# Integration of Heterogeneous Data and Processes in Digital Home

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*Abstract*—**The research work in the field of data and process integration is considered as one of the challenges in information technologies. 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.**

## I. Introduction

THE heterogeneity of electronic devices and communications networks in modern buildings is growing rapidly, the complexity of the infrastructure is constantly increasing too. The broadband is widely available now in living environment, personal digital devices became very popular, local networks and wireless technologies get emergent interest. Today many of professional and home digital systems have network functions and can be supplemented with connection to the Internet. This gives a possibility to monitor and control various home appliances by network. From the other side the tendency for bringing more intelligence into building automation can be seen. It is observed that smart environments have growing demand. This conceptually desirable technology provides a new kind of lifestyle.

Technologies themselves are rapidly changing. The next generation networks are moving to Software-Defined Networking where the network's data layer is decoupling from the control layer [22]. Network access needs to be available on a range of client devices over Wi-Fi and cellular links as well as wired connections.

Network traffic in digital home includes data, voice and video; application-specific traffic management becomes an increasingly important issue in order to ensure acceptable performance.

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The problems of smart environment attract attention of researches, home techniques manufacturers, mobile operators, civil engineers and other organizations. The scope of these problems is very wide and covers different scientific, technological and psychological aspects [8], [9], [13], [18], [20].

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.

The paper is organized as follows. First some problems connected with heterogeneous data and information sources are outlined. After then we consider involving semantics into infrastructures. Finally some proposal trends for solutions are suggested.

## II. Problems of Heterogeneous data and process integration

The research work in the field of data and process integration is considered as one of the challenges in information technologies.

The methods for integration themselves, the tools for standardization, specification, semantic description of the resources, as well as the corresponding theories are still in the developing process. No fundamental theory for information resources integration has been offered until now.

The integration can be accomplished at several levels (fig. 1).

The research trends are directed towards automation of the integration with the purpose to reduce the time and the resources, necessary to achieve efficient solutions.

It is not expected that the user will participate in the selection of the integration technology when the information come from heterogeneous sources.

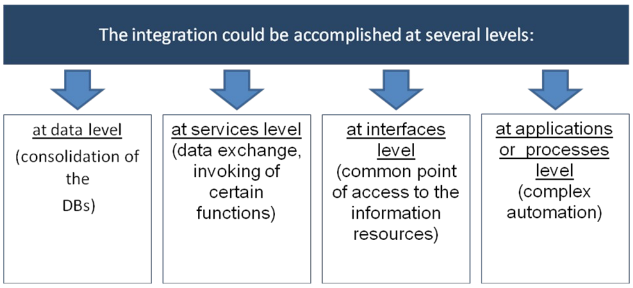


Fig. 1 Integration levels

## *I. Problems of data and process integration in the digital home*

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 [18] 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 proved 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 [12], [15] is established. The multiservice network provides 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 indweller everywhere in the house. The service can be transferred from one device to another with inference about possibilities for the transfer and service delivery.

In consideration to digital home the problems can be described as the ability to have mixed technologies work together and

- to ensure the integrity of data and processes;
- to ensure nondiscrepancy of the available information;
- to avoid the input data duplication;
- to improve the information exchange and the efficiency of the entire information infrastructure;
- to create a uniform information space.

The other part of problems depends on data and process properties that have to be described in adequate way allowing their jointly using.

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

## *II. Involving Semantics*

The semantic description and realization of methods for semantic processing may be the key to achievement of common integration objectives. Several researches suggest an idea to enhance sensors and actuators with a semantic description of their capabilities [8], [9], [13], [20].

Each sensor in the digital home network environment is related to a web service. Processing of a service combines data from different sensors/services. The semantic description of the services allows composing them on the basis of ontological matching of their capabilities.

## *III. Ontologies*

Ontologies as a core of semantics can be used for the purposes of information integration, sharing and reuse. The main components of an 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 disposals the concept on the tree.

Instances are specifications of concepts, together with the taxonomy and the relationships they form the knowledge domain. Axioms are used to restrict the values of classes or objects (examples) (fig. 2).

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.

Ontologies are created in various forms - from lexicon to dictionary terms, or as first-order logic.

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

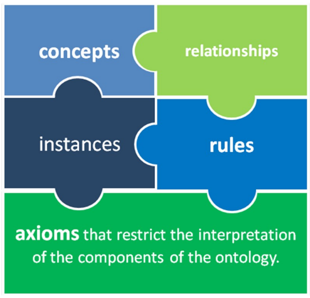


Fig. 2 Main Components of an Ontology

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.

Domain ontology has four levels: domain; category; class and instance.

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.

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. Ontologies can be built using:

- a relational database as a data source;
- a database schema to convert to the ontology;
- a graph-based formalism;
- concept map.

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

$C$ is the set of concepts,

$T$ - a thesaurus, or partial order on the set $C$, the hierarchy of relationships, "subclass" and "superclass";

$P$ - the set of predicates (properties);

$F$ - 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.

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

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

Ontologies are used for various objectives as specification, confidence, reusability, search, reliability, maintenance, and knowledge acquisition.

At development time they provide ontology–driven development (to describe the domain) or ontology–enabled development (to support developers with their activities).

At run time they form ontology–based architectures (as part of the system architecture) or ontology–enabled architectures (to provide support to the users) [21].

### *IV. Process Ontology*

Fundamental process ontologies are becoming more important in recent times [4], [6], [7]. For example, in [19] 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 are 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.

Process is constructed from a relation between events $e_1, e_2, ..., e_n$.

The processes are divided in three main classes:

- *basic* processes;
- *composition* of basic processes and
- *external* processes.

Additionally, processes can be identified that determine the *trends* and directions of changing of basic processes, depending on the analysis and 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), $R = \{R_1, ..., R_n\}$.

Extracting knowledge from a specific domain can be considered as the construction of structural design pattern – that process ontology [19]. The objective is to identify processes that have brought to the particular event, and to predict future events based on the past experience.

## III. Digital Networked House

### *I. Heterogeneous sources*

There are different devices and sensors in the building with different volumes and rates of transferred data. They can be described in three groups:

- home entertainment: high rates, large volumes of data;
- home communication: medium to high rates, middle volumes of data;
- home network management: low to medium rates, low to medium volumes of data.

The devices may have extended functionality and participate as a part of infrastructure in software defined network (SDN). SDN is relatively new field in research and consider involving intelligent control methods in network management. This will contribute to a better communication between the various actors involved with diverse objectives.

The idea is in consistency with a concept of new generation networks (NGN) [16] [17]. In NGN there is software upper level for intelligent control of resources.

These new tendencies can be observed in digital networked home environment too – in intention to construct intelligent control and monitoring methods.

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.

The semantic and formal description of services and resources is relevant to digital home, where a large diversity of resources have to be described and managed in a highly dynamic way [14]. Services with different purposes can collaborate to offer new and more complex functionalities to the user transparently.

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.

Sensor network environment in digital home may content two types of services: basic sensor services and sensor processing services. Each sensor is related to a service. Processing service combines data from different sensors/services. Semantic description of services allows combining them on the base of ontological matching of their capabilities

Besides providing information processing the integration of infrastructure with services in the networked house environment can be useful for energy savings.

## *II. Digital Networked Houses and Energy Consuming*

Energy consumption is actual and broad topic in research [10]. Some facts have to be mentioned:

- 90% of our living time is in buildings which consume 2/3 of produced energy;
- one big shop (mall) consumes 6MW*24h=144 MWh, 144*365=52 GWh electrical energy per year;
- building automation devices are complicated, non universal, and inconsistent;
- 94% of office buildings in USA cannot afford building automation;
- more than 50% of energy depends on residents' behaviour.

Uniform technology and methods for integrated interoperation of heterogeneous digital systems in living environment that are orientated to optimal using of resources and energy are not developed yet.

## *III. Proposed trends and solutions*

We consider buildings 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 (OS) for buildings and drivers for every device enriched with semantics. Thus systems can be constructed that are connected to the Internet and are controlled automatically.

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

The integration of knowledge representation features and reasoning techniques into standard home automation protocols can offer advanced services to users.

Current experiences suggest that trends from device-oriented to process-oriented control of home appliances can be seen.

Discovering process models from system event logs is definitely non-trivial. 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.

The main goal is to suggest a model in which the decision support system provides solution on choosing the optimal set of services using the given network resources on the base of reasoning on process ontologies.

Decision support system with accordance to SDN concept (fig. 3) is a coordination unit that integrates heterogeneous data and processes.

- 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. It has to be developed a logic-based ranking of approximated matches allowing to choose resources/services best satisfying a request, also taking user preferences and context into account.

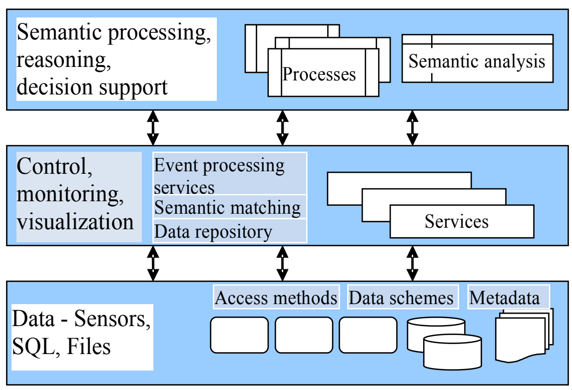


Fig. 3 Layers of data processing according to SDN concept

Ontologies are used twofold: for data integration from several sources and for intelligent systems operations.

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.

## IV. Related Work

The development of ontologies in centralized settings is well studied and there are established methodologies. However, 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 [7].

Using ontologies for telecommunication is proposed by recently [1]-[3], [5]. The approach proposed in [1] discusses using ontologies to capture networking information as well as the domain and expert knowledge needed for network configuration tasks. By semantic description and the use of formal ontologies it is showen how task complexity can be reduced.

Collaborative mechanisms between services are a crucial aspect in the development of pervasive computing systems based on the paradigm of service-oriented architecture [15]. The current network can only provide syntax-layer services and not provide semantic-layer services [5].

The investigation in [20] describes a model of services composition based on a directed acyclic graph used in a service middleware for home-automation, in which loosely coupled services-oriented systems is suggested over the peer-to-peer technology.

The presented in [8] approach proposes use of semantic description that can potentially make the digital networked home more adaptable, agile, sustainable, and dependable given the requirements of changing environment.

The development of multi-service model is discussed in [15] and it is concluded that is still at an early phase.

## V. Conclusion

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

The rapid development and emerging demands for process automation and interoperability requires systematic modeling 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 that hampers the supply and the efficient use of the information by the users. Ontology is proposed to model the relations between events and to manage process configurations. 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.

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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