Ontology for Resource Self-organisation in Cyber-Physical-Social Systems

Nikolay Teslya[1,2], Alexander Smirnov[1,2], Tatiana Levashova[1], and Nikolay Shilov[1]

[1] St. Petersburg Institute for Informatics and Automation of the Russian Academy of Sciences
39, 14th line, St. Petersburg, Russian Federation, 199178
[2] ITMO University, 49, Kronverkskiy av., St. Petersburg, Russian Federation, 197101
(teslya,smir,tatiana.levashova,nick}@iias.spb.su

Abstract. Cyber-Physical-Social Systems (CPSSs) are expected to be context-aware. Sharable contexts lie at the heart of the context-aware systems. Ontologies provide means to create sharable ontology-based context models. Such ontologies are referred to as context ontologies. Context is an ontology-based model specified for actual settings. The present research inherits the idea of context ontologies usage for modelling context in CPSSs. In this work, an upper level context ontology for CPSSs is proposed. This ontology is applied in the domain of self-organising resource network. A case study from the area of proactive recommendation systems demonstrates the proposed approach.

Keywords: Cyber-physical-social systems, upper context ontology, resource self-organization.

1 Introduction

Cyber-Physical-Social Systems (CPSSs) is a relatively new research field. It takes ideas from, but goes significantly beyond, the current progress in cyber-physical systems, socio-technical systems and cyber-social systems to support computing for human experience [1]. CPSSs tightly integrate physical, cyber, and social worlds based on interactions between these worlds in real time. Such systems rely on communication, computation and control infrastructures commonly consisting of several levels for the three worlds with various resources as sensors, actuators, computational resources, services, humans, etc.

Semantics is the basis to ensure that several resources arrive at the same meaning regarding the situation and data/information/knowledge being communicated. Ontologies provide for a shared and common understanding of some domain that can be communicated across the multiple CPSS' resources. They facilitate knowledge sharing and reuse in open and dynamic distributed systems and allow entities not designed to work together to interoperate [2].

CPSSs belong to the class of variable systems with dynamic structures. Their resources are too numerous, mobile with a changeable composition. Planned resource interactions in such systems are just impossible. Resource self-organisation is the most efficient way to organise interactions and communications between the resources making up CPSSs.

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The paper contributes to the areas of development of ontologies for CPSSs and of CPSS' resource self-organisation. It proposes an upper-level ontology for CPSSs. This ontology is used for multi-level self-organisation of CPSS' resources. A case study from the area of proactive recommendation systems demonstrates the proposed approach.

The paper is structured as follows. Section 2 discusses the upper-level ontology for CPSSs. Section 3 introduces the approach for multi-level self-organisation of CPSS' resources and presents the domain-specific view on the upper ontology from the self-organization perspective. A case study from the area of proactive recommendation systems is described in Section 4.

2 Upper Ontology

CPSSs are expected to be context-aware. Sharable contexts lie at the heart of the context-aware systems. Ontologies provide means to create sharable ontology-based context models. Such ontologies are referred to as context ontologies. The context ontologies consist of the upper ontology for general concepts, and domain specific ontologies representing knowledge of different application domains [3, 4, 5]. The upper ontology is shared by these domains. As a rule, the upper ontology represents concepts that are common for all context-aware applications (*Context Entity*, *Time*, *Location*, *Person*, *Agent*, *Activity*, *Device*, etc.) and provide flexible extensibility to add specific concepts in different application domains (i.e., *Cell Phone* can be a subcategory of the category *Device*) [6, 7, 8]. Context is described as an ontology-based model specified for actual settings. Multiple sources of data/information/knowledge provide information about the actual settings. This information is integrated within the ontology-based model. The context model is a result of the integration.

The present research inherits the idea of context ontologies usage for modelling context in CPSSs. Although a number of ontologies have been created by now, e.g., in the area of socio-technical systems [9, 10, 11], the purpose of the present research is to propose an ontology convenient to use for self-organization.

According to [12], any information describing an entity's context falls into one of five categories for context information: individuality, activity, location, time, and relations (Fig. 1). The individuality category contains properties and attributes describing the entity itself. The category activity covers all tasks this entity may be involved in. The context categories location and time provide the spatio-temporal coordinates of the respective entity. Finally, the relations category represents information about any possible relation the entity may establish with another entity.

CPSS consists of cyber space, physical space, and mental space [13]. These spaces are represented by sets of *resources*. In the upper ontology (Fig. 2) proposed for CPSSs, the resources are thought of as the entities whose contexts are to be described. The physical space consists of various interacting information and computational *physical devices*. These devices united on the communication basis organize the cyber space. The mental space is represented by *humans* with their knowledge, mental capabilities, and sociocultural elements. Information from cyberspace *interacts* with physical space (*physical device*) and mental space (*human*).