Immunity as Inspiration for Elimination of Oil Spills
Multi-Agent Coalition Formation with B-Cell Algorithm

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Abstract—Stability of water ecosystems is often disturbed by
dangerous chemicals – products of human activities having
negative economical and environmental impact. Oil spills are
typical examples of these dangerous chemicals. They are
eliminated with different strategies, e. g. self-cleaning of water
surface, usage of booms, collectors of oil spills or autonomous
robots. This paper investigates the application of the immunity-
based principles with multi-agent coalition formation technique
for elimination of oil spills. Combination of these approaches is
not usual for solving this problem. Clonal selection-based B-Cell
Algorithm (BCA) is investigated for this purpose and compared
with the algorithm Clonalg-Opt.

Keywords: oil spill, multi-agent system, coalition formation,
immunity, artificial immune system, BCA, Clonalg-Opt

I. INTRODUCTION

Occurrence of oil spills in water ecosystems is serious
problem which is in the centre of interest during the last 30
years. It is one of the main causes of the oceanic pollution
according to [1]. It is necessary to find efficient, economical
and ecological solution.

Several methods are used for cleaning of oil spills on the
sea: self-cleaning, evaporation, usage of booms, skimmers or
autonomous robots based on the methods of swarm intelligence
[1], [2], [4]. The paper investigates this problem with the
application of multi-agent coalition formation and immunity-
based algorithm inspired by clonal selection principle – B-Cell
algorithm (BCA) [5]. This algorithm is then compared with the
Clonalg-Opt algorithm that is inspired by the clonal selection
principle, too.

The paper is structured as follows: the second part explains
main ideas related to the multi-agent coalition formation, the
third part is focused on the searching the inspiration in the
biological immune system (BIS) and artificial immune systems
(AIS) for possible elimination of oil spills. The fourth part
proposes the usage of BCA for multi-agent coalition formation
in more details. The fifth and the sixth part of the paper
mentions experiments and data analysis.

II. MULTI-AGENT COALITION FORMATION

Multi-agent coalition formation is one of the main research
challenges in the multi-agent systems. It deals with the
formation of self-interested or pro-social autonomous
intelligent agents into the goal-directed and short-lived groups
– coalitions. Each coalition is aimed at the specific predefined

III. IMMUNITY AS A SOURCE OF INSPIRATION

A. Biological Immune System

Biological immune system (BIS) is a complex system
essential for surviving living organism. It is able to maintain
the homeostasis with the aid of different immune cells, organs
and other systems. Distinguishing between self and non-self
objects is the crucial ability of the BIS. These objects can play
a role of antigens – elements able to initiate immune response.

We can find similarities between formation of (immune)
cells and group behaviour of individuals which is often
necessary for solving complex problems. These similarities
occur in case of the specific and non-specific cell-mediated and
humoral immunity. Elimination of antigens is the typical example requiring the group behaviour of cells. Immune cells are able to join and cooperatively solve the specific problem on the basis of specific stimuli. We distinguish pro-social and self-interested agents in case of MAS. This classification is true for the (immune) cells, too. Normal cells behave as pro-social entities able to commit the suicide for achievement of the global goal (apoptosis). Abnormal cells have anti-social behaviour. They follow only own goals (e.g. cancer cells).

Group behaviour of immune cells became the inspiration for solving the problem of elimination of oil spills. Oil spills are perceived as antigenic fragments able to disturb homeostasis of a water ecosystem. Autonomous intelligent (robotic) agents play a role of white-blood cells which establish equilibrium of water ecosystem.

This inspiration leads to the research subarea of computational intelligence – Artificial Immune Systems.

B. Artificial Immune Systems

Artificial immune systems (AIS) are research area of computational intelligence inspired by the BIS. Two mainstreams exist in this research. Computational immunology is focused on deeper understanding of BIS with the aid of different (computational) techniques (e.g. data mining, databases, ontologies, modelling or simulations). Immunological computation is inspired by the behaviour of BIS. Immune processes are used for solving different problems (e.g. computer security, pattern recognition, prediction, planning or optimization). The paper follows the second mainstream.

Different definitions of AIS exist. One of them is mentioned in [15]: “Artificial immune systems (AIS) are adaptive systems, inspired by theoretical immunology and observed immune functions, principles and models, which are applied to problem solving.” Four groups of immunity-based algorithms are used in present:

- gene library-based algorithms (bone marrow models),
- population-based algorithms (algorithm of positive and negative selection, clonal selection-based algorithm),
- network-based algorithms (discrete and continuous artificial networks),
- danger theory-based algorithm (dendritic cell algorithm).

Research in AIS is focused on the specification of the new immunity-based algorithms, improvement of these algorithms, usage of these algorithms in the new application areas, deeper theoretical study of AIS and development of hybridized AIS using different soft computing paradigms [16], [17], [18].

IV. PROPOSED SOLUTION

The paper investigates the immunity-based algorithm B-Cell Algorithm (BCA) for the problem of generation coalition structures which can be used for elimination of oil spills on the sea. BCA is inspired by the clonal selection principle explaining the generation of antibodies against antigens [5].

A. Formal Model

Pro-social autonomous agents Cleaners \( A = \{a_1, a_2, ..., a_m\} \) are responsible for elimination of oil spills. The agent \( a \) is evaluated by points \( b \) which receives for the elimination of oil spills. Main goal of the agent Cleaner is to collect maximum points \( b \). This agent has a collection of abilities represented as an ordered n-tuple of binary values \( s = (s_1, s_2, ..., s_n) \) which are randomly generated. The agent uses an ordered n-tuple of filters for elimination of oil spills \( f = (f_1, f_2, ..., f_l) \). Each filter \( f \) has a level of attrition \( o \) representing the amount of oil fragments that can be eliminated by the agent. This level is randomly generated for each agent. If the agent has a filter with high degree of attrition, the filter has to be cleaned or replaced.

Continuous oil spills (tasks) are represented in the set \( U = \{OS_1, OS_2, ..., OS_n\} \). Each continuous oil spill is divided into the fragments (subtasks) \( os \). Each oil fragment corresponds with the one type of oil spill \( t \) according to the level of its density. The types of oil spills are represented in the set \( T = \{t_1, t_2, ..., t_s\} \). Each oil fragment is evaluated by points \( v \) which are collected by agents Cleaners.

Coalition \( c \) is a group of agents Cleaners responsible for elimination of the only one type of oil spill. Only three non-overlapping coalitions are distinguished (light, medium, heavy) in the paper. Coalition structure \( CS \) is a potential solution of the problem (antibody) which is divided into coalitions [14].

B. Optimization Model

Value of coalition structure \( V(CS) \) depends on values of coalitions \( v(c) \). Values of coalitions depend on the qualities of agents Cleaners. Quality of agent \( v(a) \) depends on its ability to fulfill the task \( a.s. \), a detention of a filter \( f.a \) and points for the one type of subtask \( v.a \). Fitness of an i-th agent performing a h-th type of task is calculated according to (1).

\[ 1 \]

Agents of stable coalition accumulate minimal required amount of sources. Minimal required amount of sources is given by subtasks (fragments of oil spills) that have to be accomplished by agents Cleaners. Goal of the multi-agent coalition formation is to keep coalitions in a stable state as long as possible. This is due to the fast reaching the goal without long time delays. Long-lasting stability of coalitions is supplied with the maximum amount of sources of agents Cleaners. Formula (2) should be valid for each stable coalition. Symbol \( t_{o,res} \) denotes the minimal required amount of sources that is given by the h-th type of subtask \( t \).

\[ 2 \]

Quality of coalition is a sum of qualities of agents Cleaners performing specific subtask (e.g. an agent Cleaner eliminating the oil spill with the medium level of density). Quality of coalition structure is represented as a tuple with coalition values \( V(CS_i) = v(c_1), v(c_2), ..., v(c_n) \) or as a sum of coalition values, see (3).

\[ 3 \]
Objective function is defined in the view of stable coalitions, see (4). Symbol x denotes the amount of oil spills of the specific type i (e. g. the amount of oil spills with medium density) [14].

C. Crucial Phases of the B-Cell Algorithm

1) Potential Solutions and Initialization: The coalition structure is a potential solution (an antibody) and structured into the coalitions. Each coalition fulfills the one specific type of subtask. Array of integers is used for the coalition structure representation. Each integer represents identification value of an agent Cleaner. The array has a stable length. Each coalition has at least one agent Cleaner because coalition without agents is not useful. This paper deals with the static multi-agent coalition formation. Number of agents Cleaners and types of subtasks are specified by the user and do not change during the calculation of the V(CS). Length of antibody (L) is specified according to (5) (a symbol m - the number of agents Cleaners involved in the coalition structure generation, a symbol n - the number of types of subtasks). Positions of coalitions are predefined in the coalition structure. The identity of coalition is defined for this purpose, see Fig. 1 [14].

2) Quality of Potential Solution: Quality of coalition structure is represented as a list (FCS) of two values. The first value cuc represents number of unstable coalitions. The second one Es represents the amount of sources allocated by agents Cleaners extra in comparison to the minimal requirements, see (6) [14].

3) Clonal Expansion: Each potential solution (coalition structure, antibody) generates set of its clones after the calculation of the quality (6). Number of clones (Rclone) is equal to the size of repertoire (population) with potential solutions [5]. The repertoire has stable size.

4) Metadynamics: One clone is randomly selected in each particular set of clones (Rclone) and mutates with the application of the swap principle.

5) Affinity Maturation: Original version of the BCA uses the contiguous somatic hypermutation operator [5]. This operator is adjusted with the usage of the swap operator for the coalition formation problem, see example in Fig. 2. Two positions in the coalition structure are randomly selected. These two positions form the boundary of the area in which the mutation will take place.

Mutation realizes in this “mutation area” with the probability p. Ordinary swap operator is applied in case of two-valued coalition structure. The original paper [5] does not mention the dependency between the level of mutation and affinity of the antibody. Proposed operator of the somatic hypermutation is based on this dependency, i. e. antibodies of higher affinity have higher mutation rate in comparison to the antibodies with lower affinity. Mutation rate is calculated according to rank of coalitions structures, see Tab. 1.

<table>
<thead>
<tr>
<th>Coalition structure</th>
<th>Cuc</th>
<th>Es</th>
<th>Order</th>
<th>Probability of mutation p (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS1</td>
<td>0</td>
<td>20</td>
<td>1</td>
<td>10%</td>
</tr>
<tr>
<td>CS2</td>
<td>0</td>
<td>17</td>
<td>2</td>
<td>20%</td>
</tr>
<tr>
<td>CS3</td>
<td>1</td>
<td>10</td>
<td>3</td>
<td>30%</td>
</tr>
<tr>
<td>CS4</td>
<td>2</td>
<td>6</td>
<td>4</td>
<td>40%</td>
</tr>
</tbody>
</table>

The first position of the “mutation area” is selected with the probability p. This probability is used also in case of the following position (bit). If both of these bits are activated for the mutation (i. e. they fulfill the probability condition), the swap-based contiguous hypermutation operator is applied. If one of the bit is not activated, the next bit is chosen.

6) Clonal Selection: One clone with the highest affinity is selected from each clonal set (Rclone) after the affinity maturation. This clone substitutes “parental” clone only if it has higher affinity, otherwise the “parental” clone stays in the repertoire and is not replaced.

V. EXPERIMENTS

A. NetLogo and BehaviourSpace

B-Cell algorithm is implemented in the NetLogo - Java-based modelling and simulation tool for multi-agent systems, see Fig. 3 [19]. Experiments were realized with the aid of
build-in tool of the NetLogo – BehaviourSpace, see Fig. 4. This environment is useful for observing the behaviour of the algorithm under different conditions and verification of the application of the algorithm for the multi-agent coalition formation and elimination of oil-spills. The computer Intel Core 2 Duo with 3.50 GB RAM, OS MS Windows XP Professional (ver. 2002, service pack 3) was used for the experiments.

Figure 3. BCA in NetLogo

![Figure 3. BCA in NetLogo](image)

Figure 4. Experiments in BehaviourSpace

![Figure 4. Experiments in BehaviourSpace](image)

**B. Results and Interpretation**

Experiments are not designed for the optimization of the parameters of the algorithm. The goal is to observe the behaviour of the BCA for different numbers of agents Cleaners and the sizes of repertoires with the possible solutions at the usage of the constant seed value, see Tab. II. There are specific symbols in tables: \( n_{\text{cleaners}} \) (a number of agents Cleaners), \( n_{\text{rep}} \) (a size of repertoire), \( n_{\text{gen}} \) (a number of generations), \( p_{\text{mut}} \) (probability of mutation - metadynamics), \( T_{\text{min}} \) (a duration of the partial experiment), \( \text{WSF} V(CS) \) (the worst possible solution founded so far), \( \text{BSF} V(CS) \) (the best possible solution founded so far).

**TABLE II. BCA – RESULTS OF EXPERIMENTS**

<table>
<thead>
<tr>
<th>( n_{\text{cleaners}} )</th>
<th>( n_{\text{rep}} )</th>
<th>( T_{\text{min}} )</th>
<th>( \text{WSF} V(CS) )</th>
<th>( \text{BSF} V(CS) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>10</td>
<td>6</td>
<td>[0.51]</td>
<td>[0.65]</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>7</td>
<td>[0.44]</td>
<td>[0.65]</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>52*</td>
<td>[0.44]</td>
<td>[0.66]</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
<td>8</td>
<td>[0.47]</td>
<td>[0.79]</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>10</td>
<td>[0.58]</td>
<td>[0.76]</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>89*</td>
<td>[0.72]</td>
<td>[0.83]</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>8</td>
<td>[0.56]</td>
<td>[0.64]</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>10</td>
<td>[0.60]</td>
<td>[0.71]</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>64*</td>
<td>[0.74]</td>
<td>[0.95]</td>
</tr>
</tbody>
</table>

The experiments use 6, 8 and 10 agents Cleaners. 40 and 50 generations are predefined by the user with probability mutation 0.01 in case of metadynamics \( p_{\text{mut}} \) and seed value 300. The size of repertoire is 10, 20 and 30 coalition structures (antibodies). The same experiments were designed for the Clonalg-Opt algorithm, see results in the Tab. III [14], where \( \beta \) is the clone factor.

**TABLE III. CLONALG-OPT – RESULTS OF EXPERIMENTS**

<table>
<thead>
<tr>
<th>( n_{\text{cleaners}} )</th>
<th>( n_{\text{rep}} )</th>
<th>( T_{\text{min}} )</th>
<th>( \text{WSF} V(CS) )</th>
<th>( \text{BSF} V(CS) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>10</td>
<td>1</td>
<td>[0.51]</td>
<td>[0.66]</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>2</td>
<td>[0.44]</td>
<td>[0.66]</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>4*</td>
<td>[0.38]</td>
<td>[0.66]</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
<td>1</td>
<td>[0.47]</td>
<td>[0.116]</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>2</td>
<td>[0.45]</td>
<td>[0.116]</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>5*</td>
<td>[0.72]</td>
<td>[0.116]</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>1</td>
<td>[0.44]</td>
<td>[0.107]</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>1</td>
<td>[0.60]</td>
<td>[0.106]</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>5*</td>
<td>[0.74]</td>
<td>[0.107]</td>
</tr>
</tbody>
</table>

Results prove that it is possible to use the clonal selection principle as the inspiration for multi-agent coalition formation, i. e. to generate the coalition structures. BCA has higher BSF V(CS) for larger sizes of repertoires \( n_{\text{rep}} \). This tendency is not occurred in case of the Clonalg-Opt. The BCA has the same BSF V(CS) as the Clonalg-Opt only in one case \( n_{\text{rep}} = 30, n_{\text{cleaners}} = 6 \). Algorithm Clonalg-Opt achieves higher BSF V(CS) in most cases in comparison to the BCA. It is obvious that BCA is much more time consuming than the algorithm Clonalg-Opt. This can be explained by the fact that clones are
generated by each cell (antibody, coalition structure) and their number is equal to the size of repertoire with antibodies in case of BCA. Rank-based selection is applied in case of the Clonalag-Opt algorithm and the number of clones are based on the $(C_i N_i)$ – number of clones generated by the $i$-th coalition structure, $\beta$ – clone factor, $R_{size}$ – size of repertoire with potential solutions) [3].

(6)

VI. COMPARISON OF THE BCA AND CLONALG-OPT

Two-sided non-parametrical test Mann-Whitney is applied for evaluation of statistical significance between data produced by BCA and Clonalag-Opt (related to the different $n_{cleaners}$ and $n_{rep}$). The IBM SPSS Statistics (ver. 20) is applied for this purpose.

Alternative hypothesis $H_1$ is accepted on the significance level $\alpha$ 5% for all cases, see Tab. IV. Presented results and preconditions support the assertion that the results can be interpreted as statistically significant on the significance level $\alpha$ 5%.

TABLE IV. BCA VS. CLONALG-OPT - MANN-WHITNEY TEST

<table>
<thead>
<tr>
<th>$n_{cleaners}$</th>
<th>Mann-Whitney U</th>
<th>Asymp. Sig.</th>
<th>P-value (Monte Carlo)</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$n_{rep} = 10$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$n_{cleaners} = 6$</td>
<td>405.000</td>
<td>0.000</td>
<td>0.000</td>
<td>$H_1$</td>
</tr>
<tr>
<td>$n_{cleaners} = 8$</td>
<td>85.000</td>
<td>0.000</td>
<td>0.000</td>
<td>$H_1$</td>
</tr>
<tr>
<td>$n_{cleaners} = 10$</td>
<td>148.500</td>
<td>0.000</td>
<td>0.000</td>
<td>$H_1$</td>
</tr>
</tbody>
</table>

VII. CONCLUSION

The paper presents the initial study about immunity-based multi-agent coalition formation used for solving serious environmental problem. The future research is aimed at the investigation of the others immunity-based algorithms for the elimination of oil spills and their comparison with each other and with genetic algorithms. The second part of the future research is focused on the dynamic multi-agent coalition formation and application of relevant immunity-based algorithms for this purpose.

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