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Distributed System for Real-Time Collective Computing

Victor Ababii, Viorica Sudacevschi, Mariana Oşovschi, Ana Ţurcan, Ana Nistiriuc, Dimitrie Bordian, Silvia Munteanu

Abstract

This paper presents the results of the distributed system of collective computation for the application in solving complex problems development. Distributed data processing is performed based on the Mesh network connected with a large number of Agents. For each Agent, there is predefined a task, which is solved using a strategy based on a mathematical model defined in time. In this paperwork there is elaborated the hierarchical structure of the collective calculation system, the mathematical model, the network topology, the distribution mode of tasks between the Agents, and the model for the quality evaluating of command service.

Keywords: *distributed computing systems, real-time computing, collective computing, target goals, task target, and multi-agent systems.*

1 Introduction

At the moment, distributed computing systems can be considered the most efficient and applied in such fields as: industry; technological systems, robotic and monitoring systems; finance and trade; information societies; creativity and entertainment; medical assistance; education; transport and logistics; science; environment management, etc. The most important characteristics of these systems can be considered: parallelism; competition; lack of a global clock; independent errors; resource sharing and virtualization; heterogeneity; scalability; adaptability, etc. [1].

The real-time concept has been introduced in the computing systems to be able to specify them, from the point of view, of the time variable that has an important role in the correctness of the decision. The characteristics of a real-time system are: response time, multiple processes, determinism, flexibility, adaptability, and irreversibility. Another aspect of real-time systems is the ability to synchronize the processes of calculation and communication between them [2].

Solving complex problems [3] requires the involvement of essential resources of data processing and storage. One method of solving this problem is to apply distributed computing systems, especially collective calculus or collective artificial intelligence [4]. The concept of collective artificial intelligence is also specific for Multi-Agent systems [5], to which is accorded extraordinary attention by researchers from different fields, as a method of solving complex problems by dividing them into smaller individual tasks. Individual tasks are assigned to a set of agents where each agent decides on an appropriate action to solve the task using multiple inputs, for example, the history of actions, interactions with neighboring agents and its purpose.

2 Goal of research

The purpose of the research carried out by the present work, is to design a distributed Multi-Agent system of collective calculation in real-time. The described problem is specific for the areas in which there appears the necessity to combine the advantages of Multi-Agent collective calculation in combination with time restrictions. The specific feature of the Multi-Agent collective calculation is the necessity to perform the exchange of information, which imposes some time restrictions in which the system evaluates. It is obvious that a decision made by a Multi-Agent collective computing system can be restricted in time, because, the decision taken by the system at one point of time can be fatal for the evolution of the system in continuation.

In Figure 1 it is shown the structure of the Multi-Agent collective calculation system. This structure determines the hierarchy between the abstraction levels of the calculation system, where:

Target Goals – target goals collective calculation system;

Strategy – applied strategies to reach the target objectives;

$Task_1, \cdots, Task_N$ – tasks to apply the planned strategies to achieve the target objectives;

$A_1, \cdots, A_N$ – the set of agents that solve appropriate tasks $TT_n, \forall n = \overline{1, N}$;

Communication Environment – the communication environment based on the technologies Wi-Fi, GSM, GPRS, etc.;

Activity Environment – system activity environment.

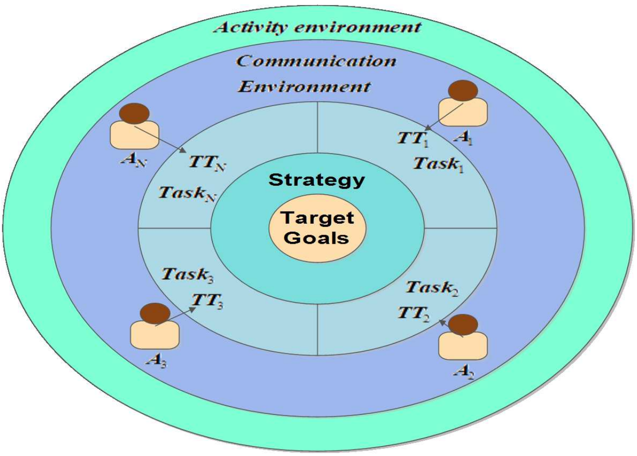

Figure 1. The hierarchical structure of the Multi-Agent collective computing system.

Each level of abstraction can communicate only with the neighbor level. The activity environment provides status information to the set of agents. Each agent solves his task based on the established strategy, to achieve the system's target objectives. The result of the performed calculations by the set of agents is applied in the activity environment to maintain it in the set up limits by the target objectives.

3 The Mathematical Model

Whether the process is defined $P = \bigcup_{n=1}^{N}(p_n)$, where p_n is a set of sub-processes and $p_i \cap p_j \neq \varnothing$, $\forall i = \overline{1,N}, \forall j = \overline{1,N}, i \neq j$; which evaluates in the ***Activity Environment***.

The process P is managed by the mathematical model defined by the system of equations 1 [6]:

$$\mathbf{X} = \mathbf{f}(\mathbf{X}(\mathbf{t}), \mathbf{U}(\mathbf{t}), \mathbf{t}), \mathbf{X}(\mathbf{t_0}) = \mathbf{X_0} \tag{1}$$

where:

$f : \mathbf{R}^N \to \mathbf{R}^N; \mathbf{X}(\mathbf{t}) = \{\mathbf{x_1}(\mathbf{t}), \mathbf{x_2}(\mathbf{t}), \cdots, \mathbf{x_N}(\mathbf{t})\}$ – state of the process vector P in the moment of time $\mathbf{t}$;

$\mathbf{U}(\mathbf{t}) = \{\mathbf{u_1}(\mathbf{t}), \mathbf{u_2}(\mathbf{t}), \cdots, \mathbf{u_N}(\mathbf{t})\}$ – the intervention vector over the process $\mathbf{P}$;

$\mathbf{X} = \{\mathbf{dx_1}(\mathbf{t})/\mathbf{dt}, \mathbf{dx_2}(\mathbf{t})/\mathbf{dt}, \cdots, \mathbf{dx_N}(\mathbf{t})/\mathbf{dt}\}$ – process dynamic $\mathbf{P}$;

$\mathbf{X_0}$ – the initial state of the process $\mathbf{P}$.

The target goals of process control $\mathbf{P}$ are defined by the expression 2:

$$\max_{x(t)\in\mathbf{R}^N}\{\varphi(\mathbf{X}(\mathbf{t}), \mathbf{t})\}, \tag{2}$$

where $\varphi : \mathbf{R}^N \to \mathbf{R}$.

With restrictions:

$$g(\mathbf{X}(\mathbf{t}), \mathbf{U}(\mathbf{t}), \mathbf{t}) = 0 \tag{3}$$

$$h(\mathbf{X}(\mathbf{t}), \mathbf{U}(\mathbf{t}), \mathbf{t}) \geq 0 \tag{4}$$

$$\mathbf{X}(\mathbf{t}) \in \mathbf{X} \subseteq \mathbf{R}^N \tag{5}$$

$$\mathbf{U}(\mathbf{t}) \in \mathbf{U} \subseteq \mathbf{R}^N \tag{6}$$

$$\mathbf{t} \in [\mathbf{t_0}, \mathbf{T}] \tag{7}$$

To achieve the goals provided in 2 it is necessary to find the vector $\mathbf{U}(\mathbf{t})$ respecting the conditions 3-7, which has to ensure the condition 8, it means the solving strategy of the collective calculation problem:

$$\nabla\varphi(x(t))_i = \frac{\partial\varphi}{\partial x(t)_i}(X(t)) > 0, \forall i = \overline{1, N}. \quad (8)$$

4 The Topology of Multi-Agent Network

The collective calculation specific consists in taking decisions based on the particular decisions of the agents. In this context, three types of decisions can be classified:

- Absolute decisions – when all the particular decisions of the agents are taken into consideration;

- Majority decisions – when the particular decisions of most agents are taken into consideration;

- Minority decisions – when the personal decisions of the agents that correspond to the personal agents' interests are taken into account.

The topology of the multi-agent collective computing network is shown in 4

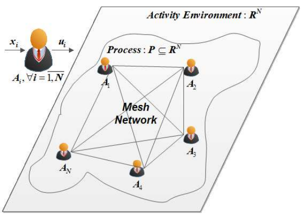

Figure 2. Multi-Agent network for Collective Computing.

In 4 there is presented the set of Agents $A_1, ..., A_N$ that forms a network Mesh. Each Agent acquires the status x_i of the process P, processing the data according to the algorithm defined by mathematical models 1-8 and influences the process with the command value u_i.

5 The distribution of collective computing tasks

In order to optimize the process of calculating and uniform distributing of computational power, the following solution is proposed, where each Agent will perform the set of instructions defined by the mathematical model 9:

$$A_i : \begin{cases} \mathbf{g_i(X(t), u_i(t), t) = 0}, \\ \mathbf{h_i(X(t), u_i(t), t) \geq 0}, \\ \mathbf{f_i(X(t), u_i(t), t) = dx_i(t)/dt}, \\ \max_{x_i(t) \in \mathbf{R}^N} \{\varphi_i(X(t), t)\}, \\ \mathbf{Q_oS_i = q_i(u_i(t)), T_{k-1} < t \leq T_k}, \\ \forall i = \overline{1, N}, \end{cases} \tag{9}$$

where: Q_oS_i – quality criterion of the command service; q_i – function to evaluate the quality criterion; T_{k-1} – the beginning of the time interval and T_k – the end of the time interval for the evaluation quality criterion.

The quality criterion Q_oS is evaluated in the graph shown in 5, where: Q_oS_max – the maximum quality criterion; Q_oS_{opt} – the optimal quality criterion; $Q_oS(t)$ – the evolution of the quality criterion in time; $C(t)$ – the convergence of the command value solution in time; T_{k-1} – the beginning of the evaluation of the quality criterion Q_oS; T_k – the end of the time interval of quality criteria evaluation Q_oS ; $U(T_k)$ – the values of the command vector obtained at the moment of time T_k.

At the beginning of each data processing cycle T_{k-1} there is acquired the state vector $X(t)$, performed by all Agents connected to the network, and the communication between them with this data. At the end of the data processing cycle T_k the action on the process P with vector values $U(T_k)$ takes place.

6 Conclusion

The results of this research are dedicated to solve some specific problems of real-time collective calculation. The collective computa-

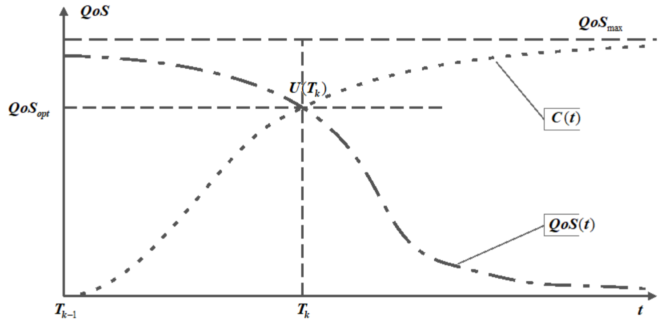

Figure 3. The graph of the quality criterion evolution Q_oS.

tion is presented as a Multi-Agent system which solves a complex problem defined in time (a process). In this paperwork there are presented: the hierarchical structure of the collective calculation system that determines the interaction between different abstract levels of the system; the mathematical model that describes the evolution of the process in time with the definition of the target goals, and the strategic methods applied in solving of the problem; the topology of the Multi-Agent network that presents a Mesh network; and the mathematical model for the distribution of computational tasks among the set of Agents. In order to synchronize the collective calculation process performed by the set of Agents, the quality criterion evaluated in time is defined. For the future, a Multi-Agent system based on the NodeMCU V3 ESP8266 and ESP32 devices development is planned. As a complex problem, the order of a production process is selected, which includes the stages of: logistics, production, marketing and delivery.

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Victor Ababii[1], Viorica Sudacevschi[1], Mariana Oşovschi[1], Ana Ţurcan[1], Ana Nistiriuc[1], Dimitrie Bordian[1], Silvia Munteanu[1]

[1] Department of Computer Science and Systems Engineering,
Technical University of Moldova
E–mail: `victor.ababii@calc.utm.md`