16th Workshop on Generalized Nets and Data Mining
10 February 2018, Sofia, Bulgaria, 59–67, ISSN 1313-6860

Generalized Net Modelling for Intelligent Control of Mobile Robots

Matthias Werner[1], Wolfram Hardt[2], Stanislav Simeonov[3], Sotir Sotirov[3], Evdokia Sotirova[3] and Neli Simeonova[3]

[1] Operating Systems Group
Chemnitz University of Technology, Germany
e-mail: `matthias.werner@informatik.tu-chemnitz.de`

[2] Chemnitz University of Technology, Germany
e-mail: `hardt@cs.tu-chemnitz.de`

[3] Intelligent Systems Laboratory
"Prof. Assen Zlatarov" University, Bourgas, Bulgaria
e-mails: `ssotirov@btu.bg`, `stanislav_simeonov@btu.bg`,
`esotirova@btu.bg`, `neli_simeonova@btu.bg`

Abstract: The operation of multiple devices at the same time in the creation of sophisticated products is related to precise refinement of the possibilities, the location and the time needed to develop the separate parts. The aim of this paper is to create a new complex model that reflects the work of several simultaneously working robots. Here we extend the problem of spatial-temporal group scheduling using Generalized nets (GN). The paper is based on [3]. The GN are proper to model the spatial, temporal, ordered and concurrent character of our mobile, distributed system. Using the GN, we model movement in a heterogeneous terrain as well as task execution or access to other resources of the devices.

Keywords: Generalized net, Mobile distributed systems, Intelligent control system.
AMS Classification: 68Q85.

1 Introduction

The integration of complex robotic systems is a big challenge in the modern systems. When perfoming processes related to successive actions, which are carried out by multiple robots, the capabilities of the respective robot, its location, the work that must be performed as well as the time it would take should be taken into account. The potential of such systems is greater than what has been realized. There are considerable challenges, particularly because the physical components of such systems introduce safety and reliability requirements qualitatively different from those in general-purpose computing. Moreover, the standard abstractions used in computing do not fit the physical parts of the system well.

Some researchers [8] are focused on the challenges of modeling tis kind of systems that arise from the intrinsic heterogeneity, concurrency, and sensitivity to timing of such systems. It uses a portion of an aircraft vehicle management systems (VMS), specifically the fuel management subsystem, to illustrate the challenges, and then discusses technologies that at least partially address the challenges. Specific technologies described include hybrid system modeling and simulation, concurrent and heterogeneous models of computation, the use of domain-specific ontologies to enhance modularity, and the joint modeling of functionality and implementation architectures.

Applications of thit systems have high potential. They include high confidence medical devices and systems, assisted living, traffic control and safety, advanced automotive systems, process control, energy conservation, environmental control, avionics, instrumentation, critical infrastructure control (electric power, water resources, and communications systems for example), distributed robotics (telepresence, telemedicine), defense systems, manufacturing, and smart structures. Networked autonomous vehicles could dramatically enhance the effectiveness and could offer substantially more effective disaster recovery techniques. In communications, cognitive radio could benefit enormously from distributed consensus about available bandwidth and from distributed control technologies. Distributed real-time games that integrate sensors and actuators could change the (relatively passive) nature of on-line social interactions.

By focusing on the physical world it becomes obvious that non-computational processes (physical actions) are strongly distributed and concurrent. Thus, designing and programming those systems have to cope with those issues. Since thinking in distributed and concurrent terms is complexity-introducing and often error-prone [7], we have studied this problem and proposed a suitable programming model [4, 5, 6] that both abstracts from distribution and concurrency by allowing the programmer to develop sequential object-oriented program code. Besides the imperative code fragments, declarative annotations can be integrated into the source code for defining spatial-temporal constraints that are glued to imperative code fragments and restrict its execution.

All this requires a coordination of resources in space and time. The aim in this paper is to address the problem of spatial-temporal group scheduling by using Generalized nets [1, 2]. Generalized nets are a suitable tool for modeling intuitive and "smart" systems, as well as training based on professional and emotional foundation [6, 7].

Our concept is to map space to time and describe physical locations based on durations needed to change locations. The computation of a schedule is based on those timed transitions. This paper is based on [3]. But, here we extend the previous paper with additional functionality.

2 Generalized Net Model

In our understanding, a task is associated with duration and a deadline at which the task has to be completed depending on hard or soft deadlines. Thus, tasks may have intelligent, real and temporal constraints.

We start to find a suitable abstraction in order to describe physical locations in which robots operate. The robot can indicate possible movements in order to reach possible targets via many different paths. We model this topology by means of GN.

The GN-model (see Fig. 1) contains $3r + 4$ transitions and $13r + 14$ places, collected in three groups and related to the three types of the tokens that will enter respective types of places:

- α-tokens and a-places represent the path that the robots follow;
- β-tokens and b-places represent the tasks of the robots;
- γ-token and c-places represent the robots;
- δ-tokens and s-places represent the decision making technics.

For brevity, we shall use the notation α-, β- and γ-tokens instead of α_k-, β_j- and γ_i-tokens, where k, j and i are numerations of the respective tokens.

In the beginning α-, β- and γ-tokens stay, respectively, in places a_{r+3}, b_{2+r+1} and c_{r+3} with initial characteristics: x_0^α = "algoritm k for movement", x_0^β = "task t, duration d of the task", x_0^γ = "robot r_i, position of the robot r_i (initial position p)", where $i \in [1,.., r]$, $j \in [1,.., p]$, $k \in [1,.., l]$.

The new decision making technics are represented by δ-tokens that enter the net from place s_0 with initial characteristics: x_0^δ = "Decision making technic m".

Let x_{cu}^α, x_{cu}^β and x_{cu}^γ be current α-, β-, and γ-tokens' characteristics, respectively.

Generalized net is presented by a set of transitions:

$$A = \{ Z_0, Z_1, Z_2, Z_4, Z_{4,1}, Z_{4,2}, \ldots, Z_{4+r-1}, Z_{4+r-1,1}, Z_{4+r-1,2}\},$$

where transitions describe the following processes:

- Z_0 – Represent the work of the intelligent system for control of the robots;
- Z_1 – The activities of the robots;
- Z_2 – Work of the algorithms for movement of the robots;
- Z_3 – Task performed of the robots;
- Z_4 – Choice of action for the robot 1; …
- Z_{4+r-1} – Choice of action for the robot r;
- $Z_{4,1}$ – Movement of the robot 1;
- $Z_{4,2}$ – Execution of a task of the robot 1;…
- $Z_{4+r-1,1}$ – Movement of the robot r;
- $Z_{4+r-1,2}$ – Execution of a task of the robot r.

The forms of the transitions are the following.

$$Z_0 = \langle\{a_2, b_{2+r}, c_{r+2}, s_0, s\}, \{a_1, b_1, c_1, s\}, R_0, \vee(\wedge(a_2, b_{2+r}\ c_{r+2}), s_0, s)\rangle$$

where:

$$R_0 = \begin{array}{c|cccc} & a_1 & b_1 & c_1 & s \\ \hline a_2 & False & False & False & True \\ b_{2+r} & False & False & False & True \\ c_{r+2} & False & False & False & True \\ s_0 & False & False & False & True \\ s & W_{s,a1} & W_{s,b1} & W_{s,c1} & True \end{array},$$

and $W_{s,a1} = W_{s,b1} = W_{s,c1}$ = "The tasks are ordered in the proper way".

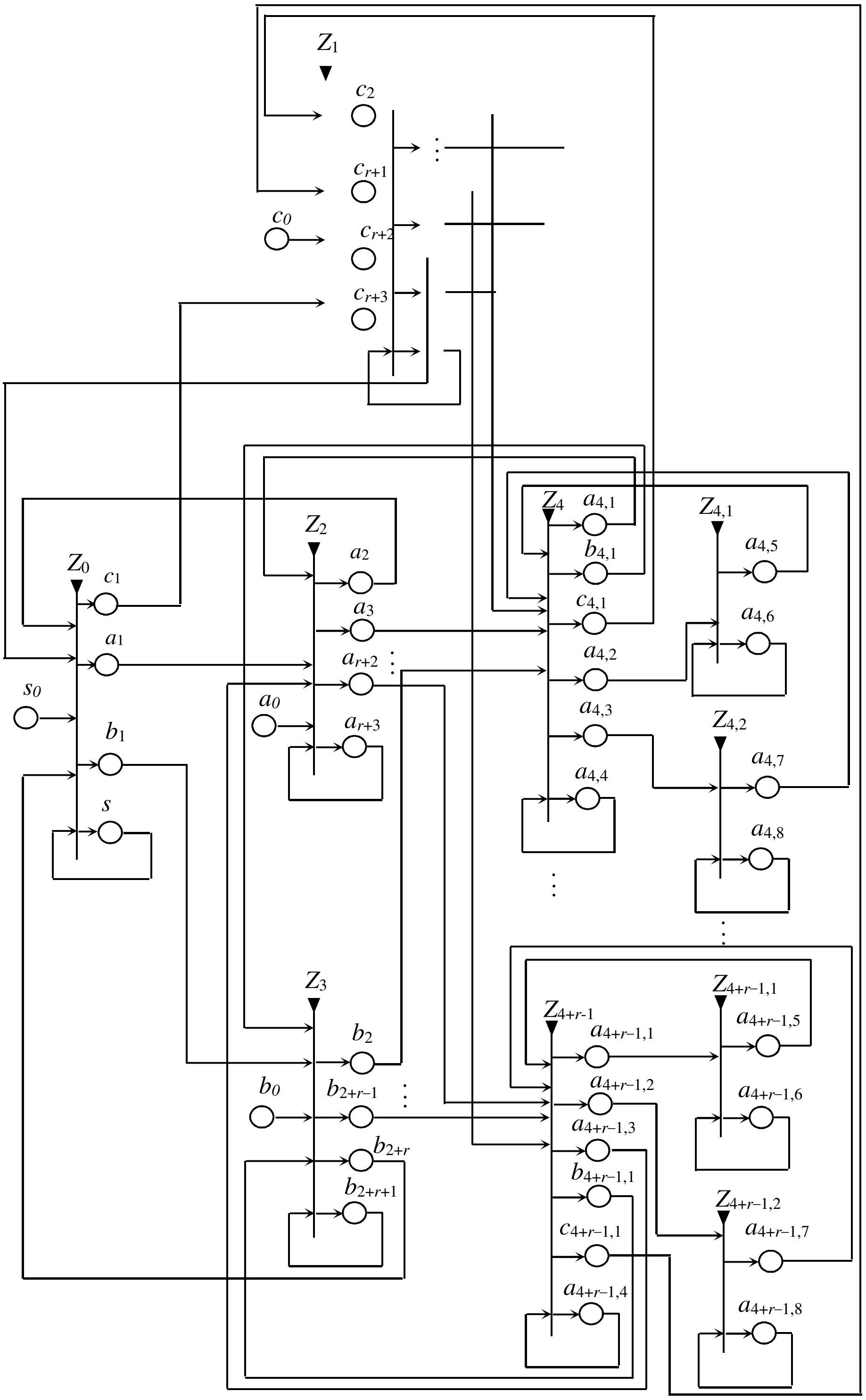

Figure 1. Generalized Net model

On the first activation of the transition Z_0 the α-, β- and γ-tokens enter place *s* (form places a_2, b_{2+r} and c_{r+2} respectively).

The α-token obtains characteristic "robot r_i, initial position *p* and the end positions p' of the robot r_i" in place a_1. The β-token obtains characteristic "task *t* for the robot r_i; duration *d* of the task, predecessor tasks T'" in place b_1. The γ-token obtains characteristic "robot r_i, task *t*; initial position *p* and the end positions p' of the robot r_i" in place c_1.

$Z_1 = \langle\{c_0, c_{4,1},\ldots, c_{4+r-1,1}, c_1, c_{r+3}\}, \{c_2,\ldots, c_{r+1}, c_{r+2}, c_{r+3}\}, R_1, \vee(c_0, c_{4,1},\ldots, c_{4+r-1,1}, c_1, c_{r+3})\rangle$

where:

$$R_1 = \begin{array}{c|ccccc} & c_2 & \cdots & c_{r+1} & c_{r+2} & c_{r+3} \\ \hline c_0 & False & \ldots & False & False & True \\ c_{4,1} & False & \ldots & False & False & True \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ c_{4+r-1,1} & False & \ldots & False & False & True \\ c_1 & False & \ldots & False & False & True \\ c_{r+3} & W_{r+3,2} & \cdots & W_{r+3,r+1} & W_{r+3,r+2} & True \end{array},$$

and

- $W_{r+3,2}$ = “The robot 1 is choosen”, …
- $W_{r+3,r+1}$ = “The robot r is choosen”,
- $W_{r+3,r+2}$ = “There is a feedback from robot r_i”.

The γ-token obtains characteristic “robot r_1, initial position p and the end positions p' of the robot r_1” in place c_2. The γ-token obtains characteristic “robot r_r, initial position p and the end positions p' of the robot r_r” in place c_{r+1}. The γ-token obtains characteristic “information for robot r_i, initial position p and the end positions p' of the robot r_i” in place c_{r+2}.

$$Z_2 = \langle\{a_0, a_{4,1}, a_1, a_{4+r-1,3}, a_{r+3}\}, \{a_2, a_3, \ldots, a_{r+2}, a_{r+3}\},$$
$$R_2, \vee(a_0, a_{4,1}, a_1, a_{4+r-1,3}, a_{r+3})\rangle$$

where:

$$R_2 = \begin{array}{c|ccccc} & a_2 & a_3 & \ldots & a_{r+2} & a_{r+3} \\ \hline a_0 & False & False & \ldots & False & True \\ a_{4,1} & False & False & \ldots & False & True \\ a_1 & False & False & \ldots & False & True \\ a_{4+r-1,3} & False & False & \ldots & False & True \\ a_{r+3} & W_{r+3,a2} & W_{r+3,a3} & \ldots & W_{r+3,ar+2} & True \end{array},$$

and

- $W_{r+3,a2}$ = “There is a feedback from robot r_i”,
- $W_{r+3,a3}$ = “There is a task for robot r_1”, …
- $W_{r+3,ar+2}$ = “There is a task for robot r_r”.

The α-token obtains characteristic “robot r_i, end positions p' of the robot r_i” in place a_2. The α-token obtains characteristic “robot r_1, end positions p' of the robot r_1” in place a_3. The α-token obtains characteristic “robot r_n, end positions p' of the robot r_r” in place a_{r+2}. The α-token obtains characteristic “robot r_i, end positions p' of the robot r_i” in place a_{r+3}.

$$Z_3 = \langle\{b_0, b_{4,2}, b_1, b_{4+r-1,1}, b_{2+r+1}\}, \{b_2,\ldots,b_{2+r-1}, b_{2+r}, b_{2+r+1}\},$$
$$R_3, \vee(b_0, b_{4,2}, b_1, b_{4+r-1,1}, b_{2+r+1})\rangle$$

where:

$$R_3 = \begin{array}{c|ccccc} & b_2 & \cdots & b_{2+r-1} & b_{2+r} & b_{2+r+1} \\ \hline b_0 & False & \cdots & False & False & True \\ b_{4,2} & False & \cdots & False & False & True \\ b_1 & False & \cdots & False & False & True \\ b_{4+r-1,1} & False & \cdots & False & False & True \\ b_{2+r+1} & W_{2+r+1,b2} & \cdots & W_{2+r+1,2+r-1} & W_{2+r+1,2+r} & True \end{array},$$

and

- $W_{2+r+1,b2}$ = “There is a task for robot r_1 for time d”, …
- $W_{2+r+1,2+r-1}$ = “There is a task for robot r_r for time d”.
- $W_{2+r+1,2+r}$ = “There is a feedback from robot r_i”,

The β-token obtains characteristic “task for robot r_1, time d” in place b_2. The β-token obtains characteristic “task for robot r_r, time d” in place b_{2+r-1}. The β-token obtains characteristic “task for robot r_i, time d” in place b_{2+r}.

$$Z_4 = \langle\{c_2, a_{4,5}, a_{4,7}, a_3, b_2, a_{4,4}\}, \{a_{4,1}, b_{4,1}, a_{4,2}, a_{4,3}, a_{4,4}, c_{4,1}\},$$
$$R_4, \vee(c_2, a_{4,5}, a_{4,7}, \wedge(a_3, b_2), a_{4,4})\rangle$$

where:

$$R_4 = \begin{array}{c|cccccc} & a_{4,1} & b_{4,1} & a_{4,2} & a_{4,3} & a_{4,4} & c_{4,1} \\ \hline c_2 & False & False & False & False & True & False \\ a_{4,5} & False & False & False & False & True & False \\ a_{4,7} & False & False & False & False & True & False \\ a_3 & False & False & False & False & True & False \\ b_2 & False & False & False & False & True & False \\ a_{4,4} & W_{4,4,a4,1} & W_{4,4,b4,1} & W_{4,4,a4,2} & W_{4,4,a4,3} & True & W_{4,4,c4,1} \end{array},$$

and

- $W_{4,4,a4,1}$ = “There is a task for robot r_1”,
- $W_{4,4,b4,1}$ = “There is a feedback from robot r_1”,
- $W_{4,4,a4,2}$ =”There is a task for movement for robot 1”,
- $W_{4,4,a4,3}$ =”There is a task for robot 1”,
- $W_{4,4,c4,1}$ =” There is a feedback from robot r_1”.

The α-token obtains characteristic “robot r_1, end positions p'” in place $a_{4,1}$. The β-token obtains characteristic “robot r_1, executed task” in place $b_{4,1}$. The α-token obtains characteristic “robot r_1, end positions p' of the robot r_1” in place $a_{4,2}$. The α-token obtains characteristic “task for the robot r_1” in place $a_{4,3}$. The γ-token obtains characteristic “robot r_1, executed task” in place $c_{4,1}$.

$$Z_{4,1} = \langle\{a_{4,2}, a_{4,6}\}, \{a_{4,5}, a_{4,6}\}, R_{4,1}, \vee(a_{4,2}, a_{4,6})\rangle$$

where:

$$R_{4,1} = \begin{array}{c|cc} & a_{4,5} & a_{4,6} \\ \hline a_{4,2} & False & True \\ a_{4,6} & W_{4,6,4,5} & False \end{array},$$

and $W_{4,6,4,5}$ = “The robot 1 performed the movement to positions p'”,

The α-token obtains characteristic “performed movement to positions p'” in place $a_{4,5}$.

$$Z_{4,2} = \langle \{a_{4,3}, a_{4,8}\}, \{a_{4,7}, a_{4,8}\}, R_{4,2}, \vee(a_{4,3}, a_{4,8})\rangle$$

where:

$$R_{4,2} = \begin{array}{c|cc} & a_{4,7} & a_{4,8} \\ \hline a_{4,3} & False & True \\ a_{4,8} & W_{4,8,4,7} & False \end{array},$$

and $W_{4,8,4,7}$ = “The robot 1 performed the task”,

The α-token obtains characteristic “performed task” in place $a_{4,7}$.

$$Z_{4+r-1} = \langle \{c_{r+1}, a_{4+r-1,5}, a_{4+r-1,7}, a_{r+2}, b_{2+r-1}, a_{4+r-1,4}\},$$
$$\{a_{4+r-1,1}, b_{4+r-1,1}, a_{4+r-1,2}, a_{4+r-1,3}, a_{4+r-1,4}, c_{4+r-1,1}\}, R_{4+r-1},$$
$$\vee(c_{r+1}, a_{4+r-1,5}, a_{4+r-1,7}, \wedge(a_{r+2}, b_{2+r-1}), a_{4+r-1,4})\rangle$$

where:

$$R_4 = \begin{array}{c|cccccc} & a_{4+r-1,1} & b_{4+r-1,1} & a_{4+r-1,2} & a_{4+r-1,3} & a_{4+r-1,4} & c_{4+r-1,1} \\ \hline c_{r+1} & False & False & False & False & True & False \\ a_{4+r-1,5} & False & False & False & False & True & False \\ a_{4+r-1,7} & False & False & False & False & True & False \\ a_{r+2} & False & False & False & False & True & False \\ b_{2+r-1} & False & False & False & False & True & False \\ a_{4+r-1,4} & W_{4+r-1,4,a1} & W_{4+r-1,4,b1} & W_{4+r-1,4,a2} & W_{4+r-1,4,a3} & True & W_{4+r-1,4,c1} \end{array},$$

and

- $W_{4+r-1,4,a1}$ = “There is a task for robot r_r”,
- $W_{4+r-1,4,b1}$ = “There is a feedback from robot r_r”,
- $W_{4+r-1,4,a2}$ = “There is a task for movement for robot r”,
- $W_{4+r-1,4,a3}$ = “There is a task for robot r”,
- $W_{4+r-1,4,c1}$ = “There is a feedback from robot r_r”.

The α-token obtains characteristic “robot r_r, end positions p' ” in place $a_{4+r-1,1}$. The β-token obtains characteristic “robot r_r, executed task” in place $b_{4+r-1,1}$. The α-token obtains characteristic “robot r_r, end positions p' of the robot r_1” in place $a_{4+r-1,3}$. The α-token obtains characteristic “task for the robot r_r” in place $a_{4+r-1,2}$. The γ-token obtains characteristic “robot r_r, executed task” in place $c_{4+r-1,1}$.

$$Z_{4+r-1,1} = \langle\{a_{4+r-1,1}, a_{4+r-1,6}\}, \{a_{4+r-1,5}, a_{4+r-1,6}\},$$
$$R_{4+r-1,1}, \vee(a_{4+r-1,1}, a_{4+r-1,6})\rangle$$

where:

$$R_{4+r-1,1} = \begin{array}{c|cc} & a_{4+r-1,5} & a_{4+r-1,6} \\ \hline a_{4+r-1,1} & False & True \\ a_{4+r-1,6} & W_{16,15} & False \end{array},$$

and $W_{16,15}$ = “The robot n performed the movement to positions p' ”, The α-token obtains characteristic "performed movement to positions p' " in place $a_{4+r-1,5}$.

$$Z_{4+r-1,2} = \langle \{a_{4+r-1,2}, a_{4+r-1,8}\}, \{a_{4+r-1,7}, a_{4+r-1,8}\},\\ R_{4+r-1,2}, \vee(a_{4+r-1,2}, a_{4+r-1,8})\rangle$$

where:

$$R_{4+r-1,2} = \begin{array}{c|cc} & a_{4+r-1,7} & a_{4+r-1,8} \\ \hline a_{4+r-1,2} & False & True \\ a_{4+r-1,8} & W_{18,17} & False \end{array},$$

and $W_{18,17}$ = "The robot r performed the task".

The α-token obtains characteristic "performed task" in place $a_{4+r-1,7}$.

3 Conclusion

The simultaneous operation of multiple devices in creating sophisticated products is related to accurate refinement of the possibilities, the exact location and the time for making the individual parts is the goal we set out in development of this article. Our efforts were aimed at creating a model that reflects the work of multiple robots running simultaneously. The proposed GN introduces model the intelligent system for ordering and concurrent character of mobile, distributed system. The model is based on a discrete topology in which devices can change their location by moving from cell to cell. With GN, we model movement in a heterogeneous terrain as well as task execution or access to other resources of the devices.

Nowadays intelligent systems can be found in areas as diverse as robotics, automotive, chemical processes, civil infrastructure, energy, healthcare, manufacturing, transportation, entertainment, and consumer appliances.

Acknowledgments

The authors are grateful for the support provided by the project NTS Germania 11, funded by the DAAD.

References

[1] Atanassov, K., Generalized Nets, World Scientific, Singapore, 1991.

[2] Atanassov, K., On Generalized Nets Theory, "Prof. M. Drinov" Academic Publishing House, Sofia, 2007.

[3] Sotirov, Sotir & Werner, Matthias & Simeonov, Stanislav & Hardt, Wolfram & Sotirova, Evdokia & Simeonova, Neli. (2014). Using Generalized nets to Model Spatial-temporal Group Scheduling Problems. Issues in Intuitionistic Fuzzy Sets and Generalized Nets. 11. 42-54.

[4] Graff, D., Richling, J., Stupp, T.M., Werner, M.: Context-aware annotations for distributed mobile applications. In: Wolfgang Karl, D.S. (ed.) ARCS'11 Workshop Proceedings: Second Workshop on Context-Systems Design, Evaluation and Optimisation (CoSDEO 2011). pp. 357–366. VDE (February 2011)

[5] Graff, D., Richling, J., Stupp, T.M., Werner, M.: Distributed active objects – a systemic approach to distributed mobile applications. In: Sterrit, R. (ed.) 8th IEEE International Conference and Workshops on Engineering of Autonomic and Autonomous Systems. pp. 10–19. IEEE Computer Society (April 2011)

[6] Graff, D., Werner, M., Parzyjegla, H., Richling, J., Mühl, G.: An object-oriented and context-aware approach for distributed mobile applications. In: Workshop on Context-Systems Design, Evaluation and Optimisation (CoSDEO 2010) at ARCS 2010 - Architecture of Computing Systems. pp. 191–200 (2010)

[7] Lee, E.A.: The problem with threads. Computer 39, 33–42 (2006)

[8] Patricia Derler, Edward A. Lee, Alberto Sangiovanni-Vincentelli. "Modeling Cyber-Physical Systems". Proceedings of the IEEE (special issue on CPS), 100(1), 2012, 13–28,

[9] Vankov, P., Vankova, D. Experience – Based Innovative Programme in Varna, Bulgaria. *Education & Professional Development of Engineers in the Maritime Industry*, 9–10 December, London, UK, The Royal Institution of Naval Architects, 23–26.

[10] Vankov, P., Vankova, D. Sustainable Educational & Emotional Model – An Experience from Bulgaria. Pr*oceedings of Edulearn 15 Conference*, 6-8 July 2015, Barcelona, Spain, 1600–1605.