Socio-Cyberphysical System Resource Semantic Interoperability: General Scenarios and Ontology

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***Abstract*—The paper addresses to socio-cyberphysical system resources interoperability support based on the core ontology utilization. Socio-cyberphysical systems consist of three levels: physical, informational and social. Such systems are used for solving a wide range of tasks involving robots and humans. The paper considers three basic scenarios that have been identified to cover the main aspects of human-robot interaction in socio-cyberphysical systems. Based on these scenarios the socio-cyberphysical system ontology has been developed that provides interoperability between robots and humans. For the ontology development the most Ontology has been developed in Protégé ontology editor.**

I. Introduction

Currently, research in the area of socio-cyber physical system area is actively developing worldwide [1], [2], [3]. Such systems consist of three spaces: physical, information, and social. They are used for solving a wide range of tasks involving robots and humans interaction. Authors have identified three basic scenarios that cover main aspects of human-robot interaction in socio-cyberphysical systems: room cleaning scenario by autonomous vacuum cleaning robots operated in smart home, interaction of two robots for assembling an object from components, interaction of a manipulating and a measuring robots for area exploring and obstacle overcoming.

One of the problems in socio-cyberphysical systems is information space organization for information interaction support between robots and humans. Robot-human coalitions are needed for implementation of joint tasks by them. Authors propose to use the smart space technology for information space organization in socio-cyberphysical systems [4], which allows to provide information sharing between different services of the system. This technology aims to the seamless integration of different devices by developing ubiquitous computing environments, where different services can share information with each other, make different computations and interact for joint tasks solving [5]. In the considered approach, the main goal of smart space technology is to provide ontology-based information sharing for the socio-cyberphysical system.

In the last years the ontological approach has been actively used to formalizes various subject areas [6], [7], [8]. Ontologies are applied for different goals, for example, collaboration of experts, software development, and organization of intelligent agents interaction. An ontology is a detailed specification of a domain model. It contains a dictionary that is a list of logical constants and predicate symbols to describe a subject area and a set of logic statements to formulate restrictions within a subject area and to define a dictionary interpretation [9].

The paper proposes a socio-cyberphysical system ontology for modeling the problem area that is based on definitions and abbreviations from suggested upper merged ontology proposed in [10] and support the identified basic scenarios of socio-cyberphysical systems. The ontology includes three main parts: “Physical Space”, “Information Space” and “Social Space”. For the ontology development the most popular ontology editors have been compared. For comparison ten criterions have been identified. The Protégé ontology editor has been chosen for ontology development as the most suitable for these purposes.

The rest of the paper is organized as follows. Section II describes the related work. Section III presents the basic scenarios identified for ontology development. Section IV describes ontology editor comparison. Section V presents the developed ontology. Finally, Conclusion summarize the paper.

II. Related work

There are several scientific papers related to the ontology based interaction of robots and robots with humans. Paper [11] presents the idea of an interaction design between humans and robots, as well as increasing awareness level of the human-based agent-oriented approach. The approach is applied when mobile agents move (autonomous robots and astronauts in protective gear) on the Moon’s surface in a limited geographically area. Paper [12] proposes the model of agents' interaction and information space. Paper [13] presents the concept for the learning factory for cyber-physical production systems (LVP) and presents robotics and human-robot collaboration. Authors of the paper [14] use ontologies in the context of flexible manufacturing scenarios to equip autonomous robots with the necessary knowledge about their environment, opportunities and constraints. In this paper, they discuss the use of semantic technologies together with cyberphysical systems for integrating decision making into smart production machinery. Paper [15] presents the research on using ontologies for modeling context in socio-cyberphysical systems. Paper [16] presents extensions to a core ontology for the robotics and automation field. Authors of the paper propose ontological approach aims at specifying the main notions across robotics subdomains. Paper [17] defines the current issues and solutions possible with ontology development for human-robot interaction. It is describe the role of ontologies in robotics at large, provide a thorough review of service robot ontologies, describe the existing standards for robots, along with the future trends in the domain, and define the current issues and solutions possible with ontology development for human–robot interaction. Paper [17] presents the ontology development process employed along with the problems and decisions taken. Paper [18] evaluates the proposed ontology through a use case scenario involving both heterogeneous robots and human–robot interactions, showing how to define new spatial notions using an ontology. It is discussed the experiment results presenting the ontology strengths. Paper [19] is concerned with the development of model-based systems engineering procedures for the behavior modeling and design of cyber-physical Systems. Three independent but integrated modules compose the system: CPS, ontology and time-reasoning modules. This approach is shown to be mostly appropriate for CPS or which safety and performance are dependent on the correct time based prediction of the future state of the system. Consequently, the ontological approach applicability for modeling the problem area is justified.

Paper [20] describes a coordinated process for the agents (in particular, mobile robots) that jointly perform a task, using the knowledge about the environment, their abilities and possibilities for communication with other agents. The effective use of knowledge about the agents capabilities is implemented by using suitability rates which allow agent to choose the most appropriate action. This approach was tested during a football match between mobile robots. The interaction in this article is considered in terms of the choice of an agent to perform an action.

Authors of the paper [21] are devoted to the problem of robots group control in non-deterministic, dynamically changing situations. Authors propose a method for solving formation task in a group of quadrotors. The method makes possible to ensure accurate compliance with distances between quadrotors in the formation, as well as featuring low computational complexity.

Paper [22] shows a system of robots interaction based on battle management language. This language is intended for expressing concise, unambiguous orders read by both humans and robots. The orders are transmitted from the system of multiple robots and processed for further distribution specific commands between them.

According to papers were reviewed ontologies are used for knowledge representation difference problem domains. Many researches inherit the idea of ontologies usage for modelling context in socio-cyber physical systems. An ontology should include description of physical components, agents, model of problem area. It consists of classes, subclasses, properties, and relationships between classes.

III. Basic Scenarios Description

There are three basic scenarios have been identified to cover the main aspects of human-robot interaction in socio-cyber physical systems for the ontology development.

1) Room cleaning scenario by autonomous vacuum cleaning robots operated in smart home [23].

The vacuum cleaner robot creates a map of the room using light-sensitive sensors and performs the cleaning. For implementation of these tasks the vacuum cleaner robot needs to organize the interaction with other devices, which take part in the scenario:

- with mobile devices; users can specify settings for the cleaning and general requirements, such as energy saving mode, cleaning mode etc;
- with manipulating robot moves the objects in the room, e.g. chairs for providing the possibility of cleaning the space by cleaning robot;
- with adaptive illumination control system, affecting to the movement possibility of participating in the scenario robots equipped by light-sensitive sensors that allows them to position in the room.

2) Interaction of two robots for assembling an object from components [24].

For this task the robots should have an access to an object model set by the human, the possibility to process incoming external information about the type of an object and its components that can be used in the assembly. It is also necessary to provide the possibility of a defective component that cannot be used in the preparation of the object.

3) The interaction of a manipulating robot and measuring robot for obstacle overcoming, area exploring, and making manipulations [25].

The manipulating robot goes to the target area and can find obstacles. It has six wheel drives and lift front and back chassis for obstacle overcoming. If the obstacle is found the measuring robot implements it scanning. Based on the obstacle characteristics the manipulating robot overcomes in automatic mode (if the appropriate algorithm is exist) or the human operator help with the obstacle in manual mode.

IV. Ontology Editor Comparison

The ontology editor selection has been implemented according to the scheme, presented in Fig. 1.

Authors of the papers [27] used the same method for software selection. The method consists of the several phases. On the first phase it is determined that the software for the ontology creation is attributed as an application software oriented to solve a narrow range of tasks. Then they decided to use the method of expert evaluations, which was complemented with a consulting methodology for grading criteria: should have, want have, should not have. Experts assigned a weights or coefficient in accordance with the importance of every criterion. For considered problem domain the ten-point scale was used.

The first criterion is “Open source”. The software should be open and freely distributable solution. All the systems meet this requirement. The next criterion is “Completeness of functionality». A software has to be relevant to all stages of the ontology development and have the necessary tools for building models. The software also has to support well-known formats, e.g. text, RDF and RDF Schema, XML, OWL, UML, etc.

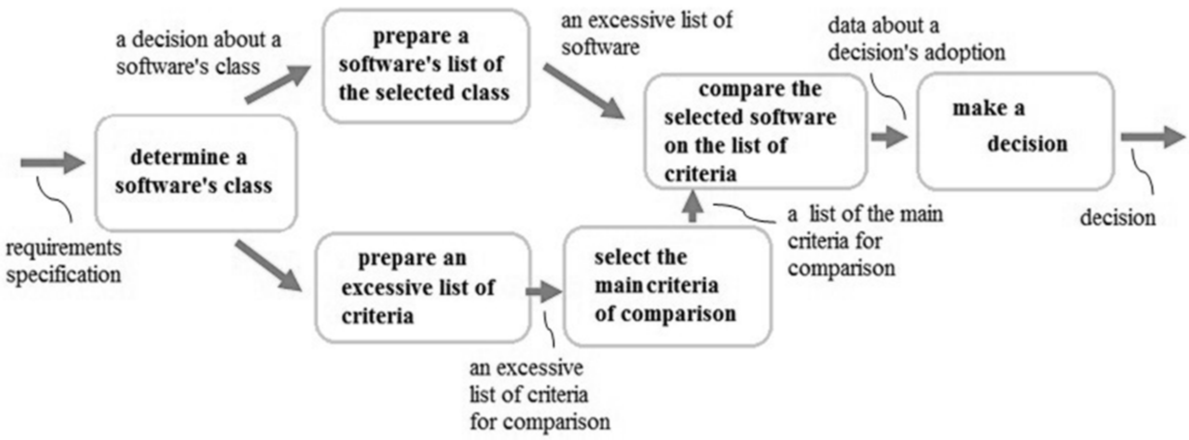

Fig. 1. The process of software selection [26]

“The simplicity of study” is a measure of rapidity of understanding the logic of a software by experts, who have already had experience in ontology development and created models in other editors. The next criterion is “Usability” that is the degree of adaptation of the interface part of the program to users’ needs as well as the usability of the system. The criterion “Graphics editing of the taxonomy of concepts” supports a visual representation of the ontology that is positively affects the development of models. The criterion “Method of storing ontologies” is render the information storage form. For example, it can be available in the form of text files or databases. Most tools use files so there is a limit to ontology complexity. The database management system allows operating and managing models with a large amount of data. The coefficient of the criterion “Hardware requirements” is not high as in the development ontology process large computing power is not required. The criterion “Methodological support” is important while working with any software, but it is not critical. However, the availability of comprehensive documentation reduces the time of familiarization with the system. The criterion “Reliability” is usually considering for all software systems, including ontology development.

With the formation of the criteria list it is conducted a market survey and prepared a list of suitable software.

The six systems were evaluated: Ontolingua, Protégé, OntoEdit, WebOnto, OilEd, OntoSaurus. Then coefficients were calculated by the group of experts. The results are presented in Table I.

In the final table the criteria of software evaluation were selected. For every criterion listed the coefficients on a ten-point scale were chosen, the systems were got estimated by experts, and the final result was calculated by the method of weighted evaluation. Systems “Protégé”, “OntoEdit”, and “Ontolingua” got the highest scores. Software was highly appreciated by the most important criteria: “Completeness of functionality”, “The simplicity of study”, “Usability”. “Ontolingua” has no graphical representation. Being the fourth criterion in the order of importance it greatly simplifies the user’s interaction with the program. Open source “OntoEdit” has limitations on generated entities and it lags behind “Protégé’’ and “Ontolingua” in terms of “Completeness of functionality”. Therefore, “Protégé” system satisfies all the requirements and has been chosen for ontology development.

“Protégé” is an open source software. It includes an editor that allows designing the ontology by expanding the hierarchical structure of abstract or concrete classes and slots. The software contains a graphical interface. “Protégé” includes necessary documents and examples. Software supports various formats and allows visualizing the model of the ontology.

V. Ontology for robots and humans interaction

Developed socio-cyberphysical system ontology is based on definitions and abbreviations from suggested upper merged ontology proposed in [10]. The ontology has been developed in according with scenarios presented in the Section 3. The model includes the description of main processes that occur when coalitions of robots are created to solve problems in cooperation. The ontology classification consists of three main parts: physical space, information space, and social space.

TABLE I. THE SOFTWARE SELECTION MATRIX

	Open source	Simplicity of study	Usability	Completeness of functionality	Reliability	Hardware requirements	The graphics editing of the taxonomy of concepts	Methodological support	Method of storing ontologies	Total:
Coefficient:	10	9	8	9	5	6	7	6	7	
Protégé	10	9	8	9	7	6	8	8	9	60
OntoEdit	10	8	8	7	7	6	7	7	7	54
Ontolingua	10	8	8	8	7	7	2	6	7	51
OntoSaurus	10	4	6	4	5	5	2	4	7	38
WebOnto	10	6	7	6	6	5	7	5	7	48
OilEd	10	6	7	6	6	5	2	5	7	44

”Physical Space” is defined as physical model objects into physical space, ”Information Space‘ referres to virtual objects of information space, ”Social Space deals with objects characterizing the users involved in interaction with robots. Consider the classification ”PhysicalSpace“ in more detail (see Fig. 2). It contains classes “Object”, ”Environment“ and”Process”. Class”Object” describes the physical facilities and collections, and control their agents. Class ”Device“ includes constituent parts of the device:”Battery”, ”Hull”,”Motor”,”Sensor”, ”Switch“, ”Whell“. ”Motor“ is divided into subclass of motor drives - «ServoMotor». «Sensor» consists of subclasses, specifying sensors installed on the device: «DistanceSensor», «HeatSensor», «LightSensor». «Whell» includes two subclasses «LeftWheel» and «RightWheel». Class ”Collection“ consists of ”Group“. Class”Object“ also includes subclass ”Agent“. Hence, class «Object» specifies physical characteristics of devices depending on the scenario.

For example, the first and second scenario need to specify the types of sensors installed. In the third scenario for a manipulating robot, it is important to understand what hull, motor and wheels are used, since it is necessary to overcome obstacles and move across the open countryside by requirement. For all scenarios the class ”Collection“ implies working together in groups.

Class “Process” consists of subclasses “Action” and “Interaction”. “Action” consists of “Movement”, “Interaction”, “Photo”, “Grip”, “Fly”, “Clean”, “Check”, and includes a route options – “Route” (“IndoorRoute”; “OutdoorRoute”). It means class “Action” represents the description of a physical object. “Interaction” consists of the interaction types – “HumanInteraction” and “RobotInteraction” (“InterGroupInteraction”, “IntraGroupInteraction”). Consequently, class “Process” specifies the device capabilities. For example, for the first and third scenarios types of routes are important. In the first case, the robots are indoors, in the third one the movement takes place outdoors. These kinds of activities “Movement”, “Interaction”, “Clean”, “Grip” are relevant to the first scenario, while “Movement”, “Interaction”, “Check”, and “Grip” are for the second. “Movement”, “Interaction”, “Photo”, “Grip”, “Fly” refer to the third scenario. Class “Environment” defines the environment and the situation during the scenario execution.

Now consider the information space (see Fig. 3). Class “InformationSpace”. It consists of “CompetenceProfile”, “Configuration”, “Context”, “Policy” and “Process_Model”. “CompetenceProfile” includes “BasicInformation” (“User_account”, “Robot_description”), “Competency” (“Basic_competencies”, “Special_competencies”), Class “History”, and “Constraint”. Competencies determine the ability to perform certain tasks by any robot. The basic information contains a description of the robot and information about its characteristics. The user account has information about the skills and knowledge of a person who can form a coalition with the robot. Besides, user-specified characteristics can be set to run the scenarios, for example, the room cleaning mode. Basic competencies include motion in space, turns, and the special ones are the ability to overcome obstacles, take photos, to do cleaning of the space and to execute the seizure of components in the process of an object assembly. Class “History” allows to back up robots’ scenarios performed, storing indicators, which were obtained during tasks performance; Class “History” provides analyzing to adjust the execution of processes. Restrictions allow to provide options, when a task cannot be implemented due to initial or emerging condition while fulfilling the process.

Class “Context” includes “Device Context”, “Environment Context” (“Spatial” (“Left”, “Off”, “On”, “Right”), “Temporal” (“Distance”: “Far”, “Near”), and “Interface” (“Wirelessinterface”: ”Bluetooth”, ”WiFi”).

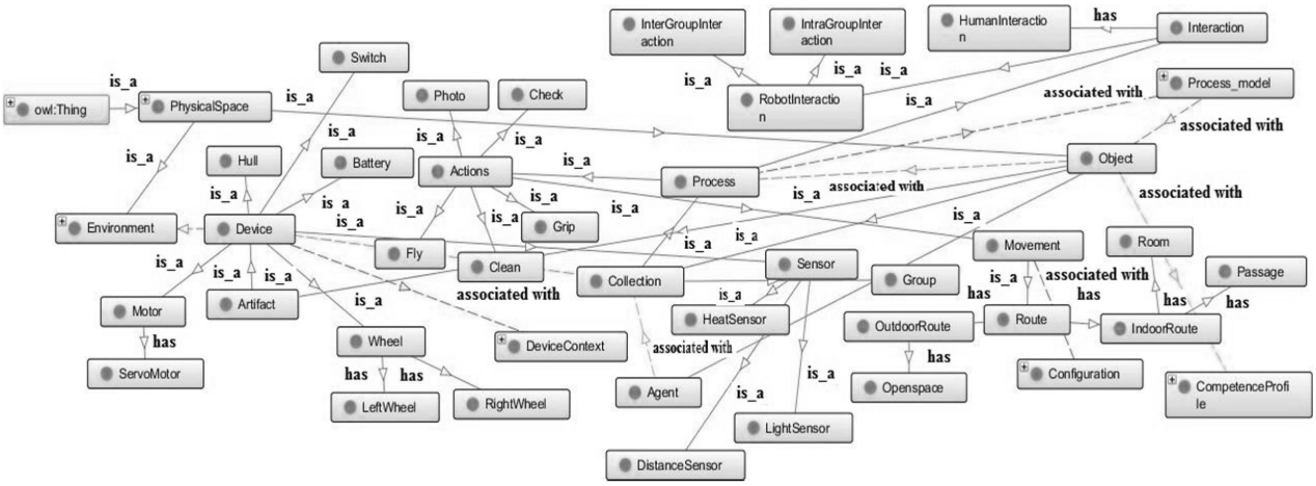

Fig. 2. An Ontology of the physical space in socio-cyberphysical system

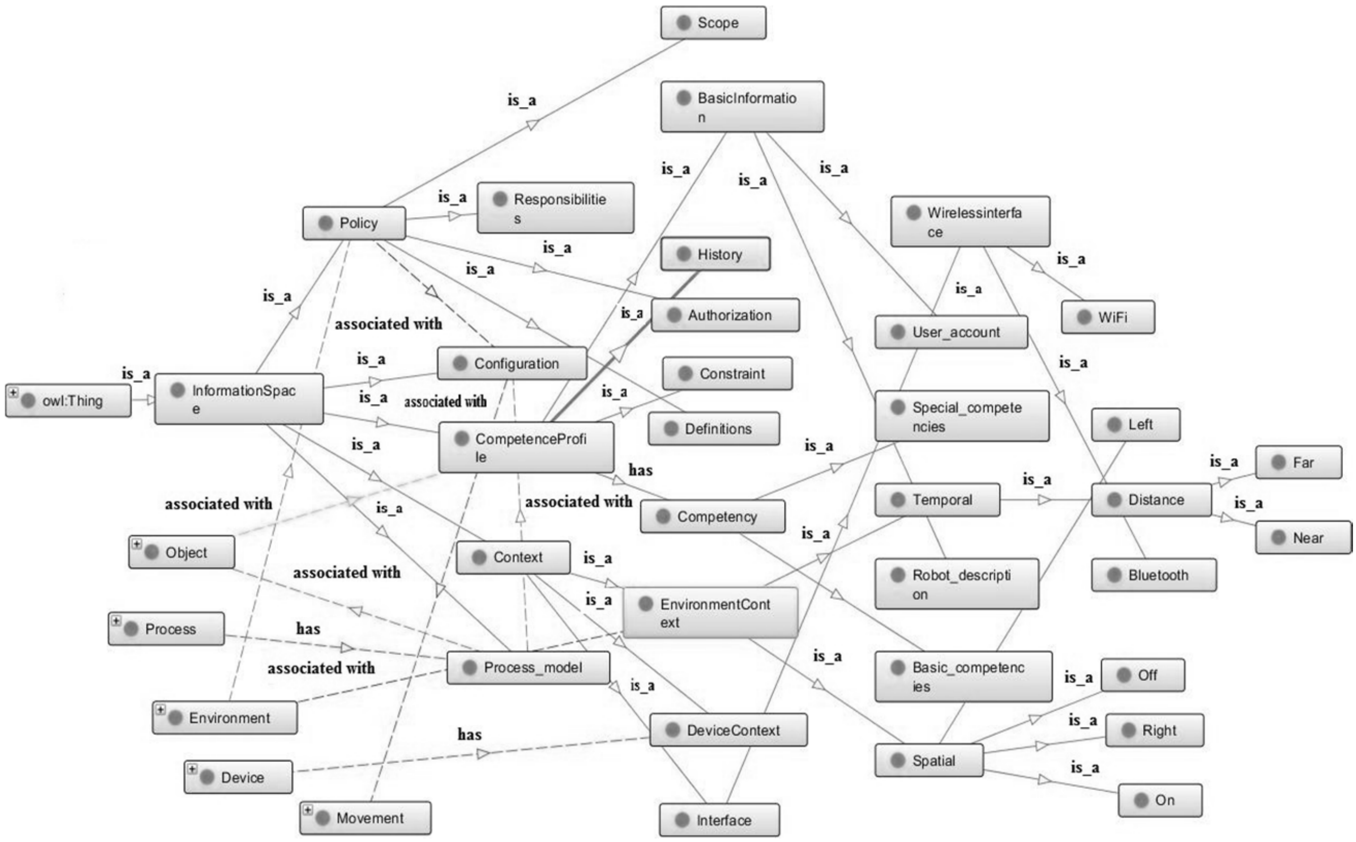

Fig. 3. An Ontology of the information space in socio-cyberphysical system

For the first, second and third scenarios, it is important to understand the constitutes of the environment. Therefore, the classes associated with space and time are important for the orientation of robots in the area of the scenario. Class "Interface" demonstrates the way of interaction between the robots through a wireless link. Class "Policy" defines the access rights, including authorization, standard definitions, opportunities and application limits. Class "Configuration" defines settings and components that must be taken into account in the physical space. "Process_model" stores the description of the scenarios that need to be implemented.

The classification "Social Space" (see Fig.4) consisting of class "User", is subdivided into subclasses "User_characteristics" and "User_group". "User_characteristics" is related to the basic properties, which can characterize the user: "Opportunities", "Profession", "Requirements", "Skills", and "Specialization". "User_group" specifies the user groups that can be formed according to any feature, for example, professions, skills or requirements. Three kinds of relationships between classes were used in the ontology: “is_a”, “has”, “associate with” [26].

VI. Conclusion

The paper presents core ontology for cyber-physical system resources description that is based on definitions and abbreviations from suggested upper merged ontology developed in scope of IEEE Standard Ontologies for Robotics and Automation. The ontology has been developed according to scenarios that have been identified as basic for socio-cyberphysical systems: room cleaning scenario by autonomous vacuum cleaning robots operated in smart home, interaction of two robots for assembling an object from components, the interaction of a manipulating robot and measuring robot for obstacle overcoming, area exploring, and making manipulations.

An ontology was designed for creation and managing robots and humans coalitions. It provides support of semantic interoperability between coalition participants of socio-cyberphysical systems. For the ontology design there are six most popular ontology editors have been analyzed and compared. There are ten criterions have been identified for ontology editors comparison: open source, simplicity of study, usability, completeness of functionality, reliability, hardware requirements, the graphics editing of the taxonomy of concepts, methodological support, and method of storing ontologies. The Protégé ontology editor wins the comparison and has been utilized for the ontology design.

The ontology classification consists of three main parts: physical space, information space, and social space. Three relationships between classes have been used for the ontology design: “is_a”, “has”, and “associate with”.

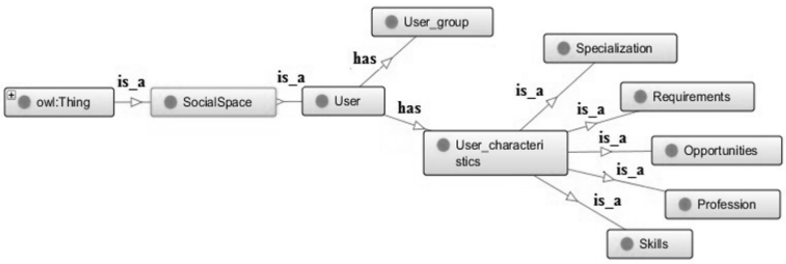

Fig. 4. An Ontology of the social space in socio-cyberphysical system

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