune inspired approach to profile adaptation. Section IV concludes this paper and outlines our future work.

## II. PRINCIPLED META-PROBE APPROACH FOR IMMUNE-INSPIRED ADAPTIVE INFORMATION FILTERING

We follow the proposal of Stepney et al. [6], that the underlying properties of classes of models can be analysed by meta-probes otherwise known as *ODISS*: Openness, Diversity, Interaction, Structure and Scale. The meta-probes are not independent. For example, interaction supports and underpins openness and assists in maintaining diversity; diversity is, in part, a factor of scale and structure; scale and structure are both concerned with the layering of complexity in systems. In [6], [7], the *ODISS* meta-probes are applied to biological systems to identify their characteristics. Here, we apply the meta-probes both to the immune system and to the target application domain, as a first step in identifying the appropriate immune inspiration for the target AIF system.

### A. *ODISS* Meta-probes applied to aspects of an immune system

The immune system is highly complex, but whilst basic processes are widely accepted, there are many theories of, for example, how adaptation, homeostasis and memory are achieved. Applying the *ODISS* meta-probes to the immune system is not only challenging, but will most certainly be incomplete. Therefore, in this section, we merely seek to demonstrate the principle of characterisation of the immune system, and to shed some light on how the immune system can be considered. Each of the five meta-probes is considered in turn.

1) *Openness*: Continual evolution is needed for the immune system to remain effective in the face of changing pathogen exposure and the evolution of viruses. A widely-accepted immune characteristic is its two levels of evolution – the innate immune system that evolves across mammal generations, and the adaptive immune system that evolves within the host individual [8], [2]. Furthermore, the immune

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system supports continual replenishing of resources in terms of production of new cells, self-maintenance of the system [9], [10] and cell death (apoptosis) [11]. *Immune network theory* [12] proposes an immune network as the basis of the regulatory mechanism that maintains homeostasis, via continuous production and recruitment of immune cells and molecules. The meta-dynamic of the immune network (or immune recruitment mechanism) allows addition of new elements to the network, to extend or adapt coverage of the space of antigens [2].

2) *Diversity*: Diversity is a hallmark of the immune system, a key feature in the ability to recognise and react to a continuously changing environment. Diversity of the adaptive immune system is maintained through *heterostasis*, in which cells are selected to clone or to become memory cells according to antigen affinity [13]. Diversity is extended through *heterogenesis* [13], either through somatic hypermutation or through recruitment of new cells and the suppression of similar antibodies [2]. Furthermore, the *double plastic structure* of the immune system means that individual cells and connections are constantly added to and removed from the network [2]. For the innate immune system, the innate repertoire is naturally diverse, comprising different cells with different functions [14]. A range of immune mechanisms, including degeneracy and pleiotropism, characterise the diversity of the immune system. Degeneracy supports adaptability, in terms of structurally different elements that yield the same or different function depending on the context in which they are expressed [15], while pleiotropism relates to the ability of effector molecules of the immune system to produce different functional effects in different cell types, or sometimes even in the same cell type [16].

3) *Interaction*: There is a wide range of interactions in the immune system, forming dialogues among agents and with the host environment. We summarise some typical interactions.

- Intercommunicating tissue cells are a feature of the clonal selection theory, which postulates an immune system composed of discrete sets of elements that are compared with the environment. This scheme of direct interaction with the environment supports a reinforcement learning strategy.
- The immune network theory has a more constrained model of interaction, in which cells interact with other cells in the network [17].
- Multiple interacting immune agents such as macrophages, T and B cells are involved, for instance, in immune correspondence [16], [9], [17].
- Networks of signaling molecules support immune agent communications in an immune dialogue [10], [16].
- Interaction between the innate and adaptive immune systems allows the initial attack to be handled by the innate immune system, in a response that alerts the adaptive immune system to the pathogen invasion [2].

4) *Structure*: The structure (architecture) of the immune system is multi-layered, with defences on many levels

(anatomic barriers, innate and adaptive immunity, etc.). Some structures are well-understood, but the full structure and its purpose are still the subject of debate.

5) *Scale*: It follows from the above sections that an immune system contains a considerable number of different types and functional variants of component. It is also the case that the natural immune system has large (and variable) populations of each type of component. Another important aspect of scale is the ability of the immune system to react to small amounts of new antigen, using cloning to amplify the effectiveness of the response.

### B. ODISS Meta-probes applied to aspects of AIF

The ODISS meta-probes have been applied to various biological subjects, but are not normally applied to application domains. Here we apply the ODISS approach to the AIF domain, to highlight the features that would be necessary in an ideal AIF system.

1) *Openness*: Openness is needed in AIF systems, because the AIF must be always acting and changing, maintaining itself through a continuous interchange with its environment. An ideal AIF system would be permanently evolving, permitting changes to profiles and data flows while the filtering activities continue. In practice, the extent of this evolutionary openness depends on the speed of adaptation that is appropriate to a particular AIF application.

2) *Diversity*: The motivation for AIF is that the content and semantics of data streams, and the relevance of data items to users, changes over time. To handle this, the AIF system needs diversity. The data stream input to an AIF system is processed into a suitable representation that identifies terms (keywords, ontologically-similar phrases, etc); the terms are the basis for matching to user interests. In AIF, a good representation would have to handle significant diversity of data items, within a data stream and over time. Good coverage of the information space improves the chance of a user's being satisfied, and also improves the quality of feedback.

3) *Interaction*: Interaction of an AIF system includes interaction with environment (the user and the data stream) and interaction of system components (agents). Adaptation in the AIF is the result of dialogues between the user and the system. In some cases, dialogues are explicit (user queries, direct editing of profile elements), but a more responsive approach is through implicit dialogues, using deduction from interaction monitoring to revise user profiles. The users have to perceive that they can rely on the filtering result and can hand over the control to the system. Furthermore, the user has to keep using the system, so that the system can learn and adapt, even when the result is not optimal. This raises challenges relating to the management of user perception, achievement of appropriate user control and trust, and the design of user interaction and response monitoring. Interaction among components reflects how the 'agents' interact with their environment and with each other, both directly and indirectly.

4) *Structure*: A typical AIF is an on-line system, whose durability and environment are not pre-determined; this requires the system to have a dynamic structure, for instance

within the filtering and learning components. The diversity of possible changes, the streaming of incoming data, and the potential adaptation of the user profile, suggest the use of a structure of multiple intelligent agents.

5) *Scale*: An agent-based AIF that maintains itself through continuous interaction with its environment typically needs a significant number of autonomous agents. It is an open question of complex systems as to how many agents are necessary to achieve the behaviour of the system, and how quantity interrelates to diversity. Over and above such questions, however, AIF face problems of sparsity and scale. For instance, a recommender system may have to cope with a significant part of the world wide web (and its phenomenal rates of growth and change). In addition, users are many and varied in their profile characteristics, interests and interaction habits. User preference may have to be deduced from only a small number of instances of feedback for each user interest or each data item, and there is much variety of behaviour across users [18]. Scale thus raises issues of quantity and quality of data, and of quality and scope of representation for both data streams and user characteristics.

### III. IMMUNE INSPIRED PROFILE ADAPTATION

Having noted the features of AIF and the immune system in Section II, we outline a possible mapping of immune inspired profile adaptation in AIF, as shown in Table I. The mappings suggest that profile adaptation can be developed by incorporating ideas from aspects of immune networks and clonal selection. This is motivated by the ability of immune networks to afford an *immune memory* via a meta-dynamic process that is useful in a dynamic environment [19]. In the case of clonal selection, “detectors” undergo a process of selection and mutation which allows the necessary increase in diversity. The use of gene library evolution, with clonal selection and hypermutation, supports learning in a dynamically changing environment [20]. Gene libraries are a “biological mechanism for generating a combinatorial diversity in the immune system”[21], [22]; they are shaped by the evolution to create detectors that preserve the ability to respond to novel threats [21], [22]. Taking this inspiration, we believed that the use of evolved gene libraries could produce reasonable coverage of detectors to detect changes of profile in varying incoming documents.

#### A. A Proposed Architecture for Immune Inspired Profile Adaptation

In this section, we outline an architecture for immune inspired profile adaptation. Figure 1 illustrates the architecture as a work flow. The proposal is for immune inspired online profile adaptation, with continuous learning; the profile dynamically adapts on the incoming data stream (from the world wide web).

We employ a scenario-based approach to help derive requirements for our system. Scenarios are defined as “facts describing an existing system and its environment including the behaviour of agents and sufficient context information to allow discovery and validation of system requirements”

TABLE I  
MAPPINGS OF PROPOSED IMMUNE INSPIRED PROFILE ADAPTATION

ODISS	Requirements	Immune inspired profile adaptation
Openness	Adaptation to changing data and user profile	Continual evolution, replenishment, addition of resources
Diversity	Need to respond to diverse and non-specific changes, diversity of user profiles across the user population, and of data items across the input data stream	Diverse, numerous detectors; tunable antibody repertoire; meta-dynamics with properties of degeneracy and pleiotropism supported by mutation, somatic hypermutation, antibody-antibody interactions and generation of new antibodies
Interaction	Responsiveness (within an acceptable time), flexible interactions, both between user and system and among agents in the system	Immune dialogue with context-dependent interaction
Structure	Robustness (able to change behaviour over time), thematic connectivity	Immune structures for adaptation on different time scales
Scale	Sparse evidence of changing data and user characteristics	Responsiveness to small amount of new antigen, amplification through dynamic clonal selection and gene library evolution

[23]. To illustrate, several scenario models are presented in Figure 2, to show how scenario-based requirements can be used to develop our understanding of immune inspired profile adaptation.

Profile construction encapsulates information about the user’s interests and includes short-term and long-term interest, as well as multiple or single interests. This information may not always be well defined or well expressed, but should capture user interests as accurately as possible with good-enough coverage.

A profile is initialised once and has to be adapted when interests change. Thus, the profile is subjected to a “learning” process as depicted in Figure 2(a). Through learning and continual maintenance, a profile is updated with changes to user interests and should thus avoid becoming obsolete. Therefore, an algorithm is required that is capable of continuous learning and has the ability to track drift in user interest. We propose an immune network approach combined with dynamic clonal selection. In addition to a suitable learning mechanism, a suitable mutation operator is required to introduce diversity and to exploit relationships and semantics between words in a vector. Choosing a suitable mutation operator is critical, and depends on the representation scheme; this is a key factor in the overall success of an adaptive system. Figure 2(b) is the scenario-based model for the process of document evaluation, thresholding strategy, ranking and recommendation. Document evaluation establishes an association between document terms and topics of interests from a profile, to assess the relevance of a document to a given topic of interest. A similarity measure with an adaptive threshold is used to match the document term distribution to the profile term. Recommendation to the user is based on the document ranking.

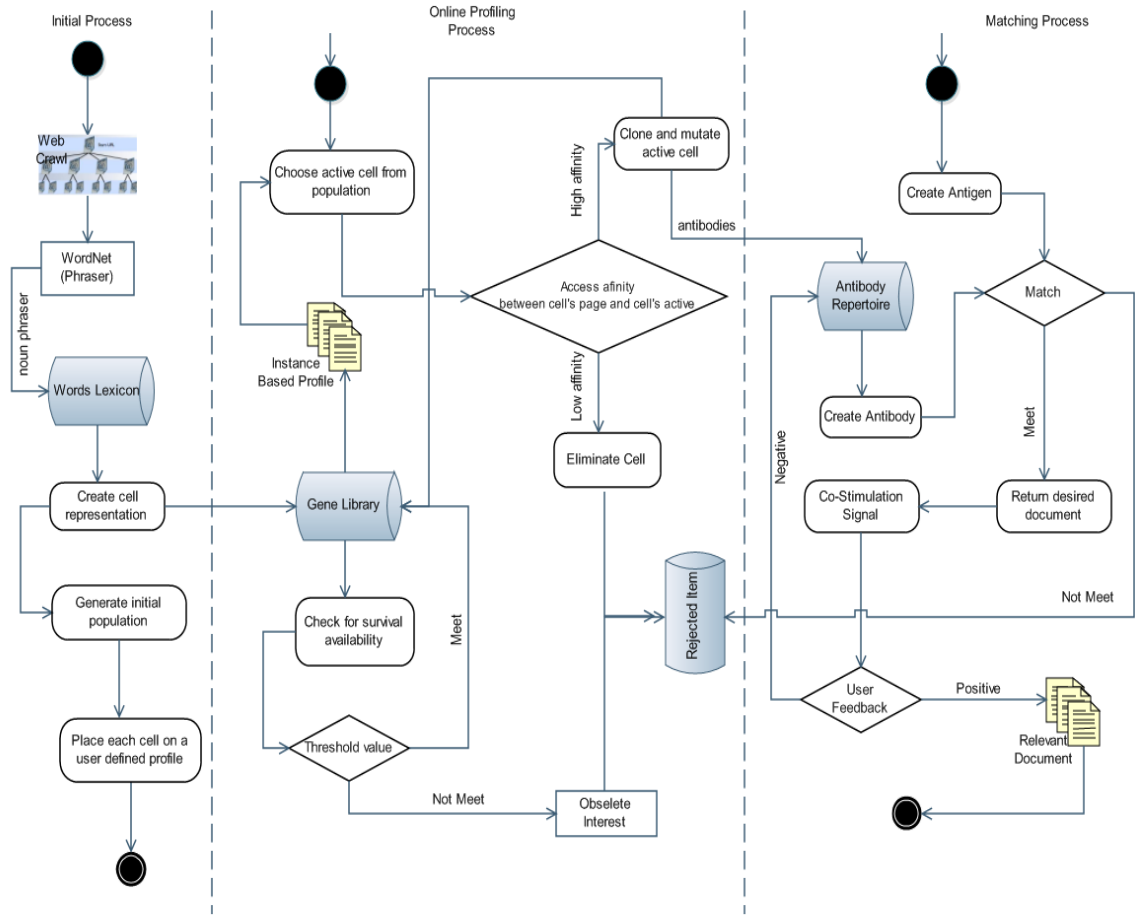


Fig. 1. The Work Flow for the Immune Inspired AIF Profile Adaptation

The user is offered the opportunity to provide feedback on the ranking of such documents. The recommendation-feedback cycle continues until either the user finds an item to consume or abandons the dialogue having found no such item.

### B. Dynamic Clonal Selection

We have suggested that profile adaptation can be developed by incorporating ideas from the aspects of immune networks and clonal selection. In this section, we propose a dynamic clonal selection approach with gene library evolution. Such approaches have been undertaken before [19], [20], [24], [25]. Considerations that must be given to the design of the algorithm include the following.

1) **Dynamic Evolution of Self:** We need to be able to re-define self over time through the addition of new detectors and removal of ones that are no longer useful. The set of detectors represents the user profile. A *memory detector population* is introduced, to handle the dynamic environment and to retain a memory of previously rejected information. Inspired by immune networks, immune memories are retained based on the survival ability, using both the stimulation level and the suppression level [24].

2) **Use of Thresholds:** Immature detectors are created within the gene library and remains immature for a certain

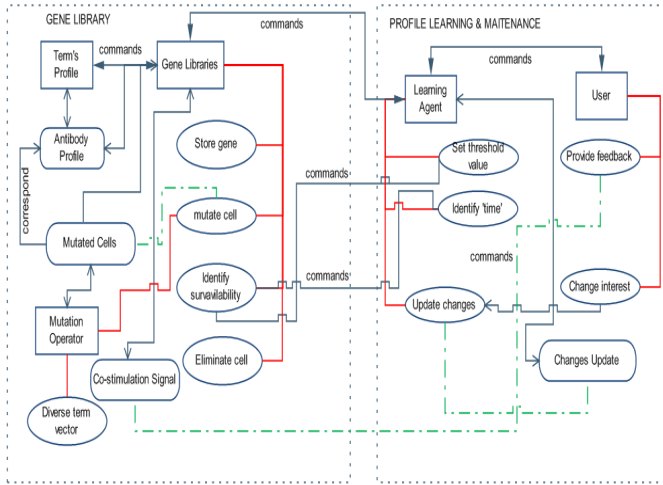
period of time (maturation period). A detector must match at least  $\tau$  strings over a given time period to be activated, where  $\tau$  represents the *activation threshold*. An activated detector that survives changes its state from immature to mature.

An *affinity threshold* determines whether a mature detector remains in the population or is eliminated. Only high affinity detector variants are selected into the pool of memory cells. In a dynamic environment, adaptation of the affinity threshold through learning is essential. When self changes, mature detectors or memory detectors should be compared to every element of the new 'self'.

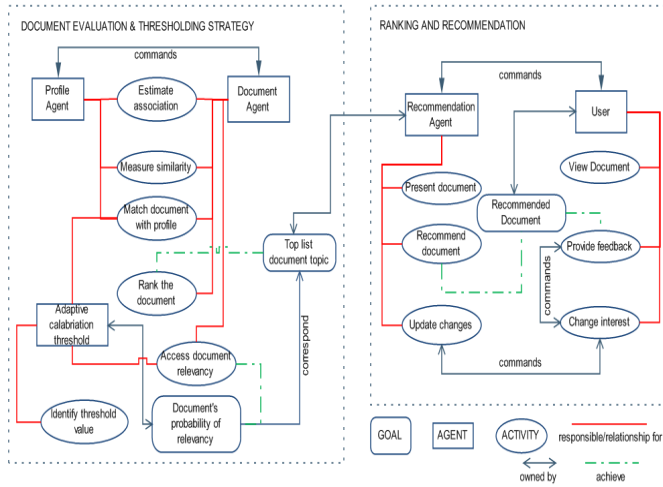
3) **Lifespan of Mature Detectors:** Thresholding results in turnover of the mature detectors, which have a finite lifetime. This gives a control mechanism on the detector population, to ensure rejected information can be later exploited to fill gaps in coverage. The lifespan mechanism also prevents the gene libraries from becoming too large.

4) **Introduction of Diversity:** Mutation via the use of gene libraries, allows the system to increase diversity, and thus to be able to identify new and potentially interesting documents.

5) **Interacting Network:** An immune network is a dynamic network and has functions of memory and learning that use interactions such as stimulus and suppression inspired by the idiotypic network hypothesis [12]. In learning and



(a) Scenario-based model for profile learning and maintenance



(b) Scenario-based model for document evaluation, thresholding strategy, ranking and recommendation

Fig. 2. Example Scenario-based Models

memory, the immune network acts as a *meta-dynamics* aimed at maintaining the network within a specific range of activity. The approach of memory and learning via a network has been used in the existing AIS, for example [19], [26]. The meta-dynamics of an immune network highlights the idea of self-organisation, emphasized in *autopoietic theory* [27], which is used in other work on profile adaptation: Nanas et al. [28], [29] use a term network to represent a user's multiple interests; a deterministic process calibrates the weight of profile terms, removes incompetent terms, and recruits new candidate terms, adjusting the network in response to changes in user interests.

6) **Co-stimulation to Stimulate the Detectors:** Feedback from the user is interpreted as a 'co-stimulation signal'. On the co-stimulation signal, the mature detector may become a memory detector. This means that the form of the detector is added to the gene library, and the memory can continue to reject material similar to that already rejected by user.

Immune inspired approaches to profile adaptation have been studied by Nanas et. al. [28], [29] through the implementation of immune networks. Their work uses the immune network metaphor to build a network of terms that represents a user's multiple interests. Adaptation is a process of self-organisation. Like Nanas et al., our proposed profile adaptation approach uses a hierarchical network of profile terms. However our adaptation is based on the evolution of detectors combined with the meta-dynamics of the memory detector population. We also incorporate adaptation of the affinity threshold, selecting suitable threshold values through learning. Algorithms 1 and 2 present pseudo code for the proposed dynamic clonal selection and gene library evolution.

```

input :  $S$  = set of terms to be recognised in a document,
          $n$  = number of elements selected for removal
output:  $M$  = set of memory detectors
begin
  Create an initial random set of detectors ;
  for terms in  $S$  do
    Determine the affinity with each detectors ;
    Generate clones of the detectors with the highest affinity ;
    Mutate attributes of these clones inversely proportional to their affinity ;
    while mutation is needed do
      Selects a random site within the detector;
      Select a random term (word) from the gene library;
      Replace the term in the detector ;
    end
    Add these clones to the detector set;
    for detectors with highest affinity do
      Place a copy into the memory detector set,  $M$ ;
    end
    Renew memory detectors;
    while renewing memory detectors do
      Check detector suppression and stimulation levels;
      Place surviving detectors in the memory detector set,  $M$ ;
    end
    Replace the  $n$  lowest affinity detectors in the memory detector set with new randomly generated detectors;
  end
end

```

Algorithm 1: Pseudo code for Dynamic Clonal Selection Algorithm

#### IV. CONCLUSION

This paper presents a novel approach to analysis of the characteristics of AIF and the the natural immune system

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begin
  Create gene library representation;
  Generate gene library ;
  Select a random portion of genes in detector
  clones;
  Perform gene mutation ;
  Replace the mutated gene in the detector's
  feature vector;
  Check survival ability of genes;
  if survival rate < threshold then
    Remove gene from library;
  end
end

```

**Algorithm 2:** Pseudo code for Gene Library Evolution Algorithm

using the ODISS meta-probes. This is the start of a principled approach to developing an AIF inspired by appropriate aspects of the immune system. The purpose of the ODISS investigation is to help analyse and evaluate the target application area in the same terms as the natural systems in which we seek inspiration. We then proposed an architecture for immune inspired profile adaptation, and illustrate the requirements analysis with examples of scenario-based models. The envisaged solution offers a novel approach to profile adaptation that incorporates the identified characteristics. This is illustrated with pseudo code of a dynamic clonal selection algorithm with adaptive behaviour, incorporating gene library evolution of terms.

The next stage of the research will prototype these algorithms in the context of e-mail classification, extending the work of [25], [30] to focus on profile adaptation and selection from terms in the body of the e-mail. The prototype allows us to experiment the changing interests based on the dynamic clonal selection algorithm with gene library evolution. By setting up a number of test scenarios related to the continuous learning process in which the user's interest in e-mails from a particular sources changes, we will evaluate the performance of the algorithm. This prototype will then be used as the basis for developing a full AIS for profile adaptation for the web-based filtering system analysed with the ODISS meta-probes.

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