Cognitive Distributed Computing System Based on Temporal Logic

Victor Ababii, Viorica Sudacevschi, Silvia Munteanu, Victoria Alexei, Radu Melnic, Ana Turcan, Vadim Struna

Abstract

The paper presents the results of the conceptual and structural design of a cognitive system of distributed computing based on temporal logic. The cognitive system has a Multi-Agent structure that forms a mesh network with broadcast communication, which ensures the organization of knowledge exchange between them. Functional elements and temporal logical operators are defined in the form of mathematical models, which allows their implementation based on hardware devices or software products. The functionality of the temporal logic is determined by the time function that calculates the credibility coefficient of the event and its influence on the decisions taken by the Agents.

Keywords: cognitive system, distributed computing, Multi-Agent system, collective decision making, temporal logic, knowledge base.

1. Introduction

Conceptually, the cognitive system has a complex structure that has the ability to learn and develop new knowledge. A cognitive system can be presented in the form of a person, a group of people, an organization, an Agent, a computer, or a combination of these. The purpose of the cognitive system is to provide services to enhance the cognitive abilities of human agents (human intelligence) to select optimal solutions in solving problems in various fields of science. [1, 2, 3].

As mentioned in papers [4, 5, 6], the most effective solutions in solving complex problems are offered by distributed computing, parallel computing, and cloud computing systems. This work provides knowledge in modeling distributed computing systems, cloud platforms, clustering technologies. Methods for improving performance in terms of scalability and reliability are analyzed. All the characteristics mentioned above are also specific to the design of Multi-Agent systems [7, 8] or of collective/collaborative decision-making systems [9], based on Artificial Intelligence.

The cognitive process is an evolutionary process that involves the analysis of a set of knowledge already known so far in order to generate new knowledge based on which optimal decisions can be made. This mechanism can very well be achieved by applying temporal logic [10, 11, 12], which allows highlighting the temporal relationship between past, present, and future.

2. Formulation of the design and research problem

Modern technologies offer a wide range of solutions that allow the development of distributed computing cognitive systems that ensure the solution of complex problems for different application areas. It can be mentioned the papers [13, 14, 17, 19], in which there were researched Multi-Agent systems oriented towards collective calculation, and [15, 16, 18], where cognitive systems based on knowledge with application in various fields are researched.

This paper proposes the conceptual and structural design of a cognitive system of distributed computing based on temporal logic. The architecture of the system presents lots of Agents that form a mesh network with broadcast communication, and it is oriented towards making collective decisions based on the knowledge accumulated over time. At the basis of the process of knowledge formation, there is the set of rules defined by temporal logic that establishes the connection between past, present, and future.

3. Synthesis of the Distributed Cognitive Calculation System

There is defined the distributed system of collective calculation consisting of the set of Agents $A=\left\{A_i, i=\overline{1,I}\right\}$. The functional model of an Agent is defined by expression (1), its diagram is presented in figure 1:

$$A_i = \{KB[T], LC : (Ev, Pp, TLP, DMP, Ac)\}_i, \quad (1)$$

where: $KB[T]$ – Knowledge Base at a time T; LC – Logic Control for synchronizing the data processing operations performed by the Agent; Ev – the set of external events perceived by the Agent and generated by the activity environment; Pp – Pre-processor for conditioning the signals generated by external events; TLP – Temporal Logic Processor that through the application of Temporary Operators processes the data from the knowledge base $KB[T]$ and input data generated by external events to generate new knowledge $KB[T+1]$; DMP – Decision-Making Processor that generates new decisions based on knowledge; Ac – Actions on the activity environment.

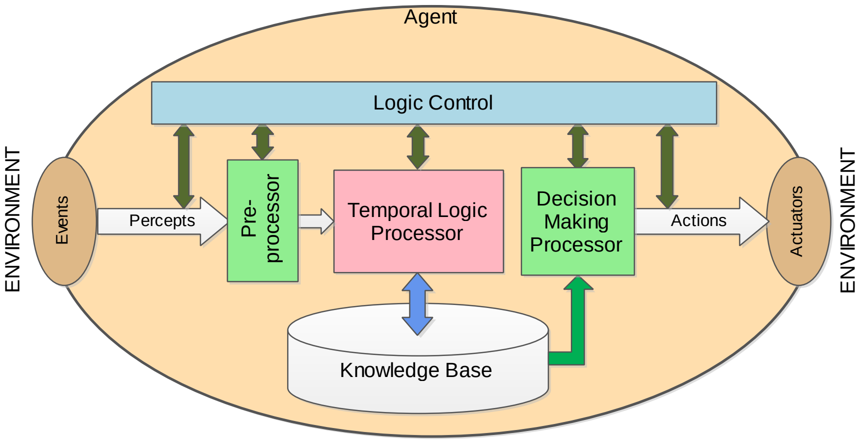

Figure 1. Agent Diagram.

Definition of functional elements of the system:

Event: $Ev[T]_i = \{X[T], KB[T]\}_i, i = \overline{1, I}$, where $Ev[T]_i$ – the set of events that took place at the time $[T-1, T]_i$, but perceived by the Agent at the time T; $X[T]_i$ – the set of events generated by the activity environment; $KB[T]_i$ – the multitude of knowledge received from all Agents involved in decision-making.

Decision:

$D[T]_i = \{DMP : KB[T] \rightarrow (Ac, Qr, Dec, Con)\}_i$, $i = \overline{1, I}$, where $D[T]_i$ – the set of decisions made by the Agent at the time T; Ac – decisions on action on the activity environment; Qr – generating questions to all the Agents; Dec – declaratory decisions communicated to all the Agents; Con – confirmatory decisions communicated to all the Agents.

Action: $Ac[T]_i = \left\{DMP : KB[T] \rightarrow \left(Ac[T]_{i,1}, ..., Ac[T]_{i,J_i}\right)\right\}$, $i = \overline{1, I}$,

where $Ac[T]_i$ is the set of actions generated by Agent A_i on the activity environment as a result of processing the decision-making block DMP of data from the knowledge base $KB[T]$.

Question: $Qr[T]_i = \left\{DMP : KB[T] \rightarrow \left(Qr[T]_{i,1}, ..., Qr[T]_{i,J_i}\right)\right\}$, $i = \overline{1, I}$,

where $Qr[T]_i$ is the multitude of questions addressed by the Agent A_i to the set of the Agents A as a result of processing the decision-making block DMP of data from the knowledge base $KB[T]$.

Declaration: $Dec[T]_i = \left\{DMP : KB[T] \rightarrow \left(Dec[T]_{i,1}, ..., Dec[T]_{i,J_i}\right)\right\}$, $i = \overline{1, I}$,

where $Dec[T]_i$ is the set of declarative information transmitted by the Agent A_i to the set of Agents A.

Confirmation:

$Con[T]_i = \left\{DMP : KB[T] \rightarrow \left(Con[T]_{i,1}, ..., Con[T]_{i,J_i}\right)\right\}$, $i = \overline{1, I}$, where $Con[T]_i$ is the set of confirmatory information transmitted by the Agent A_i to the group of Agents A as a result of processing questions $Qr[T]$ generated by the Agents A.

Temporal Logic Processor: $TLP_i = \left\{ O(\tau)_{i,1}, ..., O(\tau)_{i,J_i} \right\}, i = \overline{1, I}$, where $O(\tau)_i$ is the set of temporal logic operators defined for the Agent A_i and implemented on a processor basis. The application of the set of temporal logic operators determines the cognitive properties of the distributed computing system.

Operator: $O(\tau)_i : \left\{ Ev[T]_i, KB[T]_i \right\} \rightarrow \left\{ KB[T+1]_i \right\}, i = \overline{1, I}$, where: $Ev[T]_i$ is the set of events perceived from the activity environment; $KB[T]_i$ – the content of the knowledge base at the time T; and $KB[T+1]_i$ – knowledge base after application of the temporal logic operator $O(\tau)_i$.

The time function for temporal logic operators $O(\tau)_i$ is determined by the expression (2):

$$x(t) = x[T] / \left(k + t^2/s \right), t = \overline{T, \infty}, \quad (2)$$

where: $x(t)$ is the value of the decisional influence (credibility) of the event on the content of the knowledge base $KB[T]$; k – the attenuation coefficient of credibility; s – stability coefficient of decision-making influence (decision-making credibility).

The structure and basic components of the operator are determined by the expression (3):

$$O(\tau) : \left\{ Op_1, Op_2, ..., Op_J \right\}, \quad (3)$$

where Op_j, $j = \overline{1, J}$ is the set of operands that are part of the operator structure $O(\tau)$.

The format of the operand is determined by the expression (4):

$$Op(\tau) = \left\{ Name, X[T], k, s \right\}, \quad (4)$$

where $Name$ is the name of the operand or its content (State, Question, Confirmation, Statement).

Table 1 presents the initial data for model validation (2). The modeling results are shown in Figure 2.

Table 1. Initial data for model validation (2)

Graphic number	$x[T]$	k	s
1	1	1	10
2	1	2	10
3	1	1	5
4	1	1	20
5	1	1	40

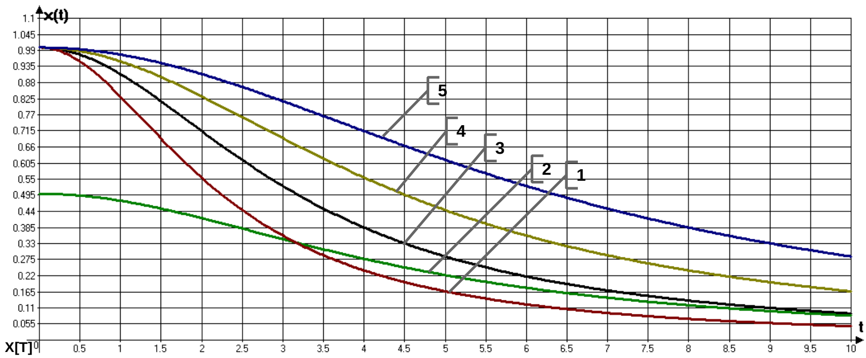

Figure 2. Model validation results (2).

4. Defining Temporal Logic Operators

The list of temporal logical operators is determined by the functionality and field of activity of the distributed cognitive computing system. In the following some examples of temporal logical operators are presented:

1) $O\left(\vee^{\tau}\right)=\max\left\{Op_1,Op_2,...,Op_J\right\}$;

2) $O\left(\wedge^{\tau}\right)=\min\left\{Op_1,Op_2,...,Op_J\right\}$;

3) $O\left(\neg^{\tau}\right)=NOT\left\{Op_1,Op_2,...,Op_J\right\}$;

4) $O\left(\cup^{\tau}\right)=\bigcup\left\{Op_1,Op_2,...,Op_J\right\}$;

5) $O\left(\cap^{\tau}\right)=\bigcap\left\{Op_1,Op_2,...,Op_J\right\}$;

6) $O\left(\sum^{\tau}\right)=\sum\left\{Op_1,Op_2,...,Op_J\right\}$;

7) $O\left(\prod^{\tau}\right)=\prod\left\{Op_1,Op_2,...,Op_J\right\}$;

The number and complexity of operators for temporal logic can be extended in relation to the solved problem.

5. Conclusion

This paper presents the results of the conceptual and structural design of a distributed cognitive computing system based on temporal logic. The system is defined as a group of Agents that forms a network of computing devices with a mesh topology. The communication between the Agents ensures the organization of the knowledge exchange which allows the implementation of the calculation models with a collective decision.

The functionality of the Agents is based on the application of temporal logic models and includes: operations to perceive the state of the activity environment, communication with other Agents for the purpose of knowledge exchange, updating knowledge, calculating decisions and acting with these decisions on the activity environment, or their communication to other Agents.

The paper proposes the synthesis of the distributed system of cognitive calculation, which includes: the functional model of Agents and its diagram, the functional elements are defined in the form of mathematical models (Event, Decision, Action, Question, Declaration, Confirmation, and Temporal Logic Processor).

A temporal Logic Processor is defined as a set of operators that performs operations on a set of operands. The purpose of the operators is to update the knowledge base, thus offering cognitive capabilities for the system. An operand is a functional description of an event and includes its name or content, the initial state of the event, its credibility attenuation coefficient, and its credibility stability coefficient.

In order to validate the model for calculating the credibility coefficient of the event, its modeling was performed for different attenuation and stability coefficients. The results are presented in the form of graphs.

The implementation of the Agents in the form of hardware computing architectures and software products is planned for the future.

The results of this paper will be applied in the development of Multi-Agent systems with calculation and collective decisions.

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References

[1] A. Gomila and V.C. Muller. *Challenges for Artificial Cognitive Systems*. Journal of Computer Science, No. 13, pp. 453-469, 2012.

[2] A. Langus and M. Nespot. *Cognitive Systems Struggling for Word Order*. Cognitive Psychology, No. 60, pp. 291-318, 2010. doi:10.1016/j.cogpsych.2010.01.004.

[3] L. Ogiela, R. Tadeusiewicz, and M.R. Ogiela. *Cognitive Techniques in Medical Information Systems.* Computers in Biology and Medicine, No. 38, pp. 501-507, 2008. doi:10.1016/j.compbiomed.2008.01.017.

[4] K. Hwang, G.C. Fox, and J.J. Dongarra. *Distributed and Cloud Computing*. ELSEVER, 670p., 2012, ISBN: 978-0-12-385880-1.

[5] B. Talekar, S. Chaudhari, and V. Shinde. *Distributed Computing Challenges.* IOSR Journal of Computer Engiinering, Vol. 16, Issue 2, pp. 28-31. 2014, ISSN: 2278-8727.

[6] K.N. Ahire. *Distributed Computing – Future and Applications.* International Research Journal of Engineering and Technology, Vol. 04, Issue 10, pp. 2005-2007. 2017, ISSN: 2395-0072.

[7] A. Byrski, R. Drezewski, L. Siwik, and M. Kisiel-Dorohinski. *Evolutionary Multi-Agent Systems.* The Knowledge Engineering Review, Vol. 30, Issue 2, pp. 171-186. 2015. DOI: 10.1017/S0269888914000289.

[8] J. Rocha. *Multi-Agent Systems.* Published by InTechOpen. 218p., 2017. ISBN 978-953-51-3535-7.

[9] L. Chen, C. Huepe, and T. Gross. *Adaptive Network Models of Collective Decision Making in Swarming Systems.* Phys. Rev. E 94, 022415 (2016). DOI: 10.1103/PhysRevE.94.022415.

[10] T. Agotnes, W. Hoek, J.A. Rodriguez-Aguilar, C. Sierra, and M. Wooldridge. *A Temporal Logic of Normative Systems.* Trens in Logic, No. 27, pp. 11-48, Springer, 2008.

[11] F. Laroussinie, N. Markey, and P. Schnoebelen. *Temporal Logic with Forgettable Past.* In: The Proceedings of the 17th Annual IEEE Symposium on Logic in Computer Sciences (LICS'02), pp. 383-392. 2002. ISBN: 0-7695-1483-9. DOI: 10.1109/LICS.2002.1029846.

[12] A. Rodionova, E. Bartocci, D. Nickovic, and R. Grosu. *Temporal Logic as Filtering.* In: The Proceedings of the 19th International Conference on Hybrid Systems: Computation and Control (HSCC'16), April 12-14, 2016, Vienna, Austria, pp. 11-20. DOI: 10.1145/2883817.2883839.

[13] V. Ababii, V. Sudacevschi, and Gh. Safonov. *Designing a Collective Agent for synthesis of Adaptive Decision-Making Systems.* Sciences of Europe (Praha, Chech Republic), Vol 1, No 17(17), 2017, pp. 70-75, ISSN: 3162-2364.

[14] V. Ababii, V. Sudacevschi, R. Melnic, and S. Munteanu. *Multi-Agent System for Distributed Decision-Making.* National Science Journal (Ekaterinburg, Russia), Vol 2, No 45, 2019, pp. 19-23, ISSN: 2413-5291. DOI: 10.31618/nas.2413-5291.2019.2.45.

[15] V. Ababii, V. Sudacevschi, R. Braniste, A. Turcan, C. Ababii, and S. Munteanu. *Adaptive computing system for distributed process control.* International Journal of Progressive Sciences and Technologies. Vol. 22, No 2, September 2020, pp. 258-264. ISSN: 2509-0119.

[16] S. Munteanu, V. Sudacevschi, V. Ababii, R. Braniste, A. Turcan, and V. Leashcenco. *Cognitive Distributed Computing System for Intelligent Agriculture.* International Journal of Progressive Sciences and Technologies. Vol. 24, No 2, January 2021, pp. 334-342. ISSN: 2509-0119.

[17] V. Ababii, V. Sudacevschi, R. Braniste, A. Nistiriuc, S. Munteanu, and O. Borozan. *Multi-Robot System Based on Swarm Intelligence for Optimal Solution Search.* In: The International Congress on Human-Computer Interaction, Optimization, and Robotic Applications, HORA-2020, June 26-28, 2020, Ankara, Turkey. pp. 269-273, Publisher: IEEE Catalog Number CFP20X32-ART, ISBN: 978-1-7281-9352-6, DOI: 10.1109/HORA49412.2020.9152926.

[18] V. Sudacevschi, S. Munteanu, V. Ababii, R. Braniste, O. Borozan, and V. Alexei. *Cognitive Computing System based on Distributed Knowledge*. In: Extended Abstracts of the 10th International Conference on Electronics,

Communications and Computing (ECCO-2019), 23-26 October 2019, Chisinau, Moldova, pp. 98, ISBN: 978-9975-108-84-3.

[19] V. Ababii, V. Sudacevschi, M. Osovschi, A. Turcan, A. Nistiriuc, D. Bordian, and S. Munteanu. *Distributed System for Real-Time Collective Computing.* In: Proceedings of the Fifth Conference of Mathematical Society of Moldova, IMCS-2019, September 28 – October 1, 2019, Chisinau, pp. 267-274. ISBN: 978-9975-68-378-4.

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