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MODELING TEAMWORK BEHAVIORS ON A COMBAT FIELD IN JADE

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Abstract:
The paper addresses some problems related to modeling collective behaviors using an example of interactions on a combat field. A multi-agent model of such a combat that is based on behavior- and communication rules was proposed. Next, the model was implemented in the JADE environment (**J**ava **A**gent **DE**velopment Framework) – the one dedicated to agent-oriented programming. A series of simulations of the combat model were carried out to observe complex behaviors within a group of soldier-agents. The analysis was also made from the perspective if the JADE environment is efficient for such simulations.

Keywords: multi-agent systems, combat-field simulation, JADE

1. GOALS AND DOMAIN OF THE RESEARCH

The wider context of the work described in the paper is author's research in the domains of:

- modeling complex collective behaviors by means of relatively simple rules for individual behaviors
- collective intelligence reflecting:
  - such group behaviors emerging from interactions
  - communication between individuals.

In the paper, however, the main focus is put on some aspects of the work as:

- definition of a multi-agent model of a team-work that uses an example of combat, and employs some behavior- and communication rules
- implementation of the combat model in JADE that supports an agent-oriented programming
- simulation of the model in some typical combat scenarios to observe complex collective behaviors.

So, in this particular case the goal of the work was to analyze and assess:

- capability to model complex collective behaviors as: (a) a move of soldier-agents in a certain formation, and (b) coordinated assault on an enemy by means of simple rules for individual behaviors of soldiers-agents
- effect of communication between soldier-agents on the effectiveness of accomplishing tasks set to the troop
- efficiency of the JADE environment for a simulation of collective behaviors on a combat field.

2. EFFECTIVENESS OF COMBAT MODELING BASED ON MULTI-AGENT SYSTEMS

2.1. Real combat vs. combat models

In the real world, a combat usually is attributed by some key features as [1]:

- High complexity and multidimensionality
  for example: parameters of weapons used, ballistics, the lay of the land, weather conditions, psychology in terms of behaviors of individual soldiers
- Big interdependencies between actors and factors
  for example: impact of the weather/terrain on troop move łusiakments, effect of logistics efficiency on fighting spirit
- High dynamics of parallel events
  for example: the current status of the combat changes rapidly dependently on movements, shootings, supplies, soldiers' morale, a series of local struggles
- Effect of local factors (behaviors) on the global result
  for example: panic or bravery of an individual(s), or local mistakes can tip the scales in one's favor, thus introducing unpredictability into the model
- Great deal of data
  for example: a combat provides with an enormous number of data that on the one hand contributes to making decisions, on the other – cannot be overestimated when validating and improving the combat model.

Because of the above, a great deal of unknown and unpredictable factors, and the fact that combat modeling addresses conflicts to come, all models are very rough and biased with many big and irremovable errors.

So, the fundamental problem of the combat modeling is how to reduce the errors and increase credibility of the models.

2.2. Limitations of standard combat modeling methods

A basic group of standard combat models is based on mathematical modeling that includes [1][2]:

- Lanchester differential equations – relate force strength to attrition
- generalized Lanchester equations: (a) partial differential equations – allow for maneuvering, (b) fuzzy differential equations – take imprecise information into account, (c)

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stochastic differential equations – model attrition processes under uncertainty
- game theory – models gains/losses of adversary forces
- non-linear dynamics – in variety of cases, e.g.: for extensions of the Lanchester equations (discretized model) or casualty dynamics by means of a casualty-based entropy.

Common limitations of the above approaches make that they are:
- high-level and simplified models
- valid for specific assumptions, e.g.: homogeneous armies continually engaged in a struggle, perfect information available, combat as a deterministic process, no spatial variations of troops, no human factors, individuals are rational and act to maximize a utility function.

Along with development of computational power and performance, another group of methods evolved, namely – computer simulations. They extend capabilities of mathematical models, and introduce an algorithmic approach. Typical examples of such simulations are those related to complex adaptive systems (e.g.: cellular automata, evolutionary programming, artificial life).

In general, computer simulations are constrained by algorithms used in terms of if they are more related to mathematical methods or modeling individual elements including rules governing their behaviors. The latter approach – based on multi-agent systems – seems to address the problem of combat simulation best.

2.3. Multi-agent approach to combat simulation

In a multi-agent system (MAS) – i.e.: one composed of at least 2 (usually different) agents interacting with each other and without any central unit – agents are characterized mostly be the following attributes [3][4]:
- autonomy and independence of taking actions in an environment to achieve a goal
- interaction and communication with other agents, especially in terms of cooperation, coordination or negotiation to achieve the given goal
- reaction to changes in the environment in which the agents act
- goal-oriented behavior
- learning and/or adaptation capabilities – usually ascribed to intelligent agents.

In a MAS system each agent has its own set of behavior rules or world descriptions – ontology.

This is why a multi-agent approach to combat modeling – where a combat is a kind of interactions between many autonomic individuals (soldiers) – demonstrates its power and usefulness, and has become a standard for such purposes [1][5].

3. CHARACTERISTICS OF JADE

JADE (**J**ava **A**gent **DE**velopment Framework) is a platform for agent-oriented programming, i.e. supports development of applications employing agents [6]. Owing to the fact that the library is in the Java language, one can easily extend its base capabilities by means of various plugins.

The agent mechanism is fundamental for JADE and the most important features of agents are [7]:
- agent is autonomous and active
- agent has its own thread in OS and controls independently the order of tasks to be executed
- agent doesn't provide with the reference to itself, so no one from outside can execute an action on the agent
- agent decides if execute a request from another agent or not
- agent can operate in a distributed environment where it is uniquely identified.

The need of interactions in MAS systems is addressed in JADE by means of the following communication system [7]:
- communication between agents is provided by asynchronous messages, i.e.: at any moment an agent can send or receive a message
- communication is direct, i.e.: the agent-sender defines a recipient or recipients
- agent has a buffer for incoming messages, processes them independently, and it's up to the agent in what way the messages are going to be served, if any.

Last but not least JADE provides with a set of useful tools for monitoring and managing agents as, for example, a sniffer to control communication between agents (Fig. 1).

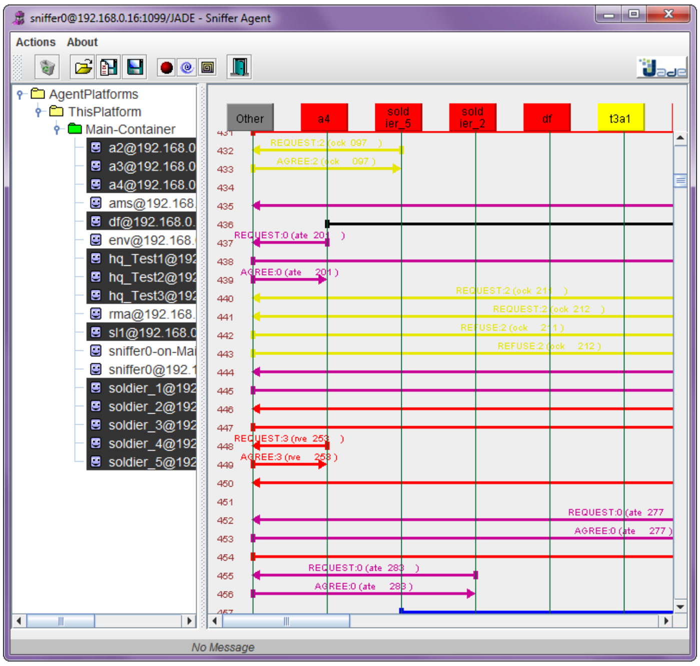

Fig. 1. Example screenshot of communication monitoring in JADE

4. COMBAT MODEL

4.1. Assumptions

Because combat modeling itself was not the primary objective of the work, some simplifications of a real combat were made, however the final model was to reflect some level of reality. In the result, it was assumed that:
- a combat field is an arena of infantry combat
- soldiers are grouped in small troops or act independently
- individuals are equipped with a military rifle.

4.2. High-level definition of the combat model

The multi-agent model – that also allows for prerequisites of the JADE environment – includes the definition of the following 4 classes of objects (Fig. 2):
- Environment (of combat)
- Head Quarter (of the army)
- Private (soldier)
- Squad Leader (a special case of *Private*).

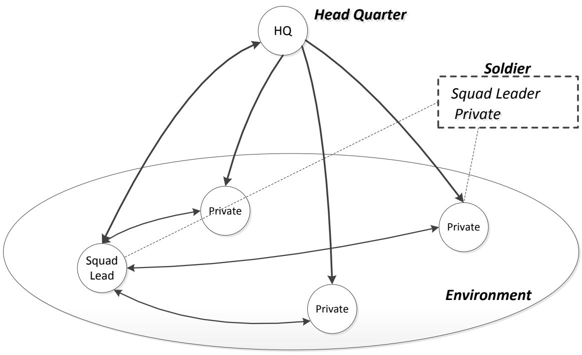

Fig. 2. JADE classes of the combat model

The key tasks for the ***Environment*** of combat are:

- Modeling a combat field
  - map of terrain: (a) flat rectangular area identified by the Cartesian system of coordinates, meter as a unit of measure, double precision
  - terrain types: (a) empty – represents a terrain without any obstacles, and thereby doesn't limit soldier's movement or their range of vision, (b) moderate – difficult to pass, however without impact on visibility, e.g.: a marshy ground. In consequence, it limits the max. speed to 45% of that as in the empty terrain, (c) confined – constraining movement capabilities and vision considerably, e.g.: a forest. It limits the max. speed to 85%, and the visibility to 33%
  - dependencies of soldiers' attributes on the terrain: (a) range of vision, (b) speed of movement
- Storing some spatial and physical attributes of soldiers for observation purposes
  - e.g.: to emulate agents' senses – *Environment* stores information on the positions of all soldiers, and an agent can get information on what it 'can see', i.e. what other agents are in the range of its vision.

Each army has its ***Head Quarter*** that is used for:

- creating soldier-agents (in JADE)
- initially assigning commanders (*Squad Leads*)
- giving orders initiating an operation of the army.

A ***Private*** is a soldier who takes part in a combat and is defined by:

- Attributes describing:
  - position
  - direction and movement
  - angle, range and direction of vision
  - health condition
  - weapon used
- Behavior rules related to:
  - observation and detection of an enemy
  - communication w/ their commander (*Squad Lead*)
  - assault, reaction on an enemy fire, start of combat
  - patrolling and keeping a formation when marching
  - taking over the command .

The ***Squad Lead*** – commander – is a special case of a soldier (*Private*) in terms of:

- Attributes – augmented by:
  - identification as the commander
  - troop identification
- Behavior rules – extended by:
  - receiving reports (from Privates)
  - giving orders (e.g.: patrol, assault).

4.3. Weapon model

The weapon model allows for only military rifles that are described by the following attributes:

- range of fire
- accuracy
- causing-injury efficiency
- magazine capacity (number of bullets in the magazine)
- reload time.

5. KEEPING A FORMATION WHILE MOVING

One of problem occurring when modeling a combat is the one related to keeping a formation of a troop when moving from point A to B (e.g.: patrolling).

For the purposes of the work, Reynold's concept of flocking [8] was employed and enhanced appropriately.

The original concept provides with some heuristic rules describing a steering behavior of a group of animals as: flocks, shoals, herds. These are [8][9]:

- *separation*: keeps a certain distance from neighboring flockmates to avoid collision or crowding together
- *cohesion*: attempts to stay not too far from nearby flockmates to form a group with them
- *alignment*: matches a direction and velocity to those of neighboring flockmates.

For the purposes of the combat model, Reynold's rules were modified and enhanced in the following way:

- steering rules computed per each agent and based on information available only to it
- follow-the-commander capability
- soldiers only from the agent team are taken into account.

6. SIMULATIONS IN JADE

6.1. Simulation scenarios

During simulations the following scenarios were taken into account:

- <u>Troop moving in a formation</u>
  Soldiers in a troop have to move from one spot to another in an empty terrain keeping a formation led by the commander. The group coherence when moving is subject to the observation during simulations.
- <u>Terrain impact on moving in a formation</u>
  The previous scenario was extended by terrain obstacles that represent a moderate or confined ground, and provide with diversified limits of soldier's velocity and range of vision.
- <u>Reaction on detecting an enemy</u>
  Troops are in the patrol mode, i.e. are moving and have to observe the vicinity to detect an enemy (each soldier has their own field of vision). Once a soldier detects opposite ones, they report that to the commander who next gives the troop the order to attack (together with information on the enemy position). The teamwork efficiency to engage all soldiers into combat is to be observed.
- <u>Coordinated assault</u>
  A modification of the previous scenario: in the follow-up of the attack order the troop focuses on one target commonly determined. If the target is 'neutralized', the fire is concentrated on another one, and so on.
- <u>Effect of communication on the combat result</u>
  A special case of previous scenarios: one troop employs fully communication, whereas soldiers in another one don't, and are in the aggressive 'detect-and-attack' mode.

The effect of communication in the direct combat is to be observed.

- Impact of terrain obstacles on the combat
  Different types of terrain are added to previous scenarios to simulate e.g.: ambush cases.
- Loss of the commander and taking over the command
  A troop under fire loses its commander and a new one from the troop is appointed. The update of information among soldiers and combat capabilities are to be observed.

6.2. Key observations

During a series of simulations some observations were made and key of them are as follows:

- Troops of soldier-agents acted autonomously as expected (i.e.: moved, patrolled, started and continued a combat). Due to Reynold's concept was employed, the formation itself was not rigorous, nevertheless the group kept coherence and used to move smoothly.
- Generally, a positive effect of communication was observed during both regular combats and ambushes. It was demonstrated by statistically more frequent wins of troops where soldiers used to communicate with each other. It can be interpreted that collectively shared knowledge and coordinated group assaults were important factors of the combat success.
- Less obvious situations were also observed when:
  - adversary troops are in the combat range and are positioned against one another more or less symmetrically
  - one troop employed communication
  - another one used the aggressive detect-and-attack mode

  The latter troop (w/o communication) used to win in statistically more cases, which at first glimpse is not expected. It turns out that:
  - tactical positions of both troops are equivalent
  - the first one loses its time on reporting, ordering, etc. w/o taking actions to fight
  - at the same time the aggressive troop immediately starts to combat

  The case demonstrates that communication itself costs.
- By the way a flaw of JADE was observed, namely: the combat model requires very frequent (every 100 ms) updates of soldiers' data. Due to the complexity of the JADE message system, already in the case of dozen agents some performance issues were observed.

7. SUMMARY

The paper described the model of combat that:

- was implemented as a multi-agent system (MAS) in the JADE environment
- allows for simple behavior rules of particular soldiers and interactions between them.

The implemented MAS system enables observing complex behaviors that result from simple rules of individual soldier-agents

During simulations a positive effect of communication on the effectiveness of the troop was observed, i.e. teamwork benefits emerged and were captured.

The JADE environment revealed its pros and cons:

- advantage: JADE supports MAS development extensively from the functional and tool perspective
- disadvantage: suffers from performance issues – the message mechanism seems to be a bottleneck in the case of very frequent communication.

So, JADE is a very useful tool for MAS prototyping, whereas in the case of realistic modeling – a dedicated application is required to address performance needs of combat models.

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MODELOWANIE DZIAŁAŃ ZESPOŁOWYCH NA POLU WALKI W ŚRODOWISKU JADE

Słowa kluczowe: sysmety wieloagentowe, symulacja pola walki, JADE

Artykuł obejmuje zagadnienia z dziedziny modelowania działań zespołowych na przykładzie interakcji zachodzących na polu walki. Zaproponowano model wieloagentowy przykładowego pola walki bazujący na kilku regułach zachowania i komunikacji, a następnie zaimplementowano go w środowisku JADE (Java Agent DEvelopment Framework) – dedykowanym do wytwarzania aplikacji opartych o działanie agentów. Wykonano szereg symulacji w celu zaobserwowania złożonych zachowań wśród grupy żółnierzy-agentów. Analizę przeprowadzono również pod kątem przydatności środowiska JADE do tego typu symulacji.