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An Immune Memory and Negative Selection Based Decision Support System to Monitor and Control Public Bus Transportation Systems

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Abstract: In urban cities, disturbances, such as accidents or traffic congestion, may affect the good performance and level of service of public bus transportation systems. Developing Decision Support Systems (DSS) to help public transportation agencies in dealing with disturbances contributes to an efficient management of public transportation networks and allows users to benefit from high quality of services, in terms of punctuality and frequency. In this article, we design a Public Transportation Control System (PTCS) based on an analogy between public bus transportation systems and biological immune systems. We rely on biological immunity to design a set of models to structure knowledge related to both disturbances and control decisions. Monitoring and control mechanisms are also presented based on the immune negative selection and the immune memory to detect and react to disturbances.

Keywords: Public transportation systems, Decision Support Systems, biological immune system, antigens, B-cells, antibodies.

1. INTRODUCTION

The control of public transportation networks is a challenge for transportation agencies due to both the complexity of such systems, and the continuous increase in mobility requirements. Agencies must analyse large streams of data captured from the network in order to detect any disturbances and assess their impact and severity. These disturbances impact pre-established schedules and organization, which affects service quality and reliability. Therefore, it has become a necessity to implement Public Transportation Control Systems (PTCS) that are able to help human regulators to monitor the good execution of early prepared transportation timetables, and to propose corrective decisions as early as possible to prevent passengers' dissatisfaction and performance degradation.

Many artificial intelligence based approaches were used to develop PTCS. The agent paradigm is widely used in the regulation of transportation systems. For example, Balbo and Pinson (2010) presented an agent-based PTCS, having a vertical architecture, which monitors the network and activates a regulation procedure when a disturbance is detected. Agents are also used in (Rahal et al., 2010) to develop an agent-based decision support system to regulate the multimodal (tram, metro and bus) public transportation network in Algiers city. Ezzedine et al. (2008) presented a system combining multi-agent approach with Petri nets. The regulation process includes three methods for the selection of a regulation strategy: a manual, a semi-automatic and an automatic method. The system uses Case-Based Reasoning (CBR) approach to build a regulation strategy based on previous experience stored in a database. This database is enriched with the activities resulting from manual regulation or those generated automatically by the system. Bouamrane et al. (2005) developed a PTCS combining CBR and multi-agent systems to detect and react to disturbances. In this system, the human regulator has to build the solution manually with the help of a toolbox of regulation decisions.

With respect to disturbance management, a few developed PTCS have considered disturbance assessment and consequence identification. Indeed, control decisions are generally activated as soon as a disturbance is detected. However, many PTCS are not able to detect a combination of different types of disturbances (Ezzedine et al., 2008). For example, the PTCS developed by Balbo and Pinson (2010) integrates a "Disturbance Model" that analyses and evaluates the seriousness of a detected problem based only on the deviation between the scheduled bus time and its real time of passing by a station. Other types of problems, such as technical problems or problems associated to passengers are neglected. Moreover, the disturbances are assessed by the system, and operators are not able to interact with the "disturbance analysis" process, which is considered as a black box.

Despite the relative number of publications presenting PTCS, only a few papers focused on the issue of disturbance management. In this field, more research and development efforts need to be spent on several aspects, including dealing with detection of occurrences and classification of several different types of disturbances, modelling and representation

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of disturbances, determination of control decisions, suggestion of reaction/regulation strategies, and evaluation of residual effects. There is still a lack of generic approaches, able to deal with a variety of disturbance types and causes, while at the same time not requiring great customization each time a new disturbance type or cause is considered. There is also still a lack of integrated approaches, able to address simultaneously detection of disturbances, identification of their consequences, reaction and evaluation of residual effects. To the best of the authors' knowledge, no much work seems to be done in order to use more than one type of control decisions within hybrid control strategies. Moreover, only a few works suggest ways to capture knowledge involved during the management of disturbances in a transportation system (Darmoul and Elkosantini, 2014). Capturing such knowledge would allow reusing it, for example by retrieving stored control strategies and adapting them to new occurrences of similar disturbances that were managed in the past.

This paper investigates the Biological Immune System (BIS) to develop a PTCS as the major limitations of existing systems concern the detection of disturbances and the determination of appropriate decisions to handle each type of disturbance. Dealing with disturbances should be achieved while preserving a high-level of service of the network. To the best of our knowledge, BIS is not well investigated to develop PTCS. Indeed, BIS seems to be a promising approach as it was discussed in (Darmoul and Elkosantini, 2014). This choice can also be justified by the analogy that exists between the BIS and the public transportation systems as it will be detailed in section 3.

This paper tries to establish and show the effectiveness of biological immunity using an analogy between the biological immune system and the bus network. It has been demonstrated in (Hunt et al., 1998; Dasgupta et al., 2003) that the immune system has the capability to recognize new patterns, learn, classify, memorize and process information. In addition, the immunity, which is the feature of recovering and maintaining a status of good health, can be preserved even in the face of a dynamically changing environment. The biological immune system can recognize different patterns and generate selective immune responses. A first investigation work is already conducted in (Darmoul and Elkosantini, 2014) and suggested a first analogy with the public transportation systems. Authors have suggested a decision support system using the immune clonal selection theory. In this paper, we investigate other immune mechanisms combining Negative Selection and the immune memory.

Therefore, this paper is organized as follows: Section 2 describes the main concepts of the biological immune system. Section 3 details the analogy between the BIS and public bus network then presents the proposed models to structure knowledge related to disturbances and decision-making. These models are then included in a PTCS. Section 4 introduces an immune Negative Selection Algorithm (NSA) for the bus network monitoring. Section 5 presents the architecture of the DSS using the NSA for the monitoring and an Immune Memory Algorithm (IMA) for the control of the system. A preliminary implementation and results are discussed in section 6. Finally, a conclusion and perspectives are presented.

2. BIOLOGICAL IMMUNE SYSTEM

The Biological Immune System – BIS – is a robust complex system. The BIS reacts to adverse environmental changes, internal and/or external stimuli to the organism by discovering and eliminating foreign pathogens, called "*antigens*" or *non-self*, such as viruses, bacteria, and other parasites. The body recognizes these antigens as foreign molecules that stimulate an *immune response*. The biological immune system develops a strategy aimed at neutralizing the detected antigen. Indeed, when an antigen enters into the body, it stimulates a subset of immune cells, named *B-cells* able to secrete substances like "*antibodies*", which bind to antigens, block them and thereby lead to their elimination (Hightower, 1996). In BIS, an antibody can identify antigens using its receptors, called "paratopes" that cover its surface in order to eliminate them. Furthermore, an antibody is not activated unless its receptors bind to the antigen with an *affinity* that exceeds *an affinity threshold*. Thus, the body relies on the *self/non-self discrimination principle* to distinguish between foreign/disease causing elements (non-self) and elements belonging to the body (self). According to this phenomenon, when an antibody recognizes a self-cell, it is destroyed in order not to react to body cells. Such a principle is called the negative selection mechanism.

As soon as a non-self-cell such as an antigen is detected, the body activates the immune response. Then, lymphocytes are generated and are divided into two main types of cells: effector cells and memory cells (Hofmeyr, 2001; Perelson & Weisbuch, 1997). Effector cells have a short lifetime and are created for the immediate defense of the organism. Memory cells are long-lived cells that circulate through the host organism. This concept is called the *immunological memory*. When confronted with the presence of an antigen that was previously recognized, memory cells are able to launch a rapid and effective response. Usually, Artificial Immune Systems (AIS) often use the idea of memory cells to retain good solutions to the problem under consideration. In our case, we rely on immune memory, and on the mechanism of affinity to control traffic at intersections.

3. IMMUNE INSPIRED KNOWLEDGE MODELS

3.1 ANALOGY BETWEEN THE BIS AND PUBLIC TRANSPORTATION SYSTEM

A PTCS should protect public transportation networks from disturbances affecting pre-established schedules, just as the biological immune system protects the body from disease causing elements. In this paper, an antigen represents a disturbance that affects the transportation network, such as a bus delay, a technical problem or successive buses. An antibody represents a corrective decision that could be recommended to regulate the system, such as "hold stations" or "skip stations". The immune response must determine the best action that will regulate the network using an Immune