How to Obtain Appropriate Executive Decisions Using Artificial Immunologic Systems

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Abstract. This paper presents a new selection algorithm based on artificial immunologic systems (AIS) and decision theory. The objective of the algorithm it to increase the performance of executive decisions by identifying more carefully what can be considered an appropriate executive decision to a given specific context. The main idea is to mimic the immunologic system, specifically the self & non-self detection mechanism. According to our proposition, 'decision cells' (analogous to immune-cells) are responsible for selection of the appropriate executive decisions. In this paper we present the motivation, theoretical approach (*i.e.* the analogy between biological and business models), the proposed algorithm and some simulated experiments aiming at real situations.

1 Introduction

The human being organism is a complex system and his functions depend greatly on the effective participation of several subsystems that ought to work together, in a collaborative and harmonious way; this is believed to sustain "life". Among the subsystems that comprise this ingenious machine of well-balanced functionalities, we observed deeply the human immunologic system. The human immunologic system is mainly specialized in defending our organism against infections cased by pathogenic agents (*e.g.*, bacteria, viruses, fungi, etc.), [1], [2]. Further investigations on the mechanisms that govern essential actions of the human immunologic system constitute a challenging theme of research as well as a source of some new approaches for solving real problems; here, the immunologic system was the major inspiration for this work.

Similarly to what was commented above, the principle that governs enterprise systems is quick response time. That is, reactions at the right time and in the proper manner. But this can only happen in the presence of good information, *i.e.* quantity as well as quality. In competitive situations, expedite decision may represent survival or death of the organization, [3], [4], [5], [6]. Sometimes, actually, most of times, the high-volume of available information turns out to be very expensive for the decision process of companies. This happens because it is time consuming to discard all unnecessary information for a given decision task. The current trend is for that problem to get worse as Management Information Systems (MIS) are ubiquitous, and increasing in number and functionalities. Meanwhile, executive decisions remain deprived of selective intelligent support tools.

Some properties of the human immunologic system, such as the capacity of pathogen memorization, the ability to distinguish self and non-self elements, decentralization of actions and learning, [1], [2], were seminal for us to suggest their relevance to executive information systems. Actually, in spite of the short history of Artificial Immunologic Systems (AIS), they are already very useful for computer applications in real world problems, [2], and have an increasing number of published papers on practical applications, [1], [2], [7].

In brief, this work approach is to consider one executive decision as a homeostatic response within a given organization, when information is available. This means that 'decision cell' select appropriate executive decisions when the necessary 'pieces of information' bind appropriately to their 'receptors'. In the human immunologic system, the same happens when antibodies binds to a pathogens.

This paper is organized as follows. Section 2 describes briefly the theoretical concepts that were used in this work, namely, the human immunologic system, decision theory, information and decision systems. Section 3 presents the considered analogy between the human immunologic system with decision systems and the proposed model for selecting of appropriate executive decisions. Sections 4 and 5 describe experiments, results and conclusions.

2 Background

2.1 The Human Immunologic System

The defense mechanism of human (and other animal) organisms against pathogenic agents is carried out by the innate immunologic system. Its functioning is continuously improved by adaptive learning. This adaptive defense mechanism is capable of memorizing specific characteristics of pathogenic agents, acting preventively in future attacks. Working in an intensive and collaborative way, the above mentioned mechanism provides immunity against a great deal of infections.

The non-trivial task of keeping the body secure is made possible by the immunologic response of an efficient layered architecture. The innate immunologic mechanism is mainly composed of two processes called: (*i*) phagocytosis and (*ii*) adaptive immunologic mechanism. Both are mediated by specialized cells. The former, engulf non-self particle and cells, and the latter recognize and destroy antigens, [1], [2], [7], [8], [9], [10], [11], [12], [13].

2.2 Information and Decision

Searching for more suitable ways of decision making is as old as the pre-historic period, when man conducted his decisions by analyzing dreams, animal viscera, smoke, among other elements, [14]. This necessity has been increasingly elaborated through time. Currently, advances in information technology (IT) are of great support for supplying those needs, especially in overcoming human limitations, [15], [16], [17], [18]. Namely, IT may help on not having emotional decisions and help on overcoming the human brain shortcoming of not be able of dealing with too many alternatives (*i.e.* solution scenarios), [19].

Decision making presents two following dimensions: (*i*) the process dimension, which focus is on decision performance (*i.e.* efficiency) and (*ii*) the problem dimension, which focus is on decision efficacy, [3]. Problem is the core of the decision theory. It can be presented in a structured or unstructured manner, the latter characterized by unpredictability, uncertainness, need for innovation, non-uniqueness of data, among other characteristics. In turn, these problems make the context of programmed decisions less relevant than its counterpart, the non-programmed decision. Where qualitative parameters compose the majority of executive decisions, [3], [5], [6], [15], [16], [20].

An important point that must be taken into account is also the culture of the enterprise, [4], [5], since it cannot be inherited, but is developed and is transferred by those who comprise the environment, that is, it is unique and innate for each organization. Decision can be seen as resolution, determination or deliberation, [10], to assume predictable risks with responsibility. According to Chiavenato, [3], decision is the action of analyzing alternatives and choosing one among the available ones, desirably, in real time, [20].

For William Starbuck, resident Professor of the Charles H. Lundquist College of Business, University of Oregon, “decision implies the end of deliberation and the beginning of action”, [14].

2.3 Information Systems

The quality of a decision is directly proportional to the trustworthiness of its data, [5], [21]. Stratification of information inside of an organization, [6], can be represented as the model shown in Fig. 1. In this model, quantitative information is gradually replaced by qualitative one and structured problems are also gradually replaced by unstructured ones, where impact of strategic decisions may be crucial to the fate of the business.

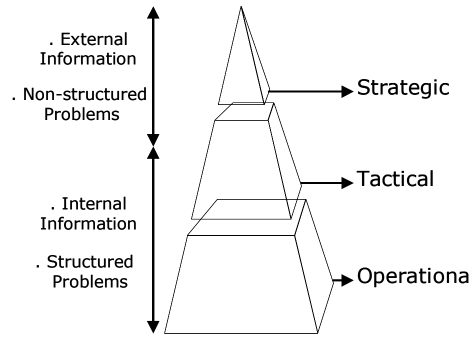

Fig. 1. Stratification of information within the organization (the tip of the tetrahedron represents the executive level).

It is import to highlight that professional skill distribution within the organization is directly proportional to the intrinsic capacity of solving more complex problems and whose decisions present more risks for the survival of the enterprise as a whole, [3], [6], [22]. This becomes easier to understand as we classify decisions in operational, tactical and strategic decisions in relation to their short-, medium- and long-term effects, respectively.

Products of information systems are always associated with decisions, [17], and for each level of information there are specific systems, as it follows:

- In the operational level, repetitive data are to be treated based on hard rules (i.e. transactional systems);
- In the tactical level, data synthesis deriving from transactional systems, such as report form, is usually the fundamental tool. Sometimes, some external information about clients, suppliers becomes necessary;
- In the strategic level, where decisions are predominantly non-repetitive and unpredictable, new approaches have to be considered regularly. In such level there are a few requirements to be observed, they are flexibility and adaptability in the presence of fast scenario changes, and desirably intuitive interface, graphic and textual support. These features guide the permanent search for modern and adaptive techniques to supporting executive decision making. Here is precisely where AISs can contribute significantly, [3], [16], [17], [23], [24], [25].

In general terms, information systems are developed to attend organizational objectives and are composed of input, transformation and output components. In this framework, a repository for storing-recovering data and information, models of representation of real problems, and an intuitive user interface are essential for its usability, [5], [17].

In this context, simple internal data and those which were transformed on information are considered as the knowledge of the enterprise about a specific segment, where reutilization of these stored information can be seen as specific memory lymphocytes that will perform quickly on future support for decision making, [17].

The main commercial techniques applied to implementations of decision support systems are the following: (*i*) statistical methods, (*ii*) decision tree, (*iii*) artificial neural networks and (*iv*) fuzzy logic. Choosing one of these methods depend, mainly, on the problem features. Specifically, fuzzy logic is the closest technique to our approach as they present some features centered in man. In general, the mentioned techniques are based on quantitative data used to construct executive indicators. Our approach uses qualitative data to directly generate appropriate decision cells. In this sense, there are not similar works with such a purpose.

3 The New Approach

3.1 Analogy between Biological and Organizational Models

In this paper we introduce the concept of Immunedecision[1]. We define it as the set of appropriate responses for information that propitiate the 'decision-homeostasis' with in the enterprise. As decisions are composed by the following six elements, [3]: (*i*) the decision maker; (*ii*) decision objectives; (*iii*) preferences of the decision maker; (*iv*) decision strategy; (*v*) environmental aspects; (*vi*) decision consequences. Fig. 2 shows a macro-vision comparison of biological and organizational systems. We correlate them in order to draw some inspirations from biology. Notice that in both systems external inputs trigger internal responses. In the proposed approach the immune response, as pathogens arrive, is equivalent to the necessity of an appropriate decision.

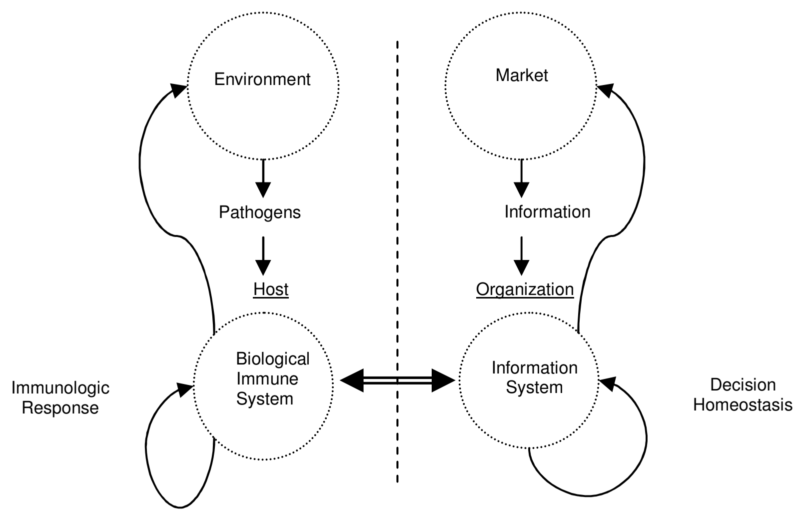

Fig. 2. Domains of the two identified analogous systems: (left) the biological and (right) the organizational.

Further issues identified in the analogy between biological immune system and information systems and their fundamental characteristics are detailed as it follows:

- In biology as in organizations, systems work normally in harmonious, integrated and collaborative way;
- Immunologic responses (as executive decisions) are unique for each individual. Various factors such as environment and market are decisive in each case;
- Fungi, viruses, bacteria and parasites are pathogenic agents for the immune system, such as internal and external information are the external element that trigger decision making;
- Pathogenic agents instantiate immunologic actions, such as information instantiate decision actions, that is, homeostatic decisions;
- Lymphocytes, macrophages and leucocytes correspond to possible actions that can be carried out by directors, managers and supervisors;
- Phagocytosis correspond to the process of knowing, analyzing and decompose an information for future decision making;
- Immune system performs efficiently against infections avoiding possible harms, in the same way appropriate decisions may promote good consequences to the organization;

[1] Immunedecision is a neologism, created to better illustrate the hidden connection between immunology and decision theory.

- Antigens can not trespass through the epidermis, the first defense barrier, in the same manner that external information that keep that way (*i.e.* that do not enter the organization) do not trigger any decision action;
- The work of the innate immunologic mechanism on phagocytosis can correspond to specific decisions for structured problems;
- Multiple antigens detections can occurs in the body simultaneously without the need of a central control mechanism. The same happens with simple decisions that can be made (*i.e.* detection, analysis and action) in any of the three levels of an organization structure;
- Detections based on affinity are carried out by the immune system based on a number of ‘non-self’ patterns if this number is greater than a specified threshold. This corresponds to decision making without complete knowledge about all needed aspects of the decision;
- Generation of diversity of lymphocytes receptors can be seen, in the organizational domain, as the use of scenarios creation techniques. This is of fundamental importance for supporting decisions;
- Immune system learns pathogens structures to propitiate future quick responses against these agents. The same happens as in new decisions opportunities, when the decision maker can make good use of new information and prior knowledge;
- As ability of recognizing ‘self’ and ‘non-self’ is vital in the immune system, selection of relevant information for solving a problem is also vital in the business world;
- Performance in response of the immune system is not attached to any particular process such as phagocytosis, affinity maturation, etc., but it is due to a well integrated sequence of processes. Decision responses in organizations are judge to obey the same rule;
- Transactional systems are intimately associated with the daily routines of an enterprise. This is believed to be similar in innate immune system.

3.2 Characteristics of the Proposed Model

The proposed model, introduced in this paper, aims at developing an appropriate information selection system for supporting executive decision making. The algorithm is based on the negative selection algorithm. This reunites AIS and decision theory; the previous section explains why we judge they are complementary.

Fig. 3 shows a model for the proposed architecture, where the repository database (DB) stores quantitative indicators of self performance for an enterprise, those, derived from transactional systems and external information.

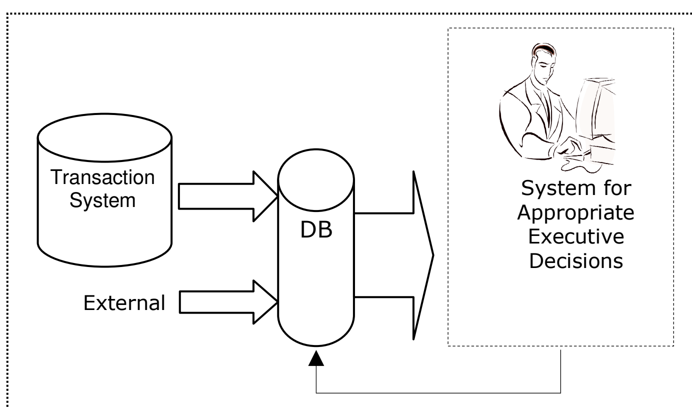

Fig. 3. Overview of the proposed Architecture.

A major problem that can be tackled by our approach is to minimize the undesirable fact that most other approach requires, that is need of complete information [5] [6]. Additionally, our approach tackles another difficult aspect of executive decision systems, that is, the ill-posed logic attached to those systems. In Fig. 4, the encapsulation of information can be seen as a hierarchy of concepts, they are: category (Cg), component (Cp) and element (E_t) [26] [27]. According to [28], this principle is central to best representing information for decision making. We find that, together, these concepts are equivalent to the receptors of an antigen. Here we refer to them as ‘decision receptors’. They are needed for the computation of affinity (refer to section 3.3).

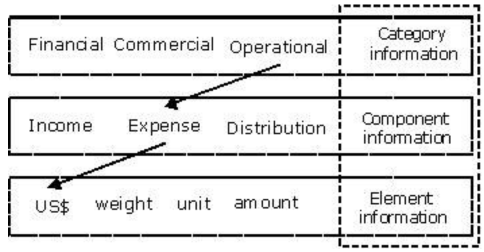

Fig. 4. Information encapsulation according to the hierarchy of concept.

We propose that the decomposition of a decision problem into its decision receptors is highly necessary for the mapping of solutions to the various decision cells (D_c). Each decision cell is then composed of *n* decision receptors. The higher the affinity with the problem the most receptors are matched. In Fig. 5 we shown the analogy of lymphocytes and decision cells (refer also to Fig. 4).

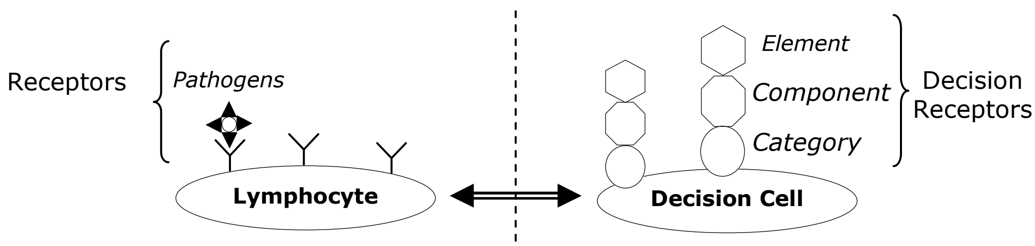

Fig. 5. Analogy between Lymphocyte and Decision cell (left and right, respectively).

In the repository database (DB) are also stored collections of Cg, Cp, E_t and *decision memory* (D_m) that correspond to the decision cell approved by the decision maker.

Our proposed algorithm is made of two distinct stages (see Fig. 6). In the learning stage, strategic information is stored in DB (for instance: consuming market, suppliers, technology, etc.). With this information the decision maker will generate the first decision cells. These cells make the initial repository of self cells for future generalizations that propitiate a secondary answer (similar to immunological system) in future company expositions to information that have originated these cells.

In the operation stage, the decision maker requests to the system a decision cell of a specific type (for instance: to buy, to sell, to transform, etc.). After generation and presentation of the most appropriate cell, the decision maker may be requested (not always) to decide whether it is self or non-self. In the affirmative case, the generated cell is added to the pool of memory cells. Also at this stage, new cells of memory can be created.

The non-linear characteristic of the system emerges from diversity of stored decision receptors that propitiates a better generalization through the increasing number of memory cells.

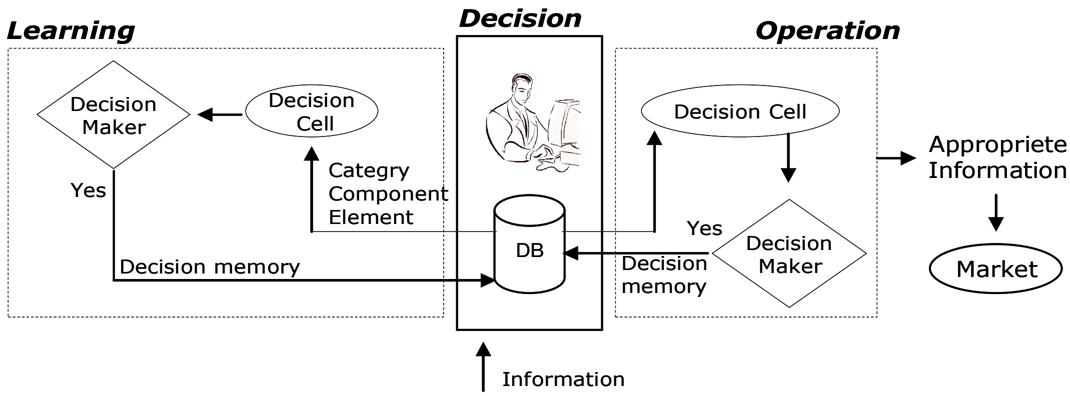

Fig. 6. Stages of the proposed system.

3.3 Computations within the Proposed System

The pseudo-code for execution of Appropriate Executive Decision (AED) is presented in Fig. 7 and its principle is based on the negative selection algorithm, modified for the real condition of work. Hamming distance is used to evaluate the affinity of the cells. Three parameters, predefined by the decision maker, are supplied at this stage for generation of cells, where:

- $\boldsymbol{a}$ – represents the type of cell that will be created;
- $\boldsymbol{\varepsilon}$ – represents the minimum affinity threshold that $\boldsymbol{n}$ cells generated randomly in the interval [1, $\boldsymbol{n}$], where **n** is equal to the number of memory cells, should have in relation to each original memory cell;
- $\boldsymbol{\varepsilon_c}$ – represents the minimum crossed affinity threshold that each cell should have in relation to other original cells;

The growth of $\boldsymbol{\varepsilon}$ represents a larger similarity between the memory cell and $\boldsymbol{n}$ generated cells, and the growth of $\boldsymbol{\varepsilon_c}$ represents the similarity level in relation to other memory cells. This strategy assures a larger reliability of the cell that will be presented to the decision maker, since $\boldsymbol{\varepsilon_c} < \boldsymbol{\varepsilon}$ In our proposal, we adopted the values of $\boldsymbol{\varepsilon}$ and $\boldsymbol{\varepsilon_c}$ in the interval [1,10].

The function $\boldsymbol{r}$, given by (1), represents the reliability of the produced answer, defined in function of: $\boldsymbol{n_\varepsilon}$ - number of cells that attend $\boldsymbol{\varepsilon}$, and $\boldsymbol{n_{\varepsilon c}}$ – number of cells that attend $\boldsymbol{\varepsilon_c}$ ($\boldsymbol{n_{\varepsilon c}}$ is a subset of $\boldsymbol{n_\varepsilon}$); $\boldsymbol{r}$ varies in the interval [1-100] and represents the degree of the appropriateness of a candidate decision.

$$r = \exp \frac{-(n_\varepsilon - n_{\varepsilon c})^2}{2 * {n_{\varepsilon c}}^2} \qquad \textbf{(1)}$$

```
AED(a, ε, εc)//Appropriate Executive Decisions(AIS-based)
a: decision type
ε: affinity threshold
εc: cross affinity threshold
// Learning stage
While decision maker is not satisfied
   Input nm decision memory cells (by decision maker)
// Operation stage
While decision maker is not satisfied
    While ε is not satisfied
        Generate na decision cells in the interval {1, n}
    End While
    While εc is not satisfied
        Present decision cell that satisfies εc
    End While
    Evaluation of r
    If decision cell is approved by decision maker
       Save decision cell as a decision memory
    End If
End While
```

Fig. 7. Pseudo-code for the AED-AIS Algorithm.

4 Experiments and Results

To illustrate our approach we conceived one application where seven (actual) decision makers, responsible for purchases and sales contributed with their views on 'how to decide about good bargains'. Based on that, we have created sound initial decision-cells, they can be seen in Table 1.

Table 1. Initial memory cells used as a basis for future purchases (they were provided by real people)

Decision Memory	Decision Receptors
D_{m1}	Price, stock, cash, quality, support
D_{m2}	Price, stock, cash, quality, period
D_{m3}	Price, stock, payment, quality, demand, period, supplying
D_{m4}	Price, stock, cash, climate, market, seasonality
D_{m5}	Price, stock, cash, profit, demand
D_{m6}	Price, warranty, service, quality, demand, period, support, attendance
D_{m7}	Cost, stock, cash, return, demand

The algorithm presented in the previous section was implemented and a simple graphic interface was prepared for testing our ideas. This application was utilized for the insertion of all decision receptors, of all 7 memory cells during the initialization of the system.

In the operation stage, the same decision makers (mentioned above) were invited to use the system, which has generated decision cells that could be approved or rejected by them. Table 2 contains results produced after intensive use of the system; each line is an example of a generated decision (cell) by the AED-AIS. Notice that their 'receptors' were not in any arrangement previously known. However, they are organized in such a way that, collectively, they are within boundaries of affinity that may be sound to executive users.

Three examples of generated decisions, presented in Table 2, may now be re-visited by the decision makers (*i.e.* they may be customized as appropriate decisions). The first one, despite the fact of a very low reliability, an actual decision maker considered the generated cell as appropriate. The second one, because of the increment of accepted cells, despite of the generated decision cell be of high reliability, the consulted decision maker is entitled to consider it as non-appropriate. Finally, in the third example, a cell of high reliability was generated and it was in deed accepted by the decision maker.

The column n_{memory}, represents the number of cells stored and competent for future decisions and the column "yes/no" represents the power of personal inference of the decision maker on the system.

Table 2. Results of generated decision cells after intensive use of the system.

Decision Type	ε	ε_c	n_{memory}	n_ε	$n_{\varepsilon c}$	r (%)	Yes / No
Purchase	3	2	7	25	7	4	Yes
	Price, stock, cash, supplying, market, profit						
Purchase	7	3	8	21	17	97	No
	Price, stock, payment, quality, demand, period, supplying						
Purchase	3	1	8	32	27	98	Yes
	Price, stock, cash, market, service, seasonality						

The parameters presented in Table 3 were used in the experiments carried out for validation of reliability; results are presented in Fig. 8. Notice the slow decay of the reliability as cell numbers are increased.

Table 3. Parameters used experiment.

Parameter	Value / range
a	Purchase
E	Set [2,7]
ε_c	Set [1,7] for $\varepsilon_c < \varepsilon$
Memory cells	[1,7] increased by interaction
Total of presented samples	111

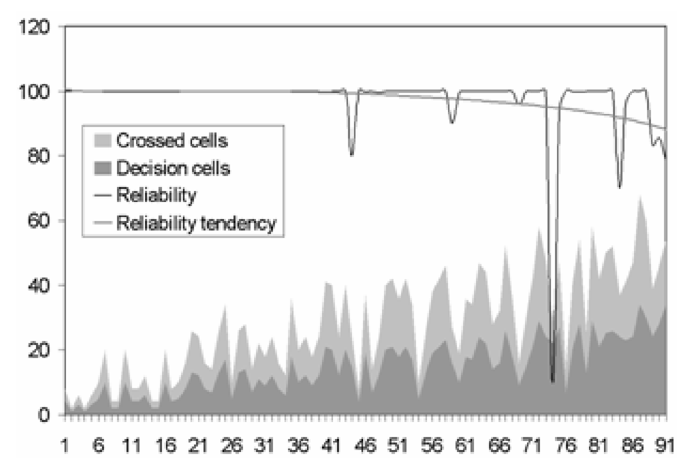

Fig. 8. Evolution of the reliability in function of cell number (x-coordinate is sample number; y-coordinate is reliability).

After analyzing the graph presented in Fig. 8, we highlight:

1. System reliability stays close of 100% at the major part of the experiment, except in intervals where the system does not generate crossed cells, that is, points with high values of ε e ε_c;
2. For values with reliability less than 100%, (e.g. sample 44, 59, 74) the number of crossed cells is smaller than of decision cells, ratifying the low reliability presented;
3. Between sample 1 and 90, number of memory cells were increased in steps of 1 unit. Notice that the growth of the number of memory cells increases the number of crossed cells and propitiate a larger reliability of the system. The growth in the number of memory cells acts like the secondary answer supplied by the artificial immunological systems.

5 Conclusion

This paper presented a new approach for selecting appropriate executive decision. The algorithm was inspired upon negative selection. A comprehensive analogy between human immune system and decision systems was presented as well.

The experiments show that the proposed intelligent algorithm is able to produce new instances of what we refer to as decision cells (in a clear reference to lymphocytes). The operation of the algorithm relies on a set of primordial decision that is kept as memory cells to guide the selection of new appropriate decisions. The reliability of generated decision cells, as an indicative of how appropriate information is, presented a marked increase growth as a function of number of memory cells. In addition to this, reliability values tune-up very quickly according to specific executive decisions domains. This is good because as we discussed earlier, decision maker preferences vary greatly.

We understand that some other aspects should be considered and further investigated. Namely, (*i*) how much learning of the system is dependent on the decision maker ability to provide good primes (*i.e.* on make good decisions); (*ii*) the possibility to gather good prototypical good decisions (as in a public repository for specific decision domains); (*iii*) how important is the number of memory cells to drive decisions in a more appropriate manner.

We conclude by highlighting that the fast adaptation and convergence of the proposed algorithm are strong indications that such a system can be modified to be used in selecting appropriate executive decisions in real organizational environments.

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