INFORMATYKA EKONOMICZNA BUSINESS INFORMATICS 3(33) • 2014
ISSN 1507-3858

Tatiana Atanasova
Bulgarian Academy of Science Sofia, Bulgaria
e-mail: atanasova@iit.bas.bg

INTEGRATED SEMANTIC-BASED PROCESSES IN DIGITAL HOME[1]

Summary: The purpose of this work is to investigate the specifics in the development of technologies for heterogeneous data and process integration in digital home and to show possible solutions during design of integrated applications. The analysis of the integrated data can be useful for the development of improved algorithms for monitoring and control of digital networked home.

Keywords: Process ontology, semantic, integrated data, digital home.

DOI: 10.15611/ie.2014.3.02

The only thing that is constant is change

Heraclitus

1. Introduction

The tendency for bringing more intelligence into building automation can be seen. It is observed that smart environments have growing demand. The technology development provides a new kind of lifestyle and the designing of smart environment attracts attention of researchers, home techniques manufacturers, mobile operators, civil engineers and other organizations. The scope of arising problems in digital networked homes is very wide and covers different scientific, technological and psychological aspects [Kofler et al. 2012; Chan et al. 2008; Colace, De Santo 2011; Guillory et al. 2011; Holgado-Terriza, Rodriguez-Valenzuela 2011]. Difficulties results from the rapid growth of heterogeneity of electronic devices and communications networks in modern buildings. Home appliances are evolving from purely particular devices to complex systems that contain processors, sensors and

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use interfaces. The complexity of the underlying infrastructure is increasing as well. The broadband is widely available now in living environment, personal digital devices have become very popular, local networks and wireless technologies get emergent interest.

Smart home digital systems have network functions and can be supplemented with connection to the Internet. Network access needs to be available on a range of devices over Wi-Fi and cellular links as well as wired connections. This gives a possibility to monitor and control various home appliances by network and to extend their capabilities through connections in the cloud. Thus home networked system transfers significant functionality from it to the cloud and allows for simplifying its design and integration with other systems and services.

Technologies themselves are rapidly changing. The next generation networks are moving to Software-Defined Networking (SDN) where the network's data layer is decoupling from the control layer. SDN is a relatively new field in research and considers involving intelligent control methods in network management. This will contribute to a better communication between various actors involved with various objectives. These new tendencies can be observed in digital networked home environment too – in intention to construct intelligent control and monitoring methods.

However, a lot of problems still have to be resolved, for example: how all these house's devices will communicate, how they will be managed, aggregated, and how the data will be distributed. Besides that, methods for automation in living environment are focused at present on the construction of relatively static structures, designed in advance.

Uniform technology and methods for integrated interoperation of heterogeneous digital systems in living environment that are oriented to optimal using of resources and ensuring of comfort conditions have not been developed yet.

The investigation in this paper is focused on the problem formulation and directions in which methods and tools have to be developed for inter-operation of heterogeneous digital systems in smart living environment that have extendible functionality.

First some problems connected with heterogeneous data and information sources are outlined. Then we consider involving semantics into infrastructures. Finally some proposals for solutions are suggested. The extended functionality can be oriented to improving subjective perception of quality of life as well as optimal using of resources in digital homes.

2. Data and processes integration

The integration of heterogeneous data and processes can be accomplished at several levels (Figure 1).

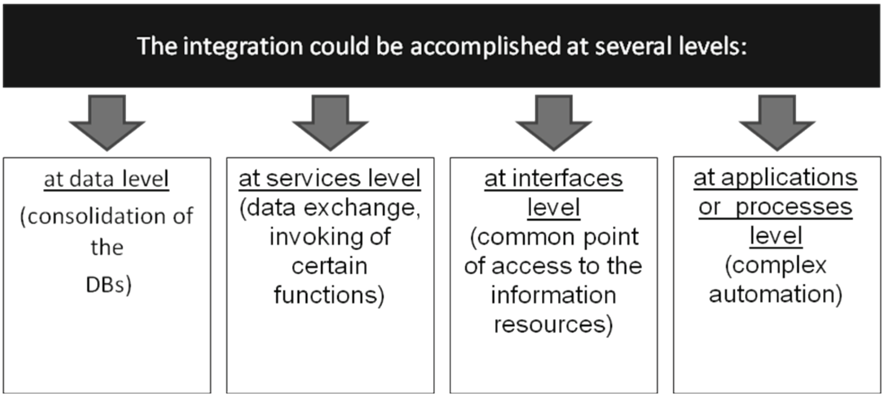

Figure 1. Integration levels

Source: own elaboration.

The existing devices, systems and local networks in a digital house are usually realized with different technologies, regarding the volume of information that is transferred from the integrated devices. We have to take into consideration the heterogeneous data processes and the signals to be conveyed: Ethernet, RF TV and radio signals for wireless-end-connectivity [Guillory et al. 2011] in the distributed building network and necessity of integration of various interfaces for different devices. When new objectives and tasks arise it may be hard to provide interaction between the diversity of the existing appliances.

Each device can be connected with a particular service or a set of services. Thus a multiservice network [Mc Dysan et al. 2000; Vilkman et al. 2011] is established. The multiservice network gives a base for existence of multiple traffic types within the house.

The service may be shared between different devices and dynamically assigned to some of them depending on inhabitants' desires. For very simple example, music or video call may follow the indwellers everywhere in the house. The service can be transferred from one device to another with inference about possibilities for the transfer and service delivery.

Besides certain functionality, the data and process integration requires the construction of an infrastructure, providing safety and security.

2.1. Ontologies

The semantic description and realization of methods for semantic processing may be the key to the achievement of common integration objectives. Several researchers suggest an idea to enhance sensors and actuators with a semantic description of their capabilities [Kofler et al. 2012; Holgado-Terriza, Rodriguez-Valenzuela 2011].

Ontologies as a core of semantics can be used for the purposes of information integration, sharing and reuse. The main components of ontology are concepts, relationship, rules and instances. Concept is a class of objects (entities) in the area. Relationships describe the interactions between concepts or properties; they can be in form of taxonomy or associative relationship. Taxonomies systematize concepts as a hierarchical tree, and the associative relationship puts the concept on the tree.

Instances are specifications of concepts, together with the taxonomy and relationships they form the knowledge domain. Axioms are used to restrict the values of classes or objects (examples).

Ontology may have logic inference, and then it is so-called formal ontology. Formal ontology must have axioms that restrict the possible interpretations of logical expressions. Web Ontology Language (OWL) can been used to describe each element in the ontology.

In a broad sense, ontologies can be distributed over three categories: general, domain or applied ontology.

The domain ontology focuses on the refinement of a more narrow meaning of the terms used in a certain area, and may represent a basic reality, in this specific area, but independent of a specific task (as ontology of time, for example).

Applied ontology is a specific sub-ontology that contains concepts and relationships which are relevant only to the definite task, such as thesauri, which are semantic relations between lexical units. Usually they contain a small number of concepts with relationships and inference rules, which are defined in detail for solution of particular independent task.

Ontologies are created in various forms – from lexicon to dictionary terms, or as first-order logic. The choice of an appropriate semantic model to represent ontology depends on the purpose for which the ontology is build and the underlying assumptions for achieving these goals.

As an ontology a symbolic system $\{C, T, P, F, A\}$ is considered, where

C is the set of concepts,

T is a thesaurus, or partial order on the set C, the hierarchy of relationships, "subclass" and "super-class";

P is the set of predicates (properties);

F is a function that assigns to each element of P an element from the set of C (considering them in T);

A is a set of axioms of the ontology [Santoso et al. 2011].

The hierarchy of concepts is represented as a graph $G = (N, E)$, N – the set of nodes, E – the set of branches, $N = \{n_1, n_2, \ldots, n_n\}$, $E = \{e_1, e_2, \ldots, e_m\}$.

The graph can be described using XML Schema Datatype (XSD).

At development time ontologies are used to provide ontology-driven development (for example, to describe a domain) or ontology-enabled development (to support developers with their activities).

At run time ontologies form ontology-based architectures (as a part of the system architecture) or ontology-enabled architectures (to provide support to the users).

2.2. Process ontology

Fundamental process ontologies are becoming more important in recent times [Liu et al. 2011; Aitken, Curtis 2002; Tempich et al. 2005]. For example, in [Palomäki, Keto 2011] the idea is discussed that everything is a process and consists of the processes.

The basic postulates are:
- the world is represented as an interconnected system of large and small events,
- some of them are relatively stable,
- the events are always changing,
- the changes represent the actualization of certain features and disappearance of others.

The processes can be divided into:
- constant processes that are interpreted as concepts,
- processes which are interpreted as events, represent a finite set of four-dimensional space-time.

Thus, the world is built from events, i.e., ontologically, all consists of processes.

The consideration of processes includes:
- when a process should be initiated and finished,
- who participates in this process,
- how this process should be performed,
- which results must be examined, analyzed and taken into account.

The surrounding of a process in such a way consists of data, event, resources, goal and output as a result of a process.

Processes can form a composition of basic processes and they can be connected with external processes. Additionally, processes can be identified that determine the trends and directions of changing of basic processes, depending on the analysis and

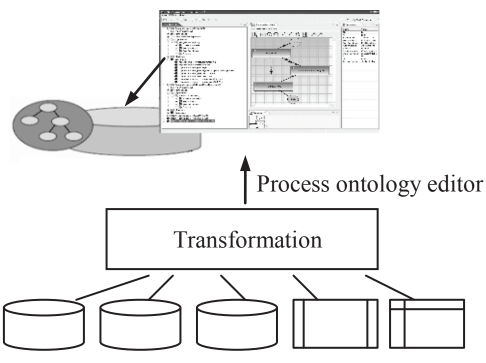

Figure 2. Constructing process ontology

Source: own elaboration.

estimated data. The processes are available in the streams of data as implicit patterns. The data is contained in a multitude of sources R (data sensors, files, databases, external resources), $R = \{R_1, ..., R_q\}$ (Figure 2).

Extracting knowledge from a specific domain can be considered as the construction of structural design pattern – process ontology [Palomäki, Keto 2011]. The objective is to identify processes that have brought the particular event, and to predict future events based on the past experience.

The development of ontologies in centralized settings is well studied and there are established methodologies. However, current experiences suggest that the ontology engineering should be subject to continuous improvement rather than a onetime effort and that ontologies promise the most benefits in decentralized rather than centralized systems [Tempich et al. 2005].

3. Proposed trends and solutions

The intelligent control methods in digital networked home aim to achieve three goals: semantic integration, providing interface to various devices and ensuring adaptation.

To supply resource control, interoperation and possibility for reconfiguration of digital systems we need to integrate the infrastructure with services on different levels. The process ontology is the key for combining devices and system knowledge.

The semantic and formal description of services and resources is useful in digital home (Figure 3), where a large diversity of resources have to be described and managed in a highly dynamic way [Rodrigues et al. 2012]. Services with different purposes can collaborate to offer new and more complex functionalities to the user transparently.

Buildings can be considered as a software problem. This problem addresses integration of information and resources which are invisible in everyday life. One possible way is to develop operating system for buildings and drivers for every

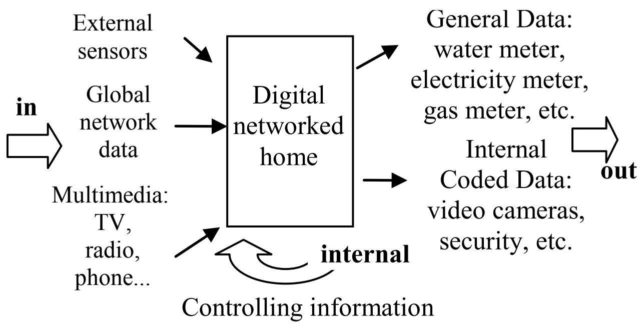

Figure 3. Digital home

Source: own elaboration.

device enriched with semantics. Thus systems can be constructed that are connected to the Internet and are controlled automatically.

It is recognized that there are obstacles in extensive use of embedded devices with limited characteristics of mobility, computing resources and memory. Semantic description may be a way to overcome this large handicap.

Semantic description and modelling of services, together with constructing and using process ontologies provided to users is a key component of autonomic service management, service negotiation and configuration.

The full exploitation of semantics in user and device description has several benefits [Atanasova 2012; Fathalipour et al. 2014]. The integration of knowledge representation features and reasoning techniques into standard home automation protocols can offer high-level services to users [Tempich et al. 2005; Ricquebourg et al. 2007; Hu et al. 2011].

Current experiences suggest that trends from device-oriented to process-oriented control of home appliances can be seen. Exchanging of various data needs to take into consideration not only syntaxes but semantics of the data and processes.

Discovering process models from system event logs is definitely non-trivial. When there is information in log file about process (as a timestamp of starting of event or a task; timestamp of the end; description of the given task; which resource was involved into accomplishment of the task; its role in the home, etc.), then it is possible to discover a process from this log information. The data and workflow technologies are merging in such a way. Statistic information is enriched with semantic description and the graph is constructed as a process map.

Within the analysis of event logs, process can be defined as the automated construction of structured process models. Each event is a part of the chain process. Thus a model is suggested in which the decision support system (DSS) is a coordination unit that integrates heterogeneous data. DSS is on the top layer of the data processing and provides semantic reasoning about solution on choosing the optimal set of services using the given network resources. The reasoning is based on process ontologies. Middle layer realize control, monitoring and visualization functions by event processing, as each device is enhanced with metadata and it is associated with service. This allows discovering functionalities and request services from other devices. Services are discovered by semantic matching. A logic-based ranking of approximated matches has to be developed allowing for choosing resources/services best satisfying a request, also taking user preferences and context into account. The composition of services for complex processes requires understanding the capabilities of the services (what they can do) and their compatibility. Decision models and methods can provide a formal foundation for guideline for composition and execution of services.

The primary aim of the use of ontologies is to integrate different applications. In the proposed framework ontologies are used twofold: for data integration from several sources and for intelligent systems operations. Thus the process ontologies pro-

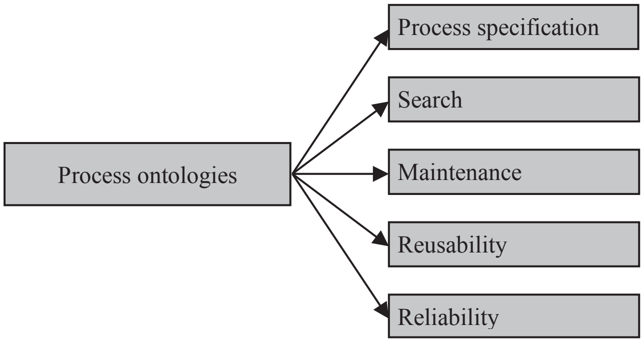

Figure 4. Using of process ontologies

Source: own elaboration.

vide process specification and their reliability, effective search of appropriate process, maintenance and reusability (Figure 4).

The system evaluates and classifies records by the use of the process ontology. The ontology of processes will determine what information to extract and how to accelerate the semantic search.

The process ontology will provide an appropriate philosophical foundation to integration problems. They will give a common conceptual framework for the researches as well as for the practice; it gives a possibility to compare different process-models and concepts and to interpret the dependencies between different models.

Using of the framework may allow for optimizing of resources, effective control and monitoring of home appliances. Possible areas of investigation based on process ontologies in digital home are:

- development of different management scenarios – depending on the daytime, on the presence of guests, in the absence of people, and others;
- reporting of energy consuming and efficient control;
- development of software, supplemented by service-oriented architecture for managing resources, and opportunities for interaction;
- tools to support the relay timers, and establish the functions executable in time (including the heating, lighting, etc.);
- support for sending and transmission of messages, such as warnings or reminders;
- using of dynamic content from the Internet for different needs and users with different skills in the living environment, for example, development of algorithms to manage resources according to the weather.

4. Conclusions

The upward trend in ubiquity and heterogeneity of networked home services and resources demands for a formal and systematic approach to home management tasks.

Current solutions of automated control systems in digital networked homes poorly support dynamic scenarios and context-awareness. Ongoing research covers sensors and how to include the description of these sensors in the control system for smart living environment [Chan et al. 2008].

In this work it is shown that the primary aim to use of ontologies is to integrate different applications. Ontology is proposed to model the relations between events and to manage process configurations. The rapid development and emerging demands for process automation and interoperability requires systematic modelling methodology and increased semantic information.

The work outlined some solutions for the hard problems during integration of heterogeneous data and processes and shows trends to overcome the lack of standard methods for integration of the information resources and processes, which hampers the supply and the efficient use of the information by the users. Process ontologies are a base for providing the whole functionality of the digital networked home in a coordinated and controllable manner.

The future living environment will need to be more intelligent and adaptive, optimizing continuously the use of its resources without any impact on the demanding services.

An effective way to acquire knowledge and share it internally and with outside strategic sources is needed. It is still a challenge to provide a robust and acceptable solution for knowledge capture from different sources.

Methods that ensure integration between the various subsystems automatically and in real time have to be designed. It is hoped that the proposed model will invite further work on integrated framework and shall become reality in the near future.

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ZINTEGROWANE PROCESY BAZUJĄCE NA SEMANTYCE W INTELIGENTNYM DOMU

Streszczenie: Celem niniejszej pracy jest zbadanie specyfiki w rozwoju technologii dla heterogenicznych danych i integracji procesów w inteligentnym domu oraz pokazanie możliwych rozwiązań podczas projektowania zintegrowanych aplikacji. Analiza zintegrowanych danych może być użyteczna dla rozwoju ulepszonych algorytmów monitorowania i kontroli inteligentnej sieci domu.

Słowa kluczowe: proces ontologii, semantyka, zintegrowane dane, inteligentny dom.