香港浸會大學
HONG KONG BAPTIST UNIVERSITY
計算機科學系
Department of Computer Science

Report production coordinator: Claudia Chui, claudia@comp.hkbu.edu.hk, +852 3411 7079
Report Web Site: http://www.comp.hkbu.edu.hk/tech-report

Autonomy Oriented Computing (AOC) for the Wisdom Web: Some Research Questions

Jiming Liu

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Department of Computer Science
Hong Kong Baptist University
Kowloon Tong, Hong Kong

Abstract

In this paper, we will discuss how the Wisdom Web (WW) from the next-generation Web Intelligence (WI) development contributes to the research studies in immunology, i.e., the scientific discovery of HIV-immune interaction dynamics. In particular, we will show that a new computing paradigm, called Autonomy Oriented Computing (AOC), will be necessary to support the Wisdom Web to meet this challenge. Throughout our discussion, we will pose several Research Questions to highlight the related issues and to stimulate thinking and innovations.

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Computer Science Department
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Abstract. In this paper, we will discuss how the *Wisdom Web (WW)* from the next-generation *Web Intelligence (WI)* development contributes to the research studies in *immunology*, i.e., the scientific discovery of HIV-immune interaction dynamics. In particular, we will show that a new computing paradigm, called *Autonomy Oriented Computing (AOC)*, will be necessary to support the Wisdom Web to meet this challenge. Throughout our discussion, we will pose several *Research Questions* to highlight the related issues and to stimulate thinking and innovations.

1 The *Wisdom Web*

We envision that the next paradigm shift in Web Intelligence (WI) should go beyond the role of supporting tools and further incorporate the notion of *wisdom* to be embedded in the Web itself [6, 13, 17, 19, 20]. According to Webster Dictionary, the word *wisdom* means *the quality of being wise; knowledge, and the capacity to make due use of it; knowledge of the best means and the best ends.* We refer to the World Wide Wisdom Web as the Web that can autonomously

- discover the best means and ends,
- mobilize distributed resources,
- enrich social interaction, and
- enable users to gain practical wisdom of living, working and playing.

In short, the Wisdom Web will enable users to go beyond the existing on-line information search and knowledge queries functionalities and to gain, from the Web,[1] practical wisdom for problem solving.

To support such a Wisdom Web, we envision that a grid-like computing infrastructure with intelligent service agencies is needed, where these agencies can interact, self-organize, learn, and evolve their course of actions, identities and interrelationships for new knowledge creation, as well as scientific and social evolution [5, 6].

[1] Hence, the notion of "Web" should be taken in a much broader sense.

2 *Web Intelligence* Meets *Immunology*

2.1 Discovering HIV-Immune Interaction: The *Open Problem*

As argued in [18], human immune system is a typical example of a highly sensitive, adaptive and self-regulated complex system involving numerous interactions among a vast number of cells that belong to different types. Immune response is an emergent phenomenon from the interactions of numerous entities, which protects the human body from invaders such as bacteria, virus and other parasites. Despite there are many clinical case studies and empirical findings [1, 15, 2, 14, 16], the working mechanism underlying the complex process of HIV invasion, erosion and eventual crash on the immune system, such as how the local interactions at the level of HIV, T cells and B cells affect this process, remains to be fully understood (i.e., characterized and predicted).

Conventional modeling and simulation technologies are useful only to a very limited extent due to computational scale and cost involved. Hence, it would be most natural and desirable to make the best use of the above-mentioned grid-like computational infrastructure with intelligence service agencies to carry out such a large-scale, distributed scientific knowledge discovery, i.e., characterization and prediction of the human immune responses [4, 10, 18].

2.2 The *Real* Challenge

This endeavor presents a tremendous challenge to the filed of computing, i.e., (1) the task of computing is seamlessly carried out in a variety of physical embodiments, and (2) there is no single multi-purpose or dedicated machine that can manage to accomplish a job of this nature. In other words, the key to success in such applications lies in a large-scale deployment of computational agents capable of autonomously making their localized decisions and achieving their collective goals.

3 Towards the *Autonomy Oriented Computing (AOC)* Paradigm

Recently, Liu et al. have been interested in the metaphors of autonomy as offered by nature and their roles in addressing our practical computing needs. His research agenda concerns the development of a new computing paradigm, called autonomy oriented computing (AOC) [7, 10]. AOC makes use of autonomous entities in solving computational problems and in modeling complex systems [8, 9, 12].

3.1 Characteristics of AOC

AOC starts from the smallest and simplest element of a complex system based on the following characteristics of the entities in the system [10, 11]:

– *Autonomous* The systems elements are rational individuals that will act independently. In other words, a central controller for directing and coordinating individual elements is absent.

  Research Question 1: *How can the behavior and utilities of the entities be goal-directed? How would the entities acquire and improve their reactive behavior based on their local and/or shared utilities?*

– *Distributed* The entities of localized decision-making capabilities are distributed in a heterogeneous computing environment and are locally interacting among themselves, without too much communication overhead.

  Research Question 2: *How would the entities measure, update, and share information among themselves?*

– *Emergent* They exhibit, often not simple, behaviors that are not present or predefined in the behavior of the autonomous entities within complex adaptive systems.

  Research Question 3: *How would you formally model and quantitatively measure the inter-relationships between the local goals of the entities and the desired global goal(s) of the AOC system?*

– *Adaptive* They often change their behavior in response to changes in the environment in which they are situated.

  Research Question 4: *How would you define (and update) the goals and on-going feedback (e.g., rewards) of individual entities?*

– *Self-organized* They are able to organize the elements to achieve the above behaviors.

  Research Question 5: *How would the entities locally interact among themselves? What are the rules?*

3.2 The AOC Approach to Discovering HIV-Immune Interaction on the Wisdom Web

In order to deal with numerous interactions among a vast number of autonomous agents in AOC-based massive multi-agent (MMAS) simulation, we have studied an AOC approach that incorporates the characteristics of Cellular Automata (CA) and system-level mathematical equation modeling to simulate the complex interactions in the process of human immune response to HIV. In our AOC approach, the mathematical equations are used within a single site, which keeps the spatial characteristics of the system and reduces the heavy computational costs of the CA model.

Research Question 6: *How would you define and model (and let entities to efficiently explore and update) the large state space during their interaction?*

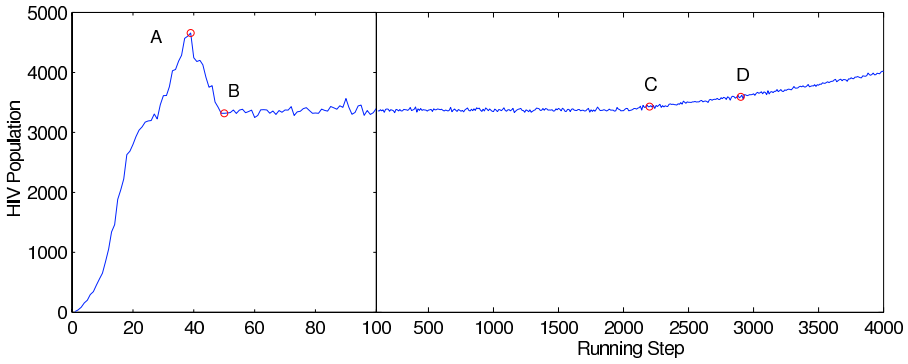

Fig. 1. The three-stage dynamics of HIV infection as generated from an AOC-based simulation [18]. This result is consistent with the earlier empirical findings [3].

Figure 1 presents the temporal emergence of three-stage dynamics in HIV infection, which was generated from our earlier AOC-based massive multi-agent (MMAS) simulation [18]. The three stages are: (1) before B: the primary response, (2) B~C: the clinical latency, and (3) after D: the onset of AIDS. At A, the HIV population reaches a maximum. Starting from C, the mechanism that decreases the natural ability of an organism in producing T cells is incorporated. This AOC-generated result is consistent with empirically observed phenomena [3].

Furthermore, it also revealed from our experiments [18] that AIDS cannot break out if HIV only destroy T cells without weakening the T cell reproduction mechanism. The emergence in "shape space" indicates that it is because the HIV's fast mutation that the immune system cannot eradicate HIV as easily as it does to other invaders. The discoveries help researchers to understand HIV-immune interaction dynamics more comprehensively.

Research Question 7: *How would you design and implement the AOC system on the Wisdom Web, consisting of such multiple entities? In real time, millions of entities must concurrently operate and interact themselves.*

4 Discussions

The AOC paradigm for the Wisdom Web computing is different from the traditional imperative, logical, constraint, object-oriented, or component-based paradigms, not only in the characteristics of its fundamental constructs as mentioned in Section 3.1 but also in the effectiveness and efficiency of computing that can be achieved through these special characteristics.

4.1 The *Real* Power

Specifically speaking, the real power of AOC in the Wisdom Web manifests in dealing with the problems of the following nature:

1. The problems are of high complexity (e.g., large- scale, high-dimension, highly nonlinear relationship, and highly interrelated variables);
2. The problems are dynamically updated or changing in real time;
3. The problems are highly-distributed and locally- interacting in nature (i.e., not centralized, not ready/efficient for batch processing); or
4. The goal of AOC in data-mining and classification is not to extract some superficial patterns/relationships (i.e., data- transformation from one form to another), but really to discover and understand the "deep patterns" —- the underlying mechanisms/processes that produce the data (i.e., to provide an explanation of the cause/origin). As in real-world we always have certain ideas or knowledge about the general mechanisms/processes that generate the data, we are able to implement AOC to achieve this goal by means of developing entities that incorporate such ideas or knowledge.

Research Question 8: *What hard data-mining and classification problems of the above-mentioned characteristics would you suggest to apply the AOC paradigm?*

Most of the presently available algorithms (e.g., competitive learning algorithms, bottom-up clustering, particle swarm, evolutionary/genetic algorithms, and neural networks – please survey them) that simply make use of some autonomy ideas are used to solve *common* sequentially batch-processing, data-mining problems. In other words, the AOC systems that successfully solve the above-mentioned hard problems differ from these algorithms in both the nature of problems to be solved and the computational philosophy to be realized.

Research Question 9: *Try to make an in-depth survey and compare AOC with the existing approaches, as mentioned above. Would you be able to formulate the former as a theoretical generalization of the latter e.g., competitive learning, active learning, and particle swarm optimization.*

4.2 The *New Frontier* in Computing

As compared to other paradigms, such as centralized computation and top-down systems modeling, the AOC on the Wisdom Web can become extremely appealing in the following aspects:

1. To capture the essence of autonomy in natural and artificial systems;
2. To solve computationally hard problems, e.g., large- scale computation, distributed constraint satisfaction, and decentralized optimization, that are dynamically evolving and highly complex in terms of interaction and dimensionality;

3. To characterize complex phenomena or emergent behavior in natural and artificial systems that involve a large number of self-organizing, interacting entities;
4. To discover laws and mechanisms underlying complex phenomena or emergent behaviors.

The two most distinct applications of AOC for the Wisdom Web have been (1) designing and developing computational solutions to hard problems, and (2) characterizing and understanding complex phenomena or systems behavior.

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